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The Social Metabolism

A Socio-Ecological Theory of Historical Change

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To Esther and Manolo…
To Patricia, Emanuel and Emilio, once again…

It is not the unity of living and active humanity with the natural, inorganic conditions of their metabolic exchange with nature, and hence their appropriation of nature, which require explanation or is the result of a historical process, but rather the separation between these inorganic conditions of human existence and this active existence, a separation which is completely posited only in the relation of wage labor and capital.

Karl Marx, Grundrisse 1973, 489.

Sustainability is of whom works on it.

Leonardo Tyrtania

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All studies, but above all those completing the construction of a general idea, are always the result of a collective reflection and a family effort. The authors wish to deeply acknowledge those colleagues, students, assistants, friends, and family who have contributed to the publication of this book. We began contemplating this book over a decade ago during the winter of 1998, when we met to work in the historic center of Granada, Spain. Since then, what is here presented became outlined aided by discussions with numerous colleagues, supervision of several theses, imparted courses, and our participation in several academic events. The list of colleagues with which we discussed one or several of the main theses contained in the book includes: Narciso Barrera-Bassols, Benjamín Ortiz-Espejel, Enric Tello, Jesús Ramos, Mario Giampietro, Fridolin Krausmann, Geoff Gunfer, José Manuel Naredo, Oscar Carpintero, Esther Velázquez, Ramón Garrabou, Gloria Guzmán, Roberto García, David Soto, Antonio Herrera, Rosalva Loreto, Stefania Gallini, Wilson Picado, and Joan Martínez-Alier.

Several years ago, Benjamín Ortiz-Espejel and Francisco Garrido Peña had already suggested the topic of dissipative systems. Juan Infante made expressly for this book the bibliometric analysis about the concept of social metabolism. More recently, our encounter with Leonardo Tyrtania and perusal of his writings was decisive. Pedro Antonio Ortiz-Báez largely made that encounter possible by building the bridges between Leonardo Tyrtania and us.

A meeting about social energy that took place in the fall of 2013 with the participation of the physicists Marco Martínez and Omar Masera, together with Alejandra Martínez and other colleagues was of great utility for differentiating the concepts of energy, emergy, and exergy. Likewise, we discussed many controversial issues of thermodynamic interpretation with Carlos Gómez Camacho from the department of thermodynamics at the University of Seville. We must also acknowledge the efforts of Eduardo García-Frapolli, María Rosa Cordón, Francisco López, Alejandra Gonzalez, Yaayé Arellanes, Patricia Claire, Antonio Cid, and Eduardo Aguilera, that made possible the application of the basic model we present here in their doctoral and post-doctoral research works.

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Chapter 1
Introduction

1.1 Worrying About the Future

Today, when visiting into a bookstore, cautiousness must be exerted to avoid being burdened by the catastrophic book covers neatly displayed in stands. In the last years we moved from *Collapse* (Diamond 2005) to *The Sixth Extinction* (Johnson 2013), then to *Field Notes from a Catastrophe* (Kolbert 2007). These books were accompanied by a special issue in *Scientific American* about the end of the world (2010), and by two crucial books: *The Revenge of Gaia* by James Lovelock (2006), and *An Inconvenient Truth* by Al Gore (2007). Today, there is a proliferation of books, technical reports, and videos containing sophisticated analyses about the future scenarios focused on a new cabalistic date: 2050 (Smith 2012; WWF 2012). It is the day for worrying about the future, about the insecurity brought about by a modernity that is increasingly incapable of assuring us of a riskless future.

In other historical periods, such anxiety for the future was nurtured by certain religious beliefs and apocalyptic ideologies, or by the desperate expressions of fortunetellers, artists, and philosophers. In this instance, worries grow not because of the several catastrophist views, but at the same rate in which scientific research unveils new discoveries about human impacts in the equilibrium of the planet. This uneasiness is also adopting an unusual magnitude, because the disequilibria are at such scale that no region in the world or sector of society can be beyond their reach. Everything points to society being already immersed into a self-perpetrated "… a giant, uncontrolled experiment on earth (McNeill2000)," in which natural and social processes become entangled in an unprecedented way, generating novel, unpredictable and surprising dynamics and synergies that threaten human life, global equilibrium, and uncountable life forms. The human species, now transformed into a new *geologic force*, has given place to a never witnessed stage in Earth's history: The *Anthropocene* (Crutzen and Stoemer 2000).

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1.2 Exploring the Past

Paradoxically, this concern about the future outcome of things prompts a renewed attraction for the past. It is as if the eyes anxiously turned to history in search of the keys allowing for understanding a future that looks uncertain. This searching in the elements of the past for the instruments needed for successfully navigating the seas of the future—a reaction which seems reasonable at the level of the individual—is today not only a challenge for the species and a generic task, but the most urgent of challenges for present day science. Will scientific thought generate the necessary knowledge for sorting the present crisis of civilization? For example, the perspective revealed by history continues to be limited, cryptic or biased, being limited to the tackling of secondary—or even insignificant—matters, or resulting either from empirically unsupported speculations, or from an unrestrained imagination. Even recent contributions aimed at discovering long-term historical patterns become limited, such as the alternation of growth mega-periods with stages of stagnation and reorganization (Modelski2007), or the expansion-contraction cycles (Chase-Dunn et al. 2007). The same applies to the frantic search for "collapses" in all time periods and regions of the world (Diamond2005).

If science as a whole is mandated to know the past in order to learn from it, i.e., to extract lessons, it becomes necessary to guide the efforts towards achieving two objectives, both appearing as having a high degree of difficulty and being urgently required: (a) To develop an integrating (interdisciplinary) socioecological conceptual framework capable of organizing research about the relations between society and nature; and (b) The application of such framework conceived as a functional, and above all, useful instrument for analyzing such reciprocal relations throughout history (temporal dimension), and across all scales (spatial dimension). Already available are some relevant contributions offering accounts of the succession along the history of the human species of increasingly complex constellations built by societies throughout the territories of the planet (McNeill and McNeill 2003). What follows, is to apply to all these descriptions the pertinent analyses allowing for interpreting the social and ecological processes through time, and in consequence, offering criteria for the positioning of the present and coming historical stages.

The book now being held by the reader belongs to the intellectual vortex that tenaciously, sometimes obsessively, and even desperately is seeking for a single goal: *to decipher the past for the sake of understanding the future*. This is thus not a conventional book about history, or about ecological and environmental sciences. Its scope places it at an uncommon field of interdisciplinary knowledge that may be called ecological and social, socio-ecological, or eco-social, given that it aims at interpreting natural and social processes within their complex and intertwined articulation, or synergy. Hence, what the present book offers, in essence, is a suite of theoretical and methodological tools based on a key concept: *social metabolism*. Grossly defined, the concept of social metabolism introduces the biophysical analysis of exchanges between society and nature; in other words, it goes beyond the conventional sociological perspective, but distancing from many reductionist approaches, it recognizes that such material exchanges are reciprocally linked to exclusively social factors. As the reader will discover, the first dimension of the analysis is focused on the *flows of mater and energy*, while the second concentrates on *flows of information*. The exploration is ambitious and saturated with risks, but is most needed in times in which interdisciplinary approaches capable of understanding the complex present situation are urgently needed.

1.3 The book Contents

The book has been divided into four sections and fourteen chapters, including the present introductory chapter. Chapters 1 through 4 are essentially theoretical and epistemological, and are directed towards localizing, signifying and clarifying the contribution of the so-called *environmental history*, and providing a detailed definition of the concept of social metabolism. Thus, these chapters lays the theoretical foundations for the necessary reconciliation between the discourse and practice of social sciences and the sciences dedicated to studying the physical and biological world. History—as a field that encompasses all human action since our appearance on Earth—is particularly suited to this purpose when using innovative axiomatic, epistemology, theories of historical change and methodologies, which, among other things, break away from the traditional parceling up of scientific knowledge. Most hegemonic theories in social sciences are still tributaries of the *metaphysical illusion* seized by modernity, which separated the human being from nature, generating an anthropocentric fiction that still endures. Hence, accounts of our past are used more to legitimate the permanence of obsolete structures of industrial civilization than to adapt to new times, hindering awareness of change towards a *sustainable society*.

This conception of history as *environmental history* requires an applied approach in which knowledge "stored" in the past can be highly useful to move along the path to the future, towards a more sustainable world. Environmental history must, therefore, although not exclusively, perform the role of a *species memory,* in which are stored the useful experiences developed by humanity as a whole throughout the history of our relationship with the natural environment. Environmental history also emphasizes the importance of processes of historical change conceived as socio-ecological transformations.

Because during the last decade the concept of social metabolism has rapidly gained a growing notoriety, and because its use has explosively expanded, Chap. 3 is devoted to document the origins and history of the concept, give a brief analysis of publications about it, and outline its principles and schools or trends. The section ends with a chapter providing with sufficient detail the *basic model* acting as the conceptual framework, thus functioning as the backbone of the book. Among the offered innovations is the adoption of an approach not restricting the use of the concept of metabolism to the purely material dimensions, be these energetic, economic, or cybernetic, but rather to what is understood as a complex integrated by material and immaterial, visible and invisible aspects. With that, it is recognized that all society is an assembly of phenomena pertaining to both dimensions: that of the *flows of mater and energy*, and that of the *flows of information* that organize, mold and give support to the latter in virtue of social conditionals such as institutions, legal rules and regimes, values, beliefs and knowledge.

The exchange between society and nature of energy, mater, and information takes place within a territorial or spatial matrix comprising several scales, which means that the studied processes are hierarchically linked. Therefore, metabolic analysis can be conducted at different scales, each one being determined by, and in turn, determining other scales. The scales on which the process of appropriation can be analyzed range from the local to the global. Between these two extremes, there is a plethora of situations defined by the breadth of the scale. Hence, *trans-scalar analysis* emerges, an approach that is gaining strength in different fields of knowledge.

Chapters 5–8 shows how social metabolism functions at the main geographic scales, providing examples from the literature about social metabolism and case studies developed by the authors. Specifically, four examples are given, each one at a different scale: the current situation of a rural community, a rural community from an historical perspective, a micro-region, and the nation state. Whereas the first three are based on field-gathered information—i.e., are derived from direct empiric research, the third is compiled through statistical data and national accounts, and the second is composed of information held in archives.

The above-mentioned chapters tests the *basic model* at the spatial dimension, for which it relies on the conceptual framework proposed and discussed in the first five chapters, deploying it at four spatial scales that are somewhat arbitrarily defined: local, regional, national, and global. At each scale level examples are provided and methodological aspects are briefly discussed.

Chapters 9–11 contain a similar analysis to that made in Chaps. 5–8, but analyzes the temporal dimension, i.e., it offers an account of social metabolism through history. In Chaps. 9–11 the material dimension of social change is examined through the description and study of different metabolic regimes that have existed throughout history. Each of them has encompassed a certain level of human appropriation of both, living or organic (capture of primary net productivity or biomass), and mineral (fossil fuels, metal and non-metallic rocks, and ore) resources, and a certain degree of human intervention in the physical and biological processes taking place in nature. The aim is to classify societies according to their material basis (flow of energy, mater and information), and to the limits this basis imposes on human practice—a practice that, at the same time, modifies and transforms metabolism itself until its total transformation. The temporal dimension of social metabolism compels a review of the principal states or "moments" in the connection between different societies with their respective natural surroundings, each one responding to historical configurations.

Three types of metabolic regimes are presented and described, constituting three key moments in the historical development of humanity from a socio-ecological perspective: the *cinegetic metabolism*, the *organic* or *agrarian metabolism,* and the *industrial metabolism*. Three principal criteria are used to define these moments according to the metabolic process of appropriation: the degree of transformationin the ecosystems or landscapes being appropriated; the main sources of energy used during appropriation; and the type of manipulation made of the different components, and ecological or scenic processes. It is within these major qualitative socio-ecological changes that variations or modifications take place, related not only with other metabolic processes, but also especially with the intangible spheres of society, such as those of knowledge, cosmovisions, technologies, institutions and ideologies. The three main social metabolisms are thus identified over time. A whole chapter (Chap. 11) is devoted to document in metabolic terms the *great transformation* of human history, the metamorphosis—otherwise sudden considering that it spanned only a few hundred years—of forms with organic metabolism to configurations with industrial metabolism. It is in this social and ecological transmutation where most of the keys for understanding the contemporaneous situation are to be found.

Finally, Chaps. 12 and 13 present a theory of socio-ecological transformations built over the basis of the concepts developed in the three previous sections. To that means, a brief review is made of two new fields of frontier knowledge that are useful form understanding the complexity of the present-day world: the so-called *sustainability science*, and the theory of *entropy of open or dissipative systems*. In both cases, the exploration we present allows for placing the proposed theory of metabolic transformations within the contemporaneous epistemological context. These chapters develop a theory regarding the direction, mode and pace of socio-ecological change, of how one metabolic regime moves into another. It is rooted in the concept of *socio-ecological transition*, understood as the process of transformation—or metamorphosis—from one metabolic regime to another, which is impelled over time and space by socio-ecological forces. However, certain factors of diverse nature are singled out, which, usually acting in combination, tend to act as impelling forces for socio-ecological changes; within which social and territorial inequality, politics, and social conflict (*social entropy*) occupy a relevant role. The above vision is not featured in other approaches to social metabolism, which have so far been too *cybernetic*. These *cybernetic* (structural-functionalist) currents in metabolism undervalue, or even ignore, the relevance in change of human agency. The processes of socio-ecological transition registered throughout the history of humanity are then studied and summarized, paying particular attention to the transition process that led from the organic to the industrial metabolic regime.

The revision made of the series of factors operating as *causes* for the transformationthrough time of societies, and of their relations with their natural surroundings, does not ignore the overwhelming complexity involved in this task, because societies appear as intricate polyhedrons that mutate and transform according to particular natural and social conditions. This also includes a dimension that has been largely ignored by the historians of this, and other currents, but appearing as substantial for understanding the transformations along time: *social entropy*, and the frictions and conflicts it triggers. It is because of this feature that a part of humanity exploits and dominates another more numerous part, which pertains to, and confronts with human exploitation of nature.

A last chapter concludes the book with a required epilogue or corollary describing the social and ecological situation of the contemporary world—i.e., the industrial civilization—and which hints the need for envisioning and performing a qualitative leap towards an *alternative modernity*. This leap, stated in the terms of this book, is the search for a new type of social metabolism that many scholars insist in calling the *sustainable society*. Thus, the book concludes by affirming the need for a new socio-ecological transition, which has already been initiated, towards a new metabolic regime based on sustainability values. The severity of the metabolic crisis in which we are immersed—and whose manifestations are well known (ecological, energetic, financial, food crisis, etc.)—highlights both the unsustainability of the modern life regime, and the impossibility of completing the entire transition towards the industrial metabolism. Some signs (growing distancing of the economies of certain countries from the consumption of energy and materials, the progression throughout the world of organic farming production, the expansion of renewable energies, etc.) indicate that the transition might have already begun towards a sustainable society.

In summary, the perspective revealing the interpretation of history in terms of social metabolism, allows us for visualizing the need for the human species to move towards a new type of social metabolism. It also offers elements to construct the profiles of a sustainable society. For example, everything that is examined throughout this book is derived from the need for change, not only in the connection between society and nature, but also between the different metabolic processes within society. This entails a rigorous and urgent reconnection between the processes of appropriation and excretion, and the world of nature. This implies a radical rethinking of the processes of transformation, circulation, and consumption, and the unavoidable suppression of *all* mechanisms of social inequality, fundamentally expressed through the forced extraction of surplus—and its undervaluing throughout the metabolic chain, a hefty legacy that human society has maintained for several thousands of years—operating as a trans-metabolic phenomenon. Overall, we arrive to a key premise: *that suppressing unequal exchange—social crisis—within society is the only possible way of suppressing unequal exchange between society and nature—i.e., the ecological crisis.*

References

Chase-Dunn Ch, Hall TD, Turchin P (2007) World systems in the biogeosphere. In: Hornborg A, Crumley C (eds) The world system and the earth system. Left Coast Press, USA, pp 132–148

Crutzen PJ, Stoermer EF (2000) The Anthropocene. Glob Change Newslett 41:17–18

Diamond J (2005) Collapse: how societies choose to fail or succeed. Viking, New York
Gore A (2007) An inconvenient truth: the planetary emergency of global warming and what we can do about it. Radale/Melcher Media, New York
Johnson G (2013) The sixth extinction: an apocalyptic tale of survival. Omnibus Edition, USA
Kolbert E (2007) Field notes from a catastrophe: man, nature, and climate change. Bloomsbury, UK
Lovelock J (2006) The revenge of gaia. Allen Lane, Santa Barbara
McNeill JR (2000) Something new under the sun: an environmental history of the twentieth century world. Penguin Books, USA
McNeill JR, McNeill WH (2003) The human web: a birds eye view of world history. Norton, New York
Modelski G (2007) Ages of organization. In: Hornborg A, Crumley C (eds) The world system and the earth system. Left Coast Press, USA, pp 180–194
Smith L (2012) The new north: our world in 2050. Profile Books, London
WWF (World Wildlife Fund) (2012) The 2050 Criteria. Washington DC, World Wildlife Fund

Chapter 2
Environmental History as Sustainability Science

2.1 History and the Crisis of Modern Civilization

There is no doubt about the profound crisis currently experienced by the industrial civilization that has exerted global dominium during the nineteenth and twentieth centuries, its foremost myths gradually collapsing one by one. The industrial growth has failed to visibly close the gap between the rich and the poor countries, thus clearly revealing the lack of connections made between economic growth, industrialization, and development. Neither were social inequalities abolished, although they dimmed during the peak of *Fordism*, currently reappearing with a particular virulence that is reaching to even a growing sector of the population of the rich countries (Milanovic 2003, 2006; Acemoglu and Robinson 2012). The feeling of deprival of the myriads of commodities offered by the markets—now boosted by globalization—spreads throughout the world. This deprival becomes a powerful motivation that—contrasting with misery and violence—thrusts migratory movements that *endanger* the *positional* privileges of the affluent countries. The modes of political organization of the nineteenth and 20th centuries, which accompanied industrial capitalism, show unequivocal signs of exhaustion in front of the constant transference to transnational decision domains of important shares of sovereignty, at the same time that small cultural communities regain their political identities in reaction to the process of globalization. The orthodox paradigms of science—together with its hegemonic core of scientific-technological rationality—have for some time sinking into an irreversible crisis. Crisis also regarding many dominant values, while others appear that some have labeled as *postmaterialistic*, but that are maybe only expressing the need for a *new modernity*—as claimed by Beck (1998). But it is the ecological crisis what perhaps better depicts the civilization crisis, its severity and its planetary dimension, and what will surely force the adoption of highly relevant changes in the conformation of society. The greenhouse effect, the gap in the ozone layer, the exhaustion of mineral resources and fossil fuels, deforestation, overexploitation, the depletion of water resources, atmospheric pollution, acid rain, erosion and desertification, among others, are tightly linked with the modes of production and consumption brought about by economic growth and industrialization.

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However, most discourses regarding the past continue to maintain the same values, and to proclaim the virtues of a single social model that an increasingly fewer sector continue to consider as viable: the industrial society. Indeed, it is discouraging to observe that among most historians the concept of nature occupies a marginal place, being only invoked by the modest minority of the environmentalist historians. Once the ambition for a Total History claimed scientism—and its pretension of the past serving as a powerful impulse for the future, which would trigger social change—have been overcome, the historical discourse has diversified in its objectives, its contents, and its theoretical and methodological orientations. No more is there a Universal History integrated by the sum of National histories, or by the aggregation of the different social classes, but a multiplicity of histories—some of which are too small and insubstantial—in which the sense of social usefulness has vanished. The crumbling propitiated by *post-modern* critical historiography has deconstructed the solid foundations of the Total History, one of the late forms of understanding the past of the industrial civilization.

But deconstruction was incomplete. *Postmodern* historiography continues to neglect nature, the discourses it produces remaining inside a material vacuum without physical or biological references, nor a relation to the laws of nature making social practices become possible or impossible. Thus, most present historiographical currents are tributaries of the *metaphysical illusion* that enraptured modernity, and that segregated human beings from nature, engendering an anthropocentric fiction that refuses to die. That is why some accounts of the past are frequently turned into a mere instrument for legitimizing the present. We are then in a strange situation in which the challenges to be faced cannot find a backup in social memory. The continuingly dominant discourse of our historiography conserves an ancillary axiomatic based on values and objectives belonging to an obsolete modernity, displaying a notorious abandonment of reality, being condemned to remain as a simple archaeological exercise or museum knowledge that is almost devoid of a connection with the surroundings, and which in reality is only useful for legitimizing a society in crisis, thus delaying the consciousness of change. It is thus urgent to recover the needed unity that must exist in the collective memory and in social demands: a recovery that transits through the necessity of reconciling society with nature. The following pages are devoted to support such a necessity by means of an attempt for relocating the accounts of the past within the *human knowledges* that can provide us with a clear and palpable social utility.

2.2 Environmental History, a Hybrid Discipline

As other fields of knowledge, Environmental History was born as a response to the limited capacity of conventional disciplines for understanding the increasingly complex reality of the present. In his devastating critic to contemporaneous science, Morin (2001) found that the main limitation of the predominant style of scientific research lays in the *simplifying paradigm*, which is a way for organizing knowledge while reducing the growing complexity of contemporaneous reality. The need for surpassing such *fragmented objectivity* by means of a multidimensional or integrating explanation has already motivated the appearance of new epistemological and methodological proposals.

Two noticeable contributions are, undoubtedly, the principle of complexity of Morin (2001), and what García (2000, 2006) has termed as the study of complex systems: "With the principle of complexity it is intended to overcome the knowledge in separate worlds characteristic of 'classical science,' [where] … not even human sciences have consciousness of the physical and biological character of human phenomena, nor natural sciences have consciousness of their inclusion within a culture, a society, a history, nor of the hidden principles orienting its constructs" (Morin 1984, p. 43). Thus, a *science with consciousness* as Morin calls it, would be that which achieves to transcend (without their abolition) the different fields of specialties. Anyways, many of the problems to be solved by researchers are present in reality unclassified regarding scientific disciplines.

García (2000) recognizes that certain situations in which multiple processes merge (e.g., of the physical-biological environment, production, technology, demography, and social organization) conform the structure of a system functioning as an organized whole, which he calls complex systems, and that is only analyzable from an interdisciplinary approach. The above obliges to propose a research strategy that cannot be limited to the simple *summation* of the partial approaches of a diversity of specialists, but build a truly systemic interpretation leading towards an integrated diagnosis.

Beyond the thoughts of the above-cited and other scholars, such as Funtowicz and Ravetz (2000) or Holling (2001), who propose a *science for sustainability*, the rupture of cognitive parceling has not occurred as a self-conscious and generalized process, but as a *spontaneous*, multipolar, and asynchronous trend, i.e., it has appeared in different time periods, and in the different domains of knowledge there where the problems to be solved have induced the creation of new integrating approaches.

The most illustrative example of the above-described methodological process is that of so called *environmental problems*. As time passes, it has been discovered that these environmental issues can be fully described, interpreted, and above all, solved, only through a comprehensive approach. Environmental or ecological issues are today maybe the most challenging of problems for contemporaneous science, not only because it urgently demands new approaches capable of offering reliable and comprehensive information for solving numerous problems, but specifically because these issues already represent a colossal threat to the survival of life and human societies in the planet. In that regards, the birth of a *science of sustainability* can be understood as a result of *evolutionary convergence* brought about by environmental pressures over the divergent branches of science.

2.3 Sustainability Science

Despite its youth, sustainable science has become a field of science that has experienced an unusual expansion. The volume of literature produced by sustainability science—which despite its diversity has given rise to a more unified scientific practice—is impressive: over thirty seven thousand authors from one hundred and seventy four countries had produced over twenty thousand papers by the year 2010 (Bettencourt and Kaurc 2011, p. 19541).

Sustainability science, as described by the PNAS website, is "… an emerging field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems (quoted in Kates 2011, p. 19449)."

At present, sustainability science "is usually understood as research providing the necessary insights to make the normative concept of sustainability operational, and the means to plan and implement adequate steps towards this end (Spangenberg 2011, p. 276)." It is, hence, a predominantly practical or applied science: "sustainability science is a different kind of science that is primarily use-inspired, as are agricultural and health sciences, with significant fundamental and applied knowledge components, and commitment to moving such knowledge into societal action (Kates 2011, p. 19450)." It persues "real-world solutions to sustainability problems (Spangenberg 2011, p. 275)."

Sustainability science is not a subtopic of other sciences, or a transversal topic, or merely a new discipline. Despite that the term encompasses several theories, methods, and orientations (Kastenhofer et al. 2011), it has emerged as a research field defined by the problems of unsustainability rather than by the disciplines it recurs to (Clark 2007; Kajikawa et al. 2007). Beyond possible semantic differences, sustainability science must include both the *science for sustainability*, and the *science of sustainability*.

According to Spangenberg (2011, p. 276), sustainability science is characterized by three constitutive features, over which some consensus seems to exist: it may be basic or applied research, but it must be linked to a defined objective; the approach to the complex scientific and technological topics is based on integrated analyses and evaluations, understood as iterative participatory processes of reflection and discussion in that knowledge (science) is coupled with action (politics); the participation in it of scientists, decision makers, and stakeholders is essential. Finally, it is indispensable that sustainability science is multidisciplinary, or as stated by Clark and Levin (2010, p. 6), "extraordinarily multidisciplinary."

Thus, this new field of scientific practice has been created as a response to the challenges derived from the ecological crisis, encompassing within it several *hybrid disciplines* that operate as particular reactions to the general process of excessive compartmentalization and specialization, and as expressions of a sort of *salvage science* seeking for information to stop and revert the environmental crisis. This phenomenon presents two main characteristics: First, it has had its main *infectious focus* in Ecology, the discipline that has achieved an original synthesis—of knowledges from other Earth and Biological Sciences, including Physics and Chemistry—that crystalized in the proposal, rigorousness and decantation of the concept of ecosystem: its object of study.

Second, it has been a multipolar process in which, on one side, there has been a gradual overcoming of the resistance of ecologists who insist in circumscribing their approach to the study of phenomena whose nature is conceived as a pure, pristine, or untouched entity, and in the other side, the impermeable barriers of disciplinary purity have been removed from at least nine areas of knowledge. As a result, nearly twenty *hybrid disciplines* have arisen (Fig. 2.1), which can be seen as interdisciplinary modes of approaching reality based on the integration of the synthetic study of nature (Ecology), with different applications on the study of the social or human universe.

Heterogeneity has been the main feature of this reciprocal fertilization, such that all attempts for considering these hybrid disciplines as fractions of a supposed *metascience* becomes premature, if not illusive. Nevertheless, interdisciplinarity requires at least the use of a common language. Examples of this can be found at present in many fields of study, as are the cases of the Integrated History and Future of People on Earth (IHOPE), for whose participants "one of the major challenge for reaching this goal is developing 'workable' terminology that can be accepted by scholars of all disciplines (Costanza et al. 2012, p. 106)," and in the more ambitious proposal of Gintis (2009, p. 225) of extending History as a science studying human behavior in the past, regarding which he stated: "In fact all four [disciplines] (Economics, Anthropology, Sociology and Psychology) are flawed but can be modified to produce a unified framework for modeling choice and strategic interaction for all of the behavioral sciences."

From the sociological perspective, the triggering factors of all these new hybrid disciplines have undoubtedly been the process of globalization of the human phenomenon, the development of specialized knowledge itself, the deployment of new technologies, and, in the center of all this, the appearance and aggravation of the so called environmental or ecological crisis, which is today present at the global scale and that during the past decades has become more frequent, severe and extended. In sum, Environmental History has surged in parallel with other areas of knowledge, among which the most conspicuous are Ecological Economics, Political Ecology, Environmental Education, or Agroecology, among others.

2.4 What is Environmental History, and What Are Its Goals

Certain academic groups also designate Environmental History as Ecological History, which should not be confused with Historical Ecology. Historical Ecology is the subdiscipline of Ecology that deals with the study of ecosystems in the past.

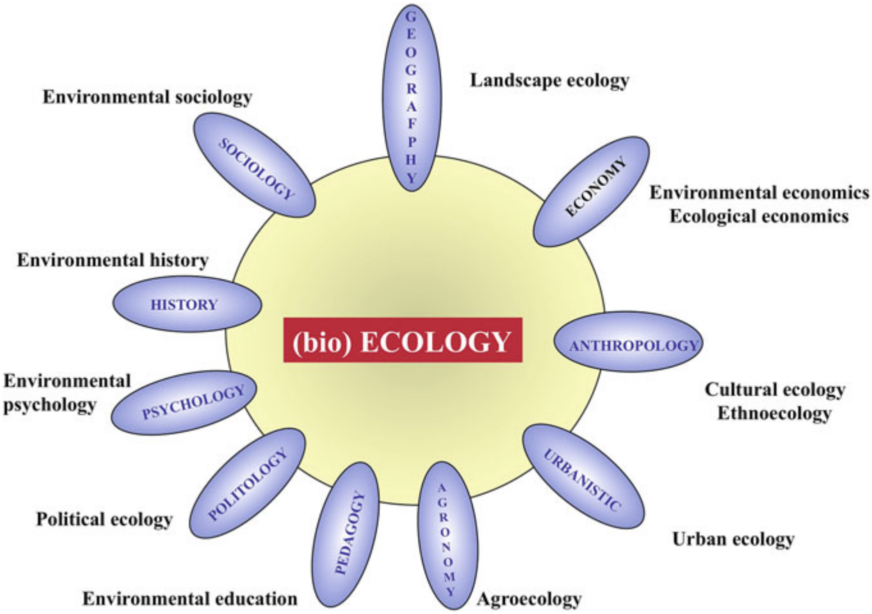

Fig. 2.1 Diagram showing the birth of at least 12 hybrid disciplines resulting from the integration of biological ecology with other areas of knowledge (See text)

Although its origins go back to the 18th century, it was until the 1950s that it became defined (Rackham 2003). History has interested ecologists for a long time (for example, see Peterken 1981; McDonnell and Pickett 1993; Worster 1993; Russell 1997; Meine 1999; Bowman 2001; Egan and Howell 2001; Foster et al. 2003; Rackham 2003; Verheyen et al. 2004; Crumley 2007; Dietl and Flessa 2009). That interest arises because: it aids to understand the present processes involving nature, it favors both decision making and the implementation of better supported modes of management of ecosystems (Newell and Wasson 2002; Thompson et al. 2009) and, finally, because History as a discipline places Ecology in a more consequent interdisciplinary context (Bürgi and Gimmi 2007).

During its onsets, Historical Ecology shared topics and some methodologies with Environmental History, but during the last decades it has oriented more towards Ecology, in particular, to the conservation of natural resources. There is no consensus among ecologists defining themselves as historical ecologists regarding the definition of Historical Ecology (Rackham 1986, 1998, 2003; Crumley 1994, 2007; Russell 1997; Egan and Howell 2001; Balée 2006; Bürgi and Gimmi 2007). However, given human beings have become one of the main factors explaining the dynamics of ecosystems, there is an agreement about its main object of study: the interactions of humans and nature in the past. Side by side with the main stream of ecologists that conceive human activity over the environment as a *stressing agent*, a new conception is gaining terrain which considers human activity as an agent of *change*, and thus of the environmental dynamics (Dearing

2007, p. 31). In other words, the impossibility of analyzing nature and culture in a separate way is becoming clearer each day (Szabó 2010, p. 381). The terms Ecology and History as fields of study was defined by Crumley (2007, p. 27) as the former including humans, and the latter, the planetary system and the physical and social past of the human species.

Historical ecologists are more oriented towards studying the large fluctuations of the physical and biological cycles, particularly those of climate, and their repercussions on human societies and their capacity for reaction (resilience). Their view of the past is rather *naturalistic*, from the perspective of its functional rules contemplating society as separate from nature and reacting differentially in response to environmental pressures. Instead, Environmental History obeys to the growing concern of the community and historians for the environment, having a more *social* view. As a part of History, the human past remains to be the focus, but regarding material interactions, it remains to be engaged in studying the various past and extant societies as human ecosystems, or as subsystems of the more inclusive system of nature.

If the objective of study of Historical Ecology is the ecosystem—in a broad sense including anthropized ecosystems—that of Environmental History is the material part of the functioning of societies in the past. A priori, there should be no distinction between Historical Ecology and Environmental History, given that both attempt to build "a science of the past (Cornell et al. 2010; Costanza et al. 2012, p. 112)." Lets examine the example of Agroecology. An agroecosystem is an anthropized ecosystem that would be unapproachable without taking into account the energy supplied by human beings. The only possible Historical Agroecology is that of the Environmental History of agroecosystems. Thus Historical Agroecology and Environmental History have one and the same object of study and are the same thing. The ideal situation would be that both disciplines merge into one when considering the level of human intervention in the environment. To achieve this unification a language, and a theoretical and methodological framework need to be developed, which tends to be common within its diversity or to the very least, to facilitate an interdisciplinary dialogue. In this regard, the interactions between the academic communities are intense, and the border between both disciplines is being increasingly blurred.

Donald Hughes tried to establish a more precise conceptual perception of Environmental History: "The idea of environment as something separate from the human, and offering merely a set—ting for human history, is misleading. The living connections of humans to the communities of which they are part must be integral components of the historical account. Whatever humans have done to the rest of the community has inevitably affected themselves. To a very large extent, ecosystems have influenced the patterns of human events. We have, in turn, have to an impressive degree made them what they are today. That is, humans and the rest of the community of life have been engaged in a process of coevolution that did not end with the origin of the human species, but has continued to the present day. Historical writing should not ignore the importance and complexity of that process (Hughes 2002, p. 25)".

In consequence, and while the needed unification in a single field of knowledge, the objective of Environmental History is not the study of the (natural) environment, but of human beings within environment, i.e., of the relations between society and nature through time. In terms of McNeill (2005, p. 13) one of the better-known environmental historians, Environmental History deals with the reciprocal relations between the human species and the rest of nature. In the latter definition, and to which we adhere, human beings are not an external and differentiated entity, but form a part of nature together with all other living species, something we will reexamine below. Such a definition suggests a number of questions centered in the tasks of Environmental History. Worster (2004, p. 126) stated that: "all the range of human interactions, both intellectual and material, with the natural world are assumed. This concept questions how natural or anthropogenic forces have transformed the landscape and how these changes have affected human life. It concentrates in the technological power that humans have accumulated and asks how has that power affected the natural world. The new environmental history also takes care of how humans have perceived the natural world and how they have reflected about their relation with this more than human world (Worster 2004, p. 126)".

Environmental History is thus *a part of the history of humanity* throughout its evolution in the planet. It does not pretend to build a new narrative of human evolution that replaces contemporaneous theories such as Marxism or Functionalism, among others: such a pretension was buried by the crisis of modernity. But Environmental History is neither a new historiographical specialty to be added to those already existing—Economic, Agrarian, Political, and Social History, or that regarding mentality of social movements—nor does it operate independently from them. It is just one of the *crumbs* in which historical research disintegrated in present times of postmodernity. Environmental History uses theories, methods, and constructs narrations that are part of Economic History, Political History or Social History. Thus, the knowledge it provides is transversal across existing disciplines, as transversal is its position regarding many of the ongoing historiographical debates from which it nourishes.

Neither does Environmental History pretend to become a specific field of knowledge dominated by Natural Sciences, and aiming at providing environment with an explicative capability of human practices—a capacity that it, obviously, lacks. Hence, it does not pretend to understand all from the environmental perspective, legitimizing the intrusion of Natural Sciences in History, giving preference to natural over social scientists. Such a defensive reaction is common among many historians that see their status threatened by a specialized knowledge needed by the practice of Environmental History that is apparently outside of the humanistic approach (e.g., Fontana 1992, p. 65), and for which they are usually not prepared. The separation between social and natural sciences has long ago been left behind by the development of human knowledge, committed with transdiscipline (Khagram 2010). What Environmental History does pretend is to reject and overcome the traditional division—and even the confrontation—between society and nature that has characterized the narrative of modern historiography. In consequence, presuming that Environmental History be a mere translation to the historiographical field of concepts and schemes from the Natural Sciences is unwarranted, as would also be presuming History to be substituted by Ethology or Biology. Furthermore, the simplistic view placing Ecology—with which Environmental History shares many of its theoretical and epistemological postulates—in the realms of Natural Sciences, understood as disciplines exclusively in charge of the animal, physical, and biological realities, becomes terribly unfair and restrictive.

Environmental History is thus far from any *imperialistic* attitude regarding its methods and its theories, as is believed to be by some historians who hold that historical knowledge should be reserved to the exclusive and unpolluted realm of *pure* Social Science; it does not claim that all historical phenomena have an environmental explanation, even when this is necessary a part of the explanations given to a historical event. Many historical facts can be explained taking into account variables of an environmental nature, but many others can definitively not be such accounted for. Although environmental variables provide much more coherent explanations to certain trends and historical phenomena, Environmental History resigns to explain it all with the environmental prism, or to build a new meta-narrative in which the environment is the *deus ex machina* providing the key for understanding.

Environmental History is an *alternative* way of understanding evolution of human beings, which requires of a radical change in focus. To the same extend that History studies human societies and their past evolution, Environmental History attempts to understand the strategic relations established by human beings—both between themselves and with nature—in order to organize their subsistence. The historical account must consider the relations of humans with the communities of organisms to which they belong, and account for the fact that any effect over the former will affect the latter (Hughes 2002, p. 26). For that reason, History needs to be also Environmental History; it must be an inseparable part of historiographical discourse, which is therefore ecologized.

Environmental History is thus a narrative about human past that contributes to constructing and making more coherent a more general account of the evolution of the human species on Earth. The separation between Environmental History and History is useful above all for emphasizing the relevance of environment in explaining the course followed by humanity, clearly revealing the connection that History must have with Ecology in a series of common features—both of epistemological as ontological nature—that form part of the new ecological paradigm. For example, the inter- and multidiscipline in front of the analytical spirit; integrality of the knowledge it generates instead of its fragmentariness; centrality of the rational opposed to the substance of mechanicism; the importance of the temporal dimension; and the biocentric perspective, among others. All this keynotes assume a rupture with the so far dominant forms of historiographical discourses, a fact that must righteously be emphasized. The moment of Environmental History is, in addition, a constitutive period in the sense of Kuhn (1975), amidst the crisis of traditional historiographies, and it is convenient to clearly distinguish between them.

Environmental History essentially deals with the material base of social relations. In that sense, it is consequently materialistic and naturalistic (Prices 2011). Such a qualification does not, however, imply that it chooses a materialistic and objectivist theoretical over an idealistic standpoint, as artificially suggested by the dichotomy in the social sciences during modernity. Naturalism, as materiality refers here to the object of Environmental History, the flows of energy, materials, and information to which all human practice can be reduced, but also to material nature of any cultural dimension of human practice. Materialism must mean not believe that cultural forms of production and consumption are determined by the by the forces of environment, only the cultural behavior occurs within a material world whose properties limit what is possible and determine the environmental consequences of that behavior. In other words we need to support both the specificity of cultural motivations such as the universality of material laws (Hornborg 2007). As will be seen below, all individual—this including social groups or an entire society—consumes a given amount of energy and materials to feed and sustain its organism, to commute from one place to another, to dress, warm-up, and even to perform immaterial actions such as cultural and scientific activities. In this process, the individual establishes relations with nature and with other individuals that are relevant for Environmental History. However, to explain these relations is not a task corresponding exclusively to Thermodynamics, Chemistry, Physics, or Biology, but also to Sociology, Economy, Anthropology, and of course, also to History. Even the ideas and representations of nature and how to manage it—belonging to an immaterial realm—is a fundamental object of study of Environmental History. Definitively, Environmental History is materialistic because it attempts to study the manner in which the flows of energy, materials, and information have been organized through history according to the changing needs of the endosomatic and exosomatic social metabolism.

For that reason, the knowledge produced by Environmental History requires the support of theories, methods, and techniques both from the Natural and the Social Sciences with a of trans-disciplinary vocation. But Environmental History does not seek to study it all, but only the parts and the connections emerging from these parts through theoretical-methodological mediations to reduce the complexity of reality—the significant historical fact for Environmental History—allowing for its explanation. In consequence, a distinction must be made between the globalizing ambitions, the recognition of the existence of a multiplicity of possible explanations, with the totalitarian ambition of modern historiography. Behind the pretension of a Total History hid the pretension of building a normative meta-narrative to govern the historical fact, fitting it within a preconceived interpretative framework of structuring and evolution of social relations.

2.5 Is Environmental History Anachronic or Ephemeral?

Some historians have raised several questions about placing nature at the base of human practice, judging it as one more of the ephemeral fashions of postmodern historiography: Is it only the consequence of present environmental concerns? Would this make historical discourse to be a form of *Presentism*, or to be anachronic? Would it legitimize blaming nature for past environmental concerns that were then inexistent? But Environmental History is free from such a risk provided the required abandonment of the ethnocentric idea of environmental concerns being only expressed in conventional scientific terms, and that only scientists express them—or at the most, occidental ecologists; what this means is that after a careful analysis of the economic and social worries of cultures other than the occidental, rooted in the Enlightenment and motor of modernity (but as mentioned, ill with a metaphysical illusion), it will be apparent that worrying about natural resources, the environment, and even for the *sustainability* of social relations in regards to environment has always been habitual, albeit obviously such concerns were stated in different terms.

Human beings have always cared for the relation of society with nature. Before the anthropocentrism of our culture became established, and even in current oriental societies, nature was and is indissoluble from culture. Enough be to recall the nearly generalized organismic conceptions of cultures that through sacralization of space or resources, and the ritualization of main productive activities, attempt to have a *harmonic* relation with nature, among other reasons, because its survival as cultures depend on it. As rightly said by Hornborg et al. (2007), the interphase between the human and not-human spheres has always been an omnipresent theme for reflection and cosmological explanation, from the ancient written documents from Mesopotamia and China, to the myths and metaphors of contemporaneous indigenous people.

Also in the literate occidental culture an environmental reflection was present since early periods, frequently expressed through science, which rarely gained relevance in the history of ideas due to they went against the tide. Grove (2002), among many other historians, dealt with this fact considering a common fallacy to conceive environmental concerns to be new, beginning after World War II. Environmentalist reactions to changes induced by human beings originated early in the well-read culture, of which Grove (2002) provides multiple examples occurring from the 15th century to the present.

Each society has had its own perception of its environment and of the process of its metabolism with nature. Environment is not only a physical space defined by complexity and entropy, but also a social construct, which throws a shadow upon the assumed universality and uniqueness of the categories *nature* and *culture*, and on their artificial separation caused by modernity (Redclift and Woodgate 2005). Indeed, such a conceptual differentiation between nature and culture is lacking in non-western cultures and the society vs. nature antagonism so evident nowadays is in reality an *ethno-epistemological* construct of Western culture that is poor suited for accounting the ways in which other peoples or cultures speak about or interact with their physical environment (Toledo and Barrera Bassols 2008).

But even in epistemological terms such a flaw is unacceptable. As a social and therefore historical construct, History could hardly be kept unpolluted from current concerns. The historical discourse is more than compilation of a story it also involves collective *recalling* in which past events are selectively recovered under present stimuli. The historian disentangles the past through methods and theories that necessarily need to be expressed in current terms. This method differs little from that used by individuals to tolerate the mere fact of remembering. Many facts are discarded, be it consciously or unconsciously, as many others we deliberately decide to remark (Gaddis 2002, p. 176).

A demonstration of the above is seen in the mere existence of history as a professional discipline institutionalized during the construction of the nation states of the nineteenth century. History fashioned stories projecting to the past the existence of the nation, accentuating all that could create a sense of national unity since the beginning of times. But such unity obviously could neither have risen, nor could it have rose before the nation itself had been born. In a similar way have methodologies belonging to neoclassical economic history of the nineteenth and 20th centuries been blatantly applied to societies for which the notion of growth was unknown. Many more examples could be brought forward to illustrate the frequency with which even the more reputed historiography relapses into Presentism. A risk that, as seen above, Environmental History is free from as judged from the common expression of past societies of a concern for nature, or what is the same, for their own survival.

2.6 The Theoretical Foundations of Environmental History

Knowing that Environmental History deals with the material part of social relations causes a radical Copernican revolution of historiographical accounts by bridging between the social and the natural worlds. But including environmental variables is not enough given that not all of the theories incorporating the physical and biological world are convenient for the purposes of Environmental History, whose theoretical foundations lay on the adequate understanding of the relations between society and nature. Rejecting any form of determinism seems obvious at first sight, in particular that rooted in the nineteenth century and geographically originated in Europe, which pretended to compare the different cultures and the *geniality* of nations through their habitat. Environmental History opposes any form of unidirectionality in the relation between the physical and biological environment such that human behavior can be explained in terms of the relation between society and nature. The natural laws in the physical and biological environment constraints the actions of human beings, but nothing more or less than that. This clarification becomes essential, because Environmental History is frequently disqualified as *deterministic*, a pejorative adjective whose use precludes any serious and well-supported rebuttal of argumentations.

But yet another more modern version of determinism equally threatens the scientific coherence of Environmental History: the pretension of some social ecologists of understanding the dynamics of societies by means of theoretical assumptions from Ethology or Population Ecology. By thinking that there are laws that rule human behavior which do not substantially differ from those for other species, History becomes Natural History and Sociobiology (Wilson 1980), its theoretical framework. Pretending that ecological laws could explain the dynamics of human societies would be as preposterous as thinking it could be explained without the influence of such laws. Variations of this environmental reductionism can also be found in the attempts made for explaining human evolution in energetic terms (Odum 1972), or in the fatalism advocating the mechanical application of the Law of Entropy (Rifkins 1990).

Neither is there any pity for the pretensions of Environmental History coming from the attempts of Cultural Anthropology to explain the conformation of society as an adaptive response of human groups to corresponding their environments, such as the historiographical schools derived from Steward's (1955, 1977) Cultural Ecology, and from neofunctionalistic Ecology of Vayda (1969) and Rappaport (1968, 1971; also Vayda and Rappaport 1968; Vayda and Mackay 1975, 1977). In this same trend is *Cultural Materialism: the Struggle for a Science of Culture* of Harris (1977, 1983, 1985) and his Anthropology school that was so successful among environmental historians in the U.S. Harris is an adept of *functionalist* explanations of relations between humans and their environment, attempting to explain facts for their beneficial effect for the reproduction of the social system—for example, war is useful for lowering the growth rate of the population, which guarantees the reproduction of the ecological niche and thus, of the community. The fact that an event is useful does not imply that such usefulness explains the event: war cannot be explained by its consequences. A similar argumentation would be valid for the Ecological Anthropology of Hardesty (1979).

Many and very important achievements were reached within these currents that guided not few researches in the field of Environmental History, or even in that of Ecological Anthropology, although currently practiced with a less unilateral approach. Making Environmental History only relying on the theoretical arsenal and the methodological instrumentation of Ecology would be both too easy and simplifying. Social practices—because that is what History deals with—cannot be reduced in their whole complexity to environmental analysis. It is nonsense to claim that social relations move in response to physical constraints or by adaptation to them. As clearly stated by Georgescu-Roegen (1990a) regarding the second law of Thermodynamics, entropy has sets limits to the material life of humans throughout their history, but does not determine it (Georgescu-Roegen 1990b, p. 307).

2.7 Environmental Historyand the Coevolution Between Nature and Society

More recently, it has been proposed to understand the relation between nature and societies as a process of coevolution in which both interact along time, being thus impossible to understand them separately. Although this approach enjoys popularity among social scientists, maybe because it does not introduce new questions but adds a new variable to the conventional analysis of society in the form of an essential principle: the double determination of both worlds—conceived as separate from each other—which can be separately explained by social and by natural sciences. Undoubtedly nature establishes limits to human behavior, to which it sometimes reacts adaptively, other times developing solutions that change the scale or disappear. It is also certain that society generates diverse impacts on nature. Thus, the relations between society and nature are ruled by a mutual determinism (Deléage 1993, pp. 275–300). Society and nature coevolve indivisible throughout history: changes in the dynamics of the ecosystems set global limitations that by social mediation induce changes in social organization; conversely, societies have triggered more or less definitive changes that have modified even the dynamics of ecosystems (Margalef 1979; Norgaard 1987; Worster 1988, pp. 289–308). But the recognition of this reciprocity does not imply that both be considered as separate worlds having their own dynamic and interacting through time. It is a way of seeing things that improves our comprehension of human relation with the natural world, but it does not implicate a fundamental shift regarding traditional conceptions.

Environmental History is hence supported on the principle of *social* and *ecological coevolution*. The work of Norgaard (1994)—to whom the foundation as a principle of Environmental History is due–emphasizes that people's activities transform ecosystems and these in turn, set scenarios for individual and social acts. Thus, Environmental History considers society *within* nature, with which human beings establish material relationships of exchange of energy, materials, and information. The concept of *social metabolism* has been adopted to refer to this multiple determinant relation, as we will see below. It thus attends to the relation between society and nature in an integrated way, meaning it rises from considering the social system as one more part of the natural systems (Berkes and Folke 1998), or societies as *subsystems of the biosphere*, denying exceptionalism, as was demonstrated by Catton and Dunlap (1978), being and continuing to be the dominant paradigm of social sciences. Barbara Adam expressed it bluntly as the inexistence of a nature-culture duality: we are natural and our actions are natural, although we establish conditions in an evolutionary, historical process (Adam 1997, p. 171).

However, human societies have an immaterial dimension differentiating humans from other species. Human societies thus can be conceived as a *hybrid* between culture, communication, and the material world (Fischer-Kowalski and Haberl 2007, pp. 8–10). In that measure, the cultural or symbolic moiety is subject to a dynamic not belonging to the natural environment. But all human actions, including the symbolic part, can be analyzed in material terms: for example, a music concert that is seen as the paradigm of a cultural practice subject to non material rules, can also be evaluated by calculation of the endosomatic cost of energy invested by musicians during the performance and in previous rehearsals, but above all, in the exosomatic cost of transportation, instrument manufacture, illumination and maintenance of the concert hall, and so on. Even thinking implies exosomatic and endosomatic metabolic costs whenever thought is transmitted in a book, television, or a newspaper, etc. All human activities, although not belonging to the *material* world may have a cost in terms of energy and materials, and a quantifiable impact on the natural world. That is precisely what Environmental History deals with.

Agreeing to the an initial assumption of social systems forming part of nature, it becomes clearer why Environmental History cannot be limited to the simple account of environmental damages triggered by human activity. This version of Environmental History has been, as seen above, the most frequent and widespread: by means of a historical reconstruction of the undesired and unintentional consequences (or negative externalities) of human activity acting upon natural systems. This modality of Environmental History that Sieferle (2001) has ironically called *hygienist*, and McNeill (2005, p. 19) *decadentist*, has been marked by the consciousness of the ecological crisis. Many examples can be found, from pioneer works about the *smoke* caused by the Industrial Revolution, to many works about deforestation (Brimblecombe 1987; Brüggemeier 1990; Kiss 1990; Totman 1989; Gadgil 1990), and many, many others. Environmental History must be something more than the history of the negative externalities, it must also be the history of the *ecological rationality* in broad sense of each human society, both from the perspective of its productive models, as from its ideas about nature and the impacts over it from physical-biological changes (Worster 1988, p. 2002).

In consequence with what has been said, Environmental History must be a field in which natural and social sciences merge with a multidisciplinary vocation. The historian must be familiarized with theories, categories, and methods of both sciences, stemming from a holistic and systemic approach. The advances of science themselves have surpassed the cognitive virtuousness of the Newtonian paradox believing in the possibility of the compartmentalized study of specific phenomena, disconnected from their universe of relations, latter to be linked with others in a kind of pure causal relation. In our world all phenomena are connected through a vast and complex network of mutual relations that turn them in independent within the context of a dynamic process of constant evolution. Environmental History studies *social processes with environmental significance*, in a system in which, through complex relations, the physical, social, economic, and political factors intertwine.

The protagonist role of the relation between nature and society obliges taking into account the different time scales in which both operate, and how they interact between them. There is an ecological time that differs from the political, economic, and cultural times. This matter can be more clearly appreciated when comparing the duration of the large physical-biological processes with that of the social processes, either regarding natural resources as socially appropriated chunks of nature, be it because of the influence of environmental fluctuations on defining the ecological limits of development of societies, or referring to the disturbances of entropic changes on the dynamic of the ecosystem. As stated by Deléage (1993), the duration of the biophysical processes largely exceeds the actual experience of individuals and even of civilizations, such that these have only been aware and used the phenomenological manifestations of such biophysical processes. What characterizes the ecological time periods is the immensely brevity or length of its processes, therefore the impression of stability held by generations until the present.

The analysis of consumption of natural resources is an excellent example regarding the confrontation of the time needed for their consumption with the length of time invested by Nature in their production, or what Puntí (1988) has termed the *production time*. The annual rate of destruction of tropical forests currently exceeds $1 < 5$ of its total coverage, but 400 years are required for its total recovery; at the present rate of consumption, oil is predicted to be depleted by the end of the present century, but Nature invested millions of years in its production; the thin ozone layer needed two thousand millions of years to consolidate, but remains to be threatened by the use of certain gaseous compounds (Comoner 1992). Conclusively, from the human perspective, the cycles of regeneration and production of materials and energy, and the productive capacity of ecosystems is determined in the long term, and always depending on the presence of a certain measure of stability.

These long physic-biological cycles condition the performance of societies, the more characteristic example of which is climate fluctuations object of research since the late fifties (Wigley et al. 1981; Pfister 1988; and more recently, Pfister 2007; Brázdil et al. 2010; McCormick et al. 2012). Le Roy Ladurie (1967) showed that continued rainfalls between 1646 and 1651 were coincident with profound economic and social problems eventually leading to the Fronde confrontation, and although no causal relation between climate and the insurrection exists the climatic alteration generated a critical scenario. Earth has witnessed climatic periods related to modifications of the zonal flow of air masses. The first land clearings that ended Prehistory were made in a favorable temperature climatic phase; the following cooler phase had an opposite effect, favoring the growth of forests and natural vegetation; again between the ninth and twelfth centuries, a temperate phase was coincident with the peaking of agriculture in Western Europe; and subsequently therefore. An even more spectacular case is the colonization by Vikings of Greenland in the late tenth century, thus called by them for its vegetation due to mild climatic conditions; since centuries ago, Greenland was covered by snow becoming a hostile territory for human presence, which undoubtedly cooperated to the failure of the Viking colonization from the fourteenth century. Less prolonged climatic fluctuations also have had a significant effect on the evolution of agricultural activities, as exemplified by the high correlation found by Pfister (1988) between meteorological variables and the prices of cereals in the continental Europe lasting until the diffusion of railroad transportation and the integration of the national markets.

A recent meta-analysis made by of Hsiang et al. (2013) of 60 studies based on 45 databases about conflicts taking place during the last ten thousand years in the world has demonstrated a considerable influence of climatic events and human conflicts. The deviations from normal precipitation and temperature levels systematically raised the risk of conflict, sometimes substantially so. In the period from the second half of the twentieth century to the present, climate has a definite, statistically highly significant influence on contemporaneous conflicts. The authors do not mean to say that climate is the only factor when analyzing the magnitude of conflicts, but they conclude that in the eventuality of large climatic fluctuations substantial effects are produced in terms of the impact produced by conflicts (Hsiang et al. 2013).

In contrast, the changes induced by humans are abrupt and occur in a short time period relative to evolutionary trends spanning hundreds, thousands, or millions of years. For example, the desertification of Africa was favored and accelerated after World War II by erosive processes from deforestation, overgrazing, or agricultural mismanagement. Environmental History must encompass the social and the ecological timetables, which requires the coining of new—and perhaps proprietary—periods differing from those of conventional History, as for example the period of *Great Acceleration* characterized by the high increases in the rates of consumption of energy and materials occurred immediately after World War II, but coinciding in essential hiatuses such as the Neolithic Revolution or the Industrial Revolution, among others.

2.8 Sustainability, the New Meaning of History

In the beginning of this chapter we mentioned the Copernican revolution implied in substitution of conventional historiography for Environmental History. Certainly, History does not have to have a *meaning*. The project of the modern historiography was founded from the laic interpretation of the Christian *meaning of history*, and incarnated through the construct of progressive reasoning (Arostegui 1995; Hernández Sandoica 2004). History happened along a single line calculated by science and its applications, and hence guided by reason. The mission of modern man was to accelerate the evolutionary mechanism aided by Nature itself to achieve the maximum level of wellbeing. Progress therefore materialized as abundance brought about by science and technology.

This perspective explains the preponderance enjoyed by Economic History not only because it accounted the material advances made towards human progress in the form of technological achievements, but also because it did this by using Mathematics, the science most approaching Natural Sciences. Social History, second in importance, found its meaning in the corroboration of an evolutionary process towards evermore complex social models as an expression of the progressive social division of labor linked to economic growth and the material welfare of societies. Complexity was, henceforth, an expression of the growing rationalization of social organization. Political History was assigned to a secondary role consisting in measure the degree of political modernization of societies based on an abstract model concocted from the past experiences of the more affluent Occidental societies in which democracy and National states had been enthroned as the most efficient political organizations. Surely enough, most orthodox Marxist historiographies identified the modern ideal with Socialism and Communism, and with internationalist forms of territorial organization, but all social historiographies converged in preferring to study the social change towards complexity and the empire of reason, be it as a Communist society or as a Western democracy; a change performed by social classes, or by their expression through social movements.

Any economic, social, political, or ideological behavior not fitting into this general theory of modernity were condemned to an otherness in which were mixed their characterization as pre-modern or exotic, their moral rejection, and public curiosity. The pre-modern repertoire included peasants, indigenous peoples, poor countries, and not Western cultures, whose presence measured the degree in which these would, sooner or later, enter the route towards progress.

History dos not have to have a definite meaning, nor the historical discourse needs a finalistic or teleological evolutionary logic. However, Environmental History finds it *meaning* in the elaboration of a discourse centered on the concerns for sustainability, in coherence with its materialistic vocation. This does not mean that it only deals with the physical and biological worlds, or of the environmental constraints to human actions. We have already rejected such a deterministic position, as we also rejected analyzing society with the tools of natural sciences, and considering Ecology as the main objective of Environmental History. The definitive contribution of the environmental approach is the concern for sustainability. In doing such, it becomes a science that is committed with the uncountable social and political movements struggling throughout the world for constructing a new *sustainable society* (Toledo 2003).

2.9 Epistemological Foundations of Environmental History

The proposal herein made of Environmental History is thus tightly linked to the ecological paradigm that arises from the confrontation with the world vision of industrial modernity. It shares most of the assumptions of the *paradigm of complexity* (see Tyrtania 2008). It is thus the result of the efforts of criticism and of search for alternatives. Its construction was forged from diverse materials provided by criticism, but also by new scientific disciplines such as Ecology, Thermodynamics, and Systems Theory. From Ecology, it has borrowed the relevance of interactions between parts, or components of the natural and social worlds, the recognition of the complexity of reality, evolution, change, and others. From Thermodynamics, it adopted the conception that physical and biological processes in terms of finiteness, irreversibility, entropy—and simultaneously, of negentropy and order (Prigogine 1971; Adams 1975; Bailey 1990), i.e., of sustainability. From Systems Theory (Bertalanffy 1976; Luhmann 1996) were taken the holistic and systemic approach allowing for articulating concepts and theoretical constructs from Ecology, Thermodynamics, and Evolutionary Theory. In that regard, Bateson (1993) and Luhmann (1996) contributed to form an ecological theory of the symbolic systems (language, mind, communication, culture, an so on), while Morin (1984) laid the foundations for a new method, a *conscious science* centered in relation and complexity, a field in which the contributions of Rolando García (2006) are also worthy of mention, and finally, Adams (1975), Capra (1998), Tyrtania (2009), among other researchers, have aided to the construction of a general ecological theory of the living beings, including the social ones, in an expression of the articulated synthesis of the natural and the social sciences.

Complexity is thus one of the main constitutive principles of the ecological paradigm, maybe contrasting more than any other with the traditional epistemology. In face of the exclusion mania of mechanistic science, it reintroduces the local and the singular to the explanation of phenomena. In front of the reversibility of time permeating through mechanistic science, it states time as an irreversible process, endowing knowledge with historicity. By that means, it contradicts the so frequent vision of human sciences depriving social relations of its temporal dimension to singularize the *structure* that rules them. “While the simplifying thought eliminates time, or conceives but one time (that of progress or that of corruption), the complex thought confront not only time, but the problem of multi temporality in which repetition, progress, and decadence appear as linked (Morin [1999] 2007, p. 61).”

Facing the idea the reality can be reduced to its ultimate dimension, or to elementary units that conform it, it reassures the latest advances of science emphasizing more the interactions than particles themselves; it is in that way that the whole is more than the sum of its parts. In front of the idea of the universe being an ordered entity with no room for randomness, chaos, or dispersion, the ecological paradigm vindicates the insufficiency of laws determining its structure and function, and the need—as a complement to the stochastic component of processes—for its improbability. Confronting the idea that al consequences have a cause, it proposes multicausality as a reflection of the complexity of reality, where consequences contribute to configure the causes. This principle of recursion is what allows for understanding that the emergent properties of any organization will end up interacting with its components. That is particularly adequate when the forms of social organization are to be understood: “… interactions between individuals make society (…). However, society itself produces individuals, or at least consummates humanity by providing it with education, culture, and language (Morin [1999] 2007, p. 68).” Answering to the dilemma between object and environment, subject and object that is typical of the traditional scientific thought, it reintroduces the observer within the observation (Woodgate and Redclift 1998). And finally, opposing the supposed capacity of the scientific method for generating true knowledge by means of empirical verification and mathematical demonstration, it vindicates paradox in which contradiction is not a synonym of error, but a reflection of the existence of deep or unknown dimensions of reality.

From the epistemological point of view, Environmental History must be settled upon ecological epistemology, at the point of confluence between structuralism and naturalism (Blackburn et al. 2013). *Subjective naturalism* in the sense of Price (2011); which assigns to Environmental History the task of making the surrounding world comprehensible. Pragmatism in the sense of Putnam (1995), by recognizing that Environmental History—being a science—will not produce absolute truths, but partial, provisional, knowledge that will change along time, and whose relevance will be proportional to its usefulness (Sini 1999). And finally, structuralism as defined by Moulines (2006) when postulating a *structural conception of scientific theories*. Because no theory can function with exactness, the Environmental History we propose seeks for approximations to the physical reality of societies. The theoretical development of Environmental History we pursue in this book must assemble the same conditions demanded by Moulines from his structuralist typology of the theoretical development of empirical sciences: to be intuitively plausible, to be formally precise, and to be uniform and systematic; i.e., that it proposes a general scheme useful for attaching to it the diverse evolutionary forms, and that it can be applied to reconstruct concrete cases (Moulines 2011, p. 12).

Also behind the ecological paradigm are a new set of axioms and a new model of social organization based on sustainability: an objective whose achievement depends on the orchestration of several sciences, among which are the social sciences, cooperating to the proposal of sustainable modes of interacting with nature; which is the reason for which the new paradigm is obliged to be transdisciplinarity. These and other constitutional elements of the ecological paradigm does not try to be an alternative to science, but an equally scientific way of conceiving and practicing it; also, it does not pretend to rival with other existing paradigms, but aspires to integrate them and cooperate with them. It questions itself about the social utility of the knowledge it generates, such that its quality would not be the result of measurements made by scientists themselves following their own scientific logic, but also an evaluation from the whole of society in function of ethical criteria (Funtowicz and Ravetz 2000). This integration between ethics and epistemology shows the normal *modus operandi* of the ecological paradigm, which together with social movements, and in particular with the environmentalist movement, is collaborating in the quest for answers to the present civilizing crisis.

2.10 History as a Post-normal Science

Post-normal science, being aware of the uncertainty of scientific knowledge, and of the sometimes unpredictable consequences of the same *discoveries* it produces, is cautious of talking the appropriate steps to guarantee that the decisions made, and the control of scientific and technological development itself, be socially shared. Funtowicz and Ravetz (2000) propose epistemological changes—i.e., modifying the relation between facts and values, promoting axiological and strategic pluralism, introducing uncertainty and chaotic processes, adopting the systemic approach, articulating qualitative and quantitative methods, an others—and, in the social plane, the introduction of a qualitative criterion for socially evaluating the scientific and technological activities. “Post-normal science is dynamic, systemic, and pragmatic, and because of that, it demands new methodology and social organization of labor. (…) The principle of quality allows us to handle irreducible uncertainties and ethical complexities that are central to the solution of problems in this new style of science (Funtowicz and Ravetz 2000, p. 58)."

In that sense, the place of ethics and its functionality is similar to that occupied by instincts and conditioned learning in animal species evolutionary related to humans, such as higher mammals. An ethics founded upon valuing criteria that are properly ecological and oriented towards stimulation of behaviors and ecological actions, i.e., actions that generate social and environmental benefits. An ethics that in order to be consequent with its nature, requires to expand the limits of the moral community to include all living beings, whose ecosystemic organization makes life possible, given that their contribution is fundamental for maintaining human life. In this manner, the ecological paradigm adopts a biocentric perspective opposing to the anthropocentric ontology that subordinates the whole of nature to the human being, and which is responsible for behaviors leading to the ecological crisis. The ecological paradigm is thus founded upon an alternative axiology built over an ethics that is conscious both of the ecological limitations to freedom, and of equity—comprising intergenerational and interspecific equity–being one of its main values. Finally, the ecological paradigm rests on the principle of prudence or precaution. Confronting the old axiom, particularly operational in science, that all that can be made must be made, the ecological paradigm forces to reflection before action, and to questioning the social and environmental utility of science. Such symbiosis between epistemology (post-normal science) and ethics (principle of responsibility) in the construction and use of the principle of precaution is another expression of the integrative mode of operation of the ecological paradigm.

2.11 Environmental History and the Ecological Paradigm

Environmental History adapts its *modus operandi* according to this new way of generating knowledge, not pursuing—as did the old positivistic and neo-positivistic historiographies—to arrive to *the truth about what happened*, but to produce a knowledge with quality, i.e., defined by its social usefulness. The intellectual quest for knowing other past cultures and even to learn from their experience is legitimate, but in doing so we would only be making the history of the past that is useful only to scholars and the curious. The environmental crisis demands immediate solutions in which search Environmental History must contribute. Environmental History must make historical accounts of the past, but a more urgent task is to make the history of the present, i.e., to search for the historical roots of the greatest environmental problems in the present. Because the usefulness of historical knowledge cannot rest on the unreachable ambition of accounting all that happened, but on provision of an adequate *genealogy of the present*, looking for explanations and experiences that give significance to reality, allow for its understanding, and to think about a future with minimal physical and social entropy. Castel (2001, p. 69) stated: “The objective is not to tell it all, in case telling it all was a requirement of historical methodology, but it is about choosing well.” in that sense, the historical discourse, as useful knowledge, must be at the service of the seemingly more urgent objective from the standpoint of humanity—and not of a country or a social class—is the reversal of the environmental crisis.

To contemplate history from the perspective of the ecological paradigm implies to make a radical shift in the historiographical discourse, paraphrasing Rorty (1990), a necessary *environmental shift*. That, in turn, implies to reconcile society with nature, to place nature back where it should have never been moved from, inside the historiographical discourse from where it was removed by modern historiography. But it also requires abandoning the totalitarian and scientist pretensions of Marxist historiography, or the total history of the *Annals*, but without resigning to the aspirations of globalism, or to the consideration of its full equality with other social sciences. As righteously written by Cronon (1993), Environmental History is totally comprehensive, it is the only truly *general* or universal history.

Environmental History avoids fragmentation in multiple disciplines and topics, not uncommonly becoming closed upon themselves, in occasions becoming isolated from the global study of society, becoming the framed territory of a scientific practice pretending to be autonomous. It eludes the atomization in micro-sectorial histories sometimes precluding—necessarily—the view of human beings in their entirety, and of their relations with nature. In front of that, according to Fontana (1992), it is increasingly necessary to never again assume the cause of *Globalization*, but pursue a different globalization built from the integration of the fragments of such minced stories with the objective of offering a more unified view of human beings in all its dimensions, from their nurture to their dreams, and in all its relations, between its fellows and with Nature itself.

As stated above, Environmental History does not signify an attempt to reify a totalitarian history, but does have a globalizing vocation in which the particular and the global complement each other, such as is expressed by the classical environmentalist adagio: think globally, act locally. In fact, globalization is an essential condition of the discourse of Environmental History, and of its connatural methodology: systems theory, forbidding the parceling and segmentation of the historical knowledge no matter how limited or specialized may its range of study be. Environmental History cannot thus believe in the atomized specialization of knowledge, rather it believes in the inexistence of a proprietary method that is different from that adopted by any other social sciences: the distinctions are always temporal and instrumental. This does not mean that it vindicates the unity of the scientific method, but the indissoluble unity of social and natural sciences in a multidisciplinary quest.

Environmental History resigns to the unitary and totalitarian project of modern historiography, hence, it recognizes the existence of several histories within each society, varying in their scale, purpose, content, and organization. For example, there are individual and family histories, church histories, ethnic group histories, and often, a master narrative promoted by the State. There should also be an Environmental History. Furthermore, Environmental History recognizes the possibility of several accounts about the relation between society and nature through time, without this implying to fall into relativism. The compilation of History is a social process consistent in a differential retention, either active or passive, of historical facts, and their organization in the group's memory (Hassan 2007, p. 172). The historical discourse, as in the case of a map, is a *representation* of reality, but not reality itself. As stated by Gaddis (2002, p. 176), "it is a pitiful approximation to a reality which, despite the skill of the historian, would seem very strange to anyone having actually lived through it." The goal is to generate a narrative having a beginning, a plot, and an end or moral bottom line. It is not about telling what happened, which would be preposterous, given the time needed for such an intrinsically impossible task. It is about building a narrative that simplifies and makes understandable what happened, a story subject to future interpretations, and above all, devoid of any causality relation typical of more conventional historiographies. A plurality of causes can be argued in order not to define the historical event, but to explain it.

Environmental History is aware that it generates a radically distinct historiographical knowledge. Paraphrasing Funtowicz and Ravetz (2000, p. 23), it can be said that historical knowledge does not progress but evolves. Such a claim was already made during the 1950s, Collingwood, in his *The idea of History* wrote: "Each new generation must rewrite history in their own way, each new historian, not content with giving new answers to old questions, you should review the questions themselves, and—since the historical thinking is a river in which no one can enter twice—to the same historian who works on the same subject for some time may, in trying to rethink an old question find that the question itself has changed." This feature approaches Environmental History with historicism, however it is parted from it when admitting the possibility of regularities, or explanatory theories without any ontological pretension (Collingwood 1956, p. 248, quoted in Gaddis 2002, p. 140)."

In consequence with all what was exposed above, Environmental History does not pretend to be the unique form of building history from a proprietary theory and methodology, which is alternative to all other historiographical orientations. In coherence with its pluralistic vocation, it considers that there are useful constructs in other paradigms and theories, given that it is not at all obsessed with exclusivity. In fact, there may be several possible forms in which Environmental History can be conceived and operated. The common aspects are reduced to the restitution of nature and all this implies inside the historical discourse, and to the founding of an alternative axiomatic—as will be seen below, a new epistemology, new theories of historical change, and new methodologies which, among other things, brake apart from the typical parceling of traditional scientific knowledge. In that regards, Environmental History resigns to reconstruct the old historiographical project of modernity, adapting it to the new times with a varnish of environmentalism. Quite on the contrary, Environmental History pretends to produce a new discourse that, simultaneously, aids in finding a way out of the ecological and civilizing crisis by providing historical discourse with the material basis it lacks of.

2.12 Entropy and Environmental History

The Environmental History we propose has at its core an entropic conception of historical time, i.e., irreversible, which establishes an uncertainty regarding the *final outcome*, but with room for negentropy. The main consequence of the fundamental laws of nature, in particular of the Second Law of Thermodynamics, is irreversibility, given that the evolutionary process marches from order to an increasing disorder. In laying the foundations of Ecological Economy, Georgescu-Roegen (1990b) had already discovered such a process applied to all human practices. However, this does not imply admitting the degradative conception of History held by the Greeks and the Romans. Human beings may invert—in given space-time conditions—entropy to negentropy, creating order although at considerable energetic expenses. Thus, Environmental History makes a radical vindication of evolutionism in which humans interact with the environment, generating the facts on which History nourishes. That implies, on one end, giving an ontological status to the change-continuity dialectics, and placing nature in the center of the analysis of the human beings, thus eradicating anthropocentrism.

The genealogy of this entropic conception of Environmental History is rooted in the consideration of human societies as complex adaptive systems displaying emerging properties that are not analytically derived from the components of the system (Gintis 2009, p. 245). Human societies also reflect a fundamental characteristic derived from the theory of complexity: *emergentism* (Laughlin 2005; Bunge 2012). By that, our proposal for an Environmental History is non reductionist materialism focused not only on parts, but in their collective organization, assuming such organization exhibits novel properties in components themselves. Being human societies complex systems, they are determined by *stable complex organization structures* that are the main actors of historical dynamics. As stated by Laughlin's (2005, p. 106–107), our word view is changing from a deconstructive approach to that of an understanding of nature's functioning.

In this organization structures order is inseparable from disorder, its processes being accompanied by random events and disorganization, which gives place to an *organized diversity* (Morin 1980, p. 418) that transforms, produces, unites, and maintains (Morin 1977, p. 126) society. Randomness and indetermination becomes a basic ingredient of organized diversity as dictated by quantum mechanics and the Uncertainty Principle of Heisenberg. Social systems are non-linear systems in which quantic uncertainty can be *amplified by chaos*, and randomness acquires an extraordinary relevance thanks to the limitations of human knowledge. Societies are complex because they stand amid the ordered and the random, between order and chaos (Pagels 1988, p. 15).

The thermodynamic conception of complexity is of special interest in this book, as stated by Prigogine (1979, p. 201), Thermodynamics is the science of complex systems. Applying dissipative system theory to social phenomena would result in substantial advances in the field (García 2006, p. 60) and would require to consider complexity as the state of an unbalanced physical system in the verge of chaos and indetermination (Tyrtania 2008, p. 41). Complexity characterizes a system that *exists* by dissipating energy in an unbalanced regime. As a result, it at the same time produces order and disorder (Tyrtania 2008, p. 44). The more complex a system is, the farther away it is from thermodynamic equilibrium. This implies that entropy is the motor of evolution.

Our proposal agrees with what was before set forward from Anthropology by Adams (1975), and from Sociology by Bailey (1990), it sees human societies as adaptive complex systems based on entropy, or dissipative systems compiling with the *thermodynamics of irreversible processes* Prigogine (1947, 1971). Human societies are thermodynamically open systems exchanging with environment flows of energy, materials, and information that are used to increase their internal organization. Such process requires of a given amount of energy, i.e., its dissipation. Based on this fact, Prigogine conceives social structures as *dissipative structures* generated by means of self-organization processes. Thus, it can be said that energetic processes are the physical (material) foundation of all abiotic, biological and social processes.

But societies are not only structures, or said different, structures are nothing but groups of relations with a certain degree of stability. It is social relations, as held by Luhman (1996), what builds societies. Social relations can be classified in two main classes: relations occurring inside the social group, and relations established buy societies with the environment. From this perspective, the functioning of societies throughout history is in this book seen from an entropic and at the same time negentropic perspective: human societies are an organized ensemble whose main emergent property is consumption (dissipation) of energy and materials in a larger amount than the sum of the individuals that integrate it.

Considering societies as adaptive complex dissipative systems erases any artificial difference between society and nature. Human societies are natural to the same extent in which they exchange with the environment energy, materials, and information. Thus, our proposal of Environmental History assumes that all human societies are self-organized (autopoyetic) systems that occur as some form of stable organization in space and time, but given its configuration and maintenance, require of a continual input of energy, materials, and information from the environment, an inflow which increases entropy in the environment, thus generating dynamically adaptive processes that lead the course of evolution.

Seen from that angle, historical evolution has but increased the magnitude of the exchanges, expanding both exosomatic consumption, and social complexity. Being open systems, social systems are dynamic, their properties changing over time in a way that impedes predicting the outcome, when, nor the direction of the evolutionary process. Not all is explained by thermodynamics, it only dictates the reason for existence and evolutionary transformation (Georgescu-Roegen 1971). Evolution does not always lead to progress—complexity is not progress, but marked by uncertainty and risk, a reflection of entropic indetermination. The objective of Environmental History as conceived by us is the study of the evolution of societies from this entropic point of view. Among the social relations, we are most interested in are those in which societies exchange energy, materials, and information with their environment. These kind of relations can be called *socio-ecological* because the rise from the relation of humans with nature. The organized ensemble of socio-ecological relations can be called *socio-ecological systems* (Ostrom and Cox 2010), which throughout history have displayed varied forms according to their space-time coordinates. We propose to study socio-ecological systems by means of the theoretical and methodological tool of Social Metabolism.

2.13 The New Axiology

In the same way as science cannot be reduced to scientific knowledge, history is neither an account of past events. As a social activity, it is ruled by a plurality of values giving meaning to scientific praxis. The classical separation of facts and values is now obsolete. Scientific activity and, hence, its theories, are deeply influenced by several value systems needing to be analyzed and elucidated (Echeverría 1995, p. 73). In that sense, the dominant paradigms of social science were founded upon axioms magnifying progress and putting science at the service of production, providing technological progress with self-referenced autonomy. In Economy, it was economic growth; in Sociology, social modernization with its sequels of urbanization and complex labor division; in Anthropology, reinsuring of the industrial I over the otherness of primitive peoples. Social sciences became subordinated to the common objective of modernization of societies, i.e., the expansion of the way of life created by the Industrial Revolution. The modern historiographical discourse shared all these preconceived ideas thus becoming an instrument of legitimization of National States and industrialism.

Providing historical discourse with a new axiology is an essential task in which Environmental Historycan decidedly contribute because it encompasses a thematic in that facts answer to most of the *metascientific assumptions* underlying most syntheses and manuals of history, and even in a large part of research found in monographs and journal papers. Among these assumptions, some *provide character*, being intimately associated to industrial civilization with which they were born and became consolidated, and of which they have been blamed as an accessory to the crisis: anthropocentrism, unlimited progress, ethnocentrism, preponderance of the economic and material, and others. It is not infrequent to continue finding comments about the need to dominate nature in order to achieve development and human wellbeing, or the superiority of Western culture over other cultures—seen as incapable of aching a minimum of civilization—being either assumed or openly recognized, linking democratic conquests or scientific advancements to this statement, and shamelessly defending an ethnocentric conception of history.

The notion of unlimited progress is perhaps that most difficult to eradicate from history books, maybe because it confers the meaning introduced by religion in the study of time when theology was in charge of it. Thus, the idea of time incarnated in a lineal and progressive conception continues to be translated into the unquestioned principle of the accumulation of material richness as an expression of progress. The same dynamic of economic growth, its trend to incrementing its physical base of the economy, the need for expanding consumption for its own existence and materialization in a form of wellbeing identified with the possession of material commodities, have converted the idea of progress in a social evidence beyond question. However, the ecological crisis, or the nuclear threat, the incapability for generating wellbeing for all the human species, the recession rather than development experienced by most third world countries during the past decades, and the skepticism regarding humanity going in the right direction (if such existed), have reinforced the rejection not only of linear evolutionism characteristic of many *rational utopias* of modernity, but also of many sociological, economical and, of course, historical theories. That progress is the product of the evolution of nature to higher grades of complexity, or that social complexity automatically assumes the rationality of which Weber spoke.

Any renewed historical discourse that is consequently reconciled with nature must restate those objectives that remained until today in historiography: the creation of wealth, economic growth and technological development of nations, and social equity. While these are legitimate aspirations, environmental historiography must also deal with questioning if the achievement of these goals was achieved without endangering the long-term survival of society, i.e., its sustainability. Precisely so, an Environmental History that is coherent with the entropic approach herein proposed and the rejection of excessively naturalistic or anthropocentric perspectives of nature, remains centered in human societies, but within the context of its environment. In that way, sustainability becomes one of the main criteria of analysis. It does not, however pretend to merely substitute old for new objectives, what truly distinguishes Environmental History is the attention it gives to the material base of society, whatever be the cultural criteria by which it is judged. An example of this can be seen in the change being experimented in the approach made by historians of the logical aspirations of the human species of improving its situation, which are no longer limited to the increase of wealth of a country or of its individuals. From inside the United Nations, and from certain academic circles, the concept of human development has been proposed as an alternative conception emphasizing the factors of life quality, while not relegating the economic factors. It seems logical to think that concepts such as this and the needed modifications made to them in the future, will guide historians as criterion for evaluating societies, such as was distributive justice in the immediate past, and that will reasonably be expected to be so in the future. Environmental History assumes these and other innovations always from the perspective of their physical feasibility.

2.14 A New Social Function for History: The Species Memory

The philosophers of science are well aware that scientific activities and interventions in the world have as an objective more than improving scientific knowledge, but that it also modifies and transforms reality, given it attempts to know in order to modify or even radically transform that what is being known. Science has stopped being a *pure* philosophy to become a *practical* one (Echeverría 1995, p. 39). In that sense, the historical discourse has an unquestionable social utility; it makes the past to be accessible. As a modeler of the future, it is not a mere literature exercise, but has both pedagogical and a practical significances. With this reifying dimension of a *modest and prudent scientism*, history preserves its practical, hence emancipatory, its aspiration for change. The historical discourse must not only help to understand the present but also to explain it, and explain to change things and correct their courses. Explanation is the principle of understanding, thus allowing the development of learning, therefore its pedagogical function that is the same of social memory.

In consequence, Environmental History promotes a significant change in the social function of the past and of the discourses constructed about it. This new function resembles that in traditional cultures: to conform the collective memory of the group, in which is stored the knowledge useful for confronting the present. In that sense, the historical discourse is the same as the memory of a social collective and functions in a similar way as the individual memory. The experiences had, the perception of time and space, the consciousness of change, and the social dynamic are accumulated in this memory. From there, molded by the dominant ideological constructs and values, spring the ideas that guide behavior. The successful or disastrous experiences guide practice. Obviously, History as a discourse about the past goes beyond the social memory of a human group, storing forgotten aspects not remembered or having contradictory meaning for its members. But the historical discourse must *also* accomplish that task without falling in an apparently objective position beyond social demands. That is for us one, if not the main, tasks to be assumed by Environmental History.

The collective memory contains not only the experience of one or several generations, but of all not present anymore. Memory is selective, and this selective process of recovery of information is activated or materialized in front of situations or issue imposed by the present. That is why the historical discourse must retain a strong connection with the concerns of the present, a connection largely broken by conventional history. Memory is the decisive mechanism making the individual conscious of its own identity, but it is also the tool that through the resources of life experience aids its decisions when facing alternative options. The same can be said about the collective memory of the group.

As demonstrated by many mythological stories of ethnic nationalism, even the most idealized discourse about the past is adequate for satisfying the need of identity. But for historical discourse to act as group memory it is essential that the theoretical and methodological instruments with which recalls are constructed be as close to reality as possible. In that sense, most hegemonic social theories of historiography and social sciences keep the old segregation of human beings from nature. The mutual relation between society and nature was absent from most theories rooted in the Illustration such as Liberalism, Marxism, or Anarchism, among others, because of which they could be considered as idealistic. An example of this can be seen in the notion of *economic system* in one way or another shared by all these theories, and that place economy in an ideal world in which resources are endless, and environmental services are never degraded. As stated by Naredo (1987) in his splendid and enlightening book, *Economy in Evolution: History and Perspectives of the Basic Categories of Economic Thought*, such notion is supported by the "mythology of *production* and *growth* … by assuming the dogma of the permanent, and at no extra cost, replacement of 'production factors', based on a technolatry that has little to do with scientific rationality (Naredo 1987)." This example is significant because economy deals with the way society is reproduced in material terms.

Worster (2004) enumerated some of the contributions that Environmental History can provide. It can contribute to the development of environmental consciousness both inside of scientific disciplines as in society. Due in part to the book reading Cronon (Changes in the Land. Indians, Colonists, and the Ecology of New England, 1983), Worster says, scientists have changed their thinking about forest ecology. Now they are much more willing than twenty years ago to see the role of the human hand in the formation of forest processes from the Ice Age, to see the forest as a historical process and even as a historical artifact. Hughes (2002, p. 24) gives a similar example showing the usefulness of the knowledge provided by Environmental History for adequate management of current environmental problems. The Canadian Department of Environment ran into a strange phenomenon of pollution of the turbots of lake Laberge, north of Whitehouse in the Yukon. Only historical research was able to discover the cause of the black mud polluting the fish's liver, which originated during the 1920s from the exploitation of lead and silver in the middle Yukon River—used for transportation. The lengthy process of thawing that slowed down the exploitation and transportation of ore was accelerated by application of a mixture of sod, used motor oil, and diesel oil. Company files showed this practice to have been common in the middle 1940s.

Environment History must preponderantly, but not exclusively, play the role of a species memory in which is stored the useful experiences accumulated by humanity along its history of relation with environment. Its social utility is undoubted (Margalef 1995; Hughes 2002) in a moment like the present in which both the social and the natural sciences are required to contribute to the reversion of the ecological crisis. In that same measure, history acquires a certainly practical dimension: it seeks for building a narrative that is part of the flows of information that revert the high degree of entropy brought about by the industrial metabolism in both our environment and in the functioning of our society.

References

Acemoglu D, Robinson J (2012) Why nations fail: the origins of power, prosperity, and poverty. Crown Business, New York

Adam B (1997) Time and the environment. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Edward Elgar, Cheltenham, pp 169–178

Adams RN (1975) Energy and structure: a theory of social power. University of Texas Press, Austin

Arostegui J (1995) La investigación histórica: teoría y método. Crítica, Barcelona

Bailey KD (1990) Social entropy. State University of New York Press, Albany

Balée W (2006) The research program of historical ecology. Ann Rev Anthropol 35:75–98

Bateson G (1993) Una unidad sagrada. GEDISA, Barcelona

Beck U (1998) La sociedad del riesgo: hacia una nueva modernidad. Paidós, Barcelona

Berkes F, Folke C (1998) Linking social an ecological systems for resilience and sustainability. In: Berkes F, Folke C (eds) Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, pp 1–26

Bertalanffy LV (1976) Teoría general de sistemas. Fondo de Cultura Económica, Madrid

Bettencourt LM, Kaurc J (2011) Evolution and structure of sustainability science. Proc Natl Acad Sci 108(49):19540–19545

Blackburn S, Brandom R, Horwich P, Williams M (2013) Expressivism, pragmatism and representationalism. Cambridge University Press, Cambridge

Bowman DMJS (2001) Future eating and country keeping: what role has environmental history in the management of biodiversity? J Biogeogr 28:549–564

Brázdil R, Dobrovolný P, Luterbacher J, Moberg A, Pfister C, Wheeler D, Zorita E (2010) European climate of the past 500 years: new challenges for historical climatology. Clim Change 101:7–40

Brimblecombe P (1987) The big smoke: history of air pollution since medieval times. Methuen, London

Brüggemeier FJ (1990) The ruhr basin, 1850–1980: a case of large-scale environmental pollution. In: Brimblecombe P, Pfister C (eds) The silent countdown. Springer, Berlin, pp 210–227

Bunge M (2012) Tratado de filosofía. Editorial Gedisa, Barcelona

Bürgi M, Gimmi U (2007) Three objectives of historical ecology: the case of litter collecting in central European forests. Landscape Ecol 22:77–87

Capra F (1998) La trama de la vida. Anagrama, Barcelona

Castel R (2001) Presente y genealogía del presente: pensar el cambio de una forma no evolucionista. Archipiélago 47:67–74

Catton WR, Dunla RE (1978) Environmental sociology: a new paradigm? Am Sociol 13:41–49

Clark SA, Levin WC (2010) Toward a science of sustainability: report from toward a science of sustainability conference. CID Working Paper No. 196, Warrington

Clark WC (2007) Sustainability science: a room of its own. Proc Nat Acad Sci USA 104(6):1737–1738

Collingwood RO (1956) The idea of history. Oxford University Press, Oxford

Commoner B (1992) En paz con el planeta. Crítica, Barcelona

Cornell S, Costanza R, Sörlin S, van der Leeuw S (2010) Developing a systematic ‘science of the past’ to create our future. Global Environ Change 20:426–427

Costanza R, van der Leeuw S, Hibbard K, Aulenbach S, Brewer S, Burek M, Cornell S, Crumley C, Dearing J, Folke C, Graumlich L, Hegmon M, Heckbert S, Jackson S, Kubiszewski I, Scarborough V, Sinclair P-, Sörlin S, Steffen W (2012) Developing an integrated history and future of people on earth (IHOPE). Environ Sustain 4:106–114

Cronon W (1983) Changes in the land: Indians, conolists, and the ecology of New England. Hill and Wang, New York

Crumley C (2007) Historical ecology: integrated thinking at multiple temporal and spatial scales. In: Hornborg A, Crumley C (eds) The world system and the earth system: global socio-

environmental change and sustainability since the neolithi. Left Coast Press, Walnut Creek, pp 15–28
Crumley CL (1994) Historical ecology: a multidimensional ecological orientation. In: Crumley CL (ed) Historical ecology: cultural knowledge and changing landscapes. School of American Research Press, Santa Fe, pp 1–16
Dearing JA (2007) Human-environment interactions: learning from the past. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? an integrated history and future of people on earth. The MIT Press, Massachusetts, pp 19–37
Deléage JP (1993) Historia de la ecología: una ciencia del hombre y de la naturaleza. Icaria, Barcelona
Dietl GP, Flessa KW (eds) (2009) Conservation paleobiology: using the past to manage for the future, vol 15. Paleontological Society Papers, Paleontological Society, Houston
Echeverría J (1995) Filosofía de la ciencia. Editorial Akal, Madrid
Egan D, Howell EA (2001) Introduction. In: Egan D, Howell EA (eds) The historical ecology handbook: a restorationist's guide to reference ecosystems. Island Press, Washington DC, pp 1–23
Fischer-Kowalski M, Haberl yH (eds) (2007) Socioecological transitions and global change: trajectories of social metabolism and land use. Edward Elgar, Cheltenham
Fontana J (1992) La historia después del fin de la historia. Crítica, Barcelona
Foster D, Swanson F, Aber J, Burke I, Brokaw N, Tilman D, Knapp A (2003) The importance of land-use legacies to ecology and conservation. Bioscience 53:77–88
Funtowicz S, Ravetz JR (2000) La ciencia postnormal. Editorial Icaria, Barcelona
Gaddis JL (2002) El paisaje de la historia: cómo los historiadores representan el pasado. Anagrama, Barcelona
Gadgil M (1990) India's deforestation: patterns and processes. Soc Nat Resour 3:131–143
García R (2006) Sistemas complejos: conceptos, métodos y fundamentación epistemológica de la investigación interdisciplinaria. GEDISA, Barcelona
García R (2000) El conocimiento en construcción. Gedisa Editorial, Barcelona, 252 pp
Georgescu-Roegen N (1971) The entropy law and the economic process. Harvard University Press, Massachusetts
Georgescu-Roegen N (1990a) Epílogo in jeremy rifkins (entropía)
Georgescu-Roegen N (1990b) Epílogo. In: Rifkins J (ed) Entropía: hacia el mundo invernadero. Editorial Urano, Barcelona
Gintis H (2009) The bounds of reason: game theory and the unification of the behavioral sciences. Princeton University Press, New Jersey
Grove R (2002) Globalization and the history of environmentalism 1650–2000. Rev de Hist Actual 1(1):13–21
Hardesty DL (1979) Antropología ecológica. Ediciones Bellaterra, Barcelona
Harris M (1977) Cannibals and king: the origins of cultures. Vintage, New York
Harris M (1985) Good to eat: riddles of food and culture. Waveland Press Inc, Illinois
Harris M (1975) Cows, pigs, wars and witches: the riddles of culture. Hutchinson & Co, London
Harris M (1983) Cultural anthropology. Addison-Wesley Educational Publishers, USA
Hassan FA (2007) The lie of history: nations-states and the contradictions of complex societies. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? an integrated history and future of people on earth. The MIT Press, Massachusetts, pp 169–196
Hernández Sandoica E (2004) Tenencias historiográficas actuales: escribir historia hoy. Akal, Madrid
Holling CS (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390–405
Hornborg A (2007) Footprints in the cotton fields: the industrial revolution as time-space appropriation and environmental load displacement. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history: world-system history and global environmental change. Altamira Press, Lanhan, pp 259–272

Hornborg A et al (eds) (2007) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan
Hsiang SM, Burke M, Miguel E (2013) Quantifying the influence of climate on human conflict. Science 341:1235367
Hughes D (2002) The nature of environmental history. Rev de historia actual 1(1):13–21
Kajikawa Y, Ohno J, Takeda Y, Matsushima K, Komiyama H (2007) Creating an academic landscape of sustainability science: an analysis of the citation network. Sustain Sci 2(2):221–231
Kastenhofer K, Bechtold U, Wilfing H (2011) Sustaining sustainability science: the role of established inter-disciplines. Ecol Econ 70(4):835–843
Kates RW (2011) What kind of a science is sustainability science? Proc Natl Acad Sci 108(49):19449–19450
Khagram (2010)
Kiss IN (1990) Sylviculture and forest administration in Hungary 11–20th Centuries. In: Brimblecombe P, Pfister C (eds) The silent countdown. Springer, Berlin, pp 106–124
Kuhn T (1975) La estructura de las revoluciones científica. Fondo de Cultura Económica, México
Laughlin RB (2005) Un universo diferente. La reinvención de la física en la edad de la emergencia, Buenos Aires
Le Roy Ladurie E (1967) Histoire du climat depuis l'an mil. Flammarion, París
Luhmann N (1996) Introducción a la teoría de sistemas. Universidad Iberoamericana/Anthropos, México
Margalef R (1979) Perspectivas de la teoría ecológica. Blume, Barcelona
Margalef R (1995) La ecología, entre la vida real y la física teórica: investigación y ciencia junio. Academic Press, Barcelona, pp 66–73
McCormick M, Büntgen U, Cane MA, Cook ER, Harper K, Huybers P, Litt T, Manning SW, Mayewski PA, More AFM, Nicolussi K, Tegel W (2012) Climate change during and after the roman empire. Autumn 43(2):169–220
McDonnell MJ, Pickett STA (eds) (1993) Humans as components of ecosystems: the ecology of subtle human effects and populated areas. Springer, New York
McNeill J (2005) Modern global environmental history. IHDP Update, pp 1–3
Meine C (1999) It's about time: conservation biology and history. Conserv Biol 13:1–3
Milanovic B (2003) Two faces of globalization: against globalization as we know it. World Dev 31(4):667–683
Milanovic B (2006) La era de las desigualdades. Sistema, Madrid
Morin E (1980) El método, II: la vida de la vida. Cátedra, Madrid
Morin E (1984) Ciencia con conciencia. Anthropos, Barcelona
Morin E (2007) La epistemología de la complejidad. In: Garrido F, González de Molina M, Serrano JL, Solana YJL (eds) El paradigma ecológico en las ciencias sociales. Editorial Icaria, Barcelona, pp 55–84
Morin E (1977) Le méthode I: la nature de la nature. de la Seuil, Paris
Morin E (2001) Introducción al pensamiento complejo. GEDISA Editores, Barcelona
Moulines C (2011) Cuatro tipos de desarrollo teórico en las ciencias empíricas. Metatheoria 1(2):11–27
Moulines CU (2006) Ontology, reduction, emergence: a general frame. Synthese 151(3):313–323
Naredo JM (1987) La economía en evolución: historia y perspectivas de las categorías básicas del pensamiento económico. Siglo XXI editores, Madrid
Newell B, Wasson R (2002) Social system versus solar system: why policy makers need history. In: Castelein S, Otte A (ed) Conflict and cooperation related to international water resources: historical perspectives. UNESCO, Paris, pp 3–17
Norgaard R (1987) The epistemological basis of agro-ecology. In: Altieri M (ed) Agroecology: the scientific basis of alternative agriculture. Westview Press, Boulder, pp 20–35
Norgaard R (1994) Development betrayed: the end of progress and coevolutionry revisioning of the future. Routledge, London
Odum HT (1972) Environment, power, and society. Wiley, New York

Ostrom E, Cox M (2010) Moving beyond panaceas: a multi-tiered approach for social-ecological analysis. Env Cons 37:451–463
Pagels HR (1988) Los sueños de la razón: el ordenador y los nuevos horizontes de las ciencias de la complejidad. Gedisa, Barcelona
Peterken GF (1981) Woodland conservation and management. Chapman and Hall, London
Pfister C (2007) Climatic extremes, recurrent crises and witch hunts: strategies of European societies in coping with exogenous shocks in the late sixteenth and early seventeenth centuries. Med Hist J 10(1-2):33–73
Prices H (2011) Naturalism without mirrors. Oxford University Press, London
Prigogine Y (1971) Thermodynamics theory of structure, stability and fluctuations. Wiley, London
Prigogine Y (1947) Etude thermodynamique des phénomènes irreversibles. Dunod, París
Prigogine Y, Stengers I (1979) La nueva alianza: metamorfosis de la ciencia. Alianza Editorial, Madrid
Punti A (1988) Energy accounting: some new proposals. Hum Ecol 16(1):79–86
Putnam RD (1995) Bowling alone: America's declining social capital. J Democr 6(1):65–78
Rackham O (1986) The history of the countryside. Dent, London
Rackham O (1998) Implications of historical ecology for conservation. In: Sutherland WJ (ed) Conservation science and action. Blackwell Science, Malden, pp 152–175
Rackham O (2003) Ancient woodland: its history, vegetation and uses in England, New edn. Castlepoint Press, Colvend
Rappaport R (1968) Pigs for the ancestors. Yale University Press, New Haven
Rappaport R (1971) The flow of energy in an agricultural society. Sci Am 224(3):116–132
Redclift RM, Woodgate G (2005) New development in environmental sociology. Edward Elgar Publishing, Ltd. Cheltenham, U.K. and Northampton, MA, USA
Rifkins J (1990) Entropía: hacia el mundo invernadero. Urano, Barcelona
Rorty R (1990) El giro lingüístico. Paidós, Barcelona
Russell EWB (1997) People and the land through time: linking ecology and history. Yale University Press, New Haven
Sieferle RF (2001) Qué es la historia ecológica. In: Gonzalez de Molina M, Martinez-Alier YJ (eds) Naturaleza transformada: estudios de historia ambiental en España. Icaria Editorial, Barcelona, pp 31–54
Sini Carlo (1999) El pragmatismo. Ediciones Akal, Madrid
Spangenberg JH (2011) Sustainability science: a review, an analysis and some empirical lessons. Environ Conserv 38(3):275–287
Steward J (1955) The theory of culture change: the methodology of multilinear evolution. University of Illinois Press, Urbana
Steward J (1977) Evolution and ecology: essays on social transformation. University of Illinois Press, Urbana
Szabó P (2010) Why history matters in ecology: an interdisciplinary perspective. Environ Conserv 37:380–387
Thompson ID, Mackey B, McNulty S, Mosseler A (2009) Forest resilience, biodiversity, and climate change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Technical Series no. 43. Secretariat of the Convention on Biological Diversity, Montreal
Toledo VM (2003) Ecología, espiritualidad, conocimiento: de la sociedad del riesgo a la sociedad sustentable. PNUMA y Universidada Iberoamericana, México
Toledo VM, Barrera-Bassols N (2008) La memoria bio-cultural: la importancia agroecológica de las sabidurías tradicionales. Icaria, Barcelona
Totman C (1989) The green archipielago: forestry in preindustrial Japan. University of California Press, Berkeley
Tyrtania L (2008) La indeterminación entrópica notas sobre disipación de energía, evolución y complejidad. Desacatos 28:41–68

Tyrtania L (2009) Evolución y sociedad: termodinámica de la supervivencia para una sociedad a escala humana. Universidad Autónoma Metropolitana, México
Vayda A (1969) Environment and cultural behavior: ecological studies in cultural anthropology. Natural History Press, Garden City
Vayda A, Mackay YB (1975) New directions in ecology and ecological anthropology. Ann Rev Antropology 4:293–306
Vayda A, Mackay YB (1977) Problems in the identification of environmental problems. In: Bayliss-Smith TP, Feachem RGA (eds) Subsistence and survival: rural ecology in the pacific. Academic Press, New York, pp 225–240
Vayda A, Rappaport YRA (1968) Ecology, cultural and noncultural. In: Clifton JA (ed) Introduction to cultural anthropology: essays in the scope and methods of the science of man. Houghton Mifflin, Boston, pp 477–497
Verheyen K, Honnay O, Bossuyt B, Hermy M (eds) (2004) Forest biodiversity: lessons from history for conservation. CABI Publishing, Wallingford
Wigley T, Ingram M, Farmer YG (1981) Climate in history: studies in past climates and their impact on man. Cambridge University Press, Cambridge
Wilson EO (1980) Sociobiología, la nueva síntesis. Editorial Omega, Barcelona
Woodgate G, Redclift M (eds) (1998) The international handbook of environmental sociology. Edward Elgar, USA
Worster D (1988) The end of the earth: perspectives on modern environmental history. Cambridge University Press, New York
Worster D (2004) ¿Por qué necesitamos de la historia ambiental? Rev Tareas 117:119–131
Worster D (1993) History as natural history. In: Worster D (ed) The wealth of nature: environmental history and the ecological imagination. Oxford University Press, Oxford, pp 30–44

Chapter 3
Social Metabolism: Origins, History, Approaches, and Main Publications

3.1 Introduction

The main contemporaneous challenge of the human species is the growing concern for the future. As never before seen, natural and social processes become entangled to generate unpredictably surprising new dynamics and synergies threatening the human species, the planetary equilibrium, and life as a whole. We are witnessing a crisis of civilization: the crisis of modern, industrial civilization, requiring of new paradigms throughout the realms of a reality that has been transformed into a socio-natural or natural-social highly complex system (Toledo 2011). In that context, science as a whole must know the past in order to obtain lessons from it and for adopting a rigorous historical perspective allowing for understanding of present situations in a comprehensive way. The above commitment of science implies two things: one, developing a comprehensive and interdisciplinary conceptual framework that is capable of orchestrating research made of the relations between humans and nature; and two, making a functional and meaningful analysis of such relations in time and space.

As pointed out in Chap. 2, efforts in that direction have been gathered surrounding a new field known as sustainability science (Spangenberg 2011). The idea of a sustainable society and the concept of sustainability itself have unleashed an explosion of scientific research made during the past two decades. Currently, over 20,000 scientific papers about sustainability have been written in English alone by 34,000 authors from 174 countries (Bettencourt and Kaur 2011). Despite the above, sustainability science continues to lack an appropriate theoretical framework that in a coherent way organizes the information coming from numerous fields and areas of knowledge. The concept of social metabolism is a strong candidate for satisfying that want, being one of the most robust instruments of the past two decades for understanding the complex scenarios of the present. In this Chapter we will provide a narrative account of the origins, history, main exponents, interpretations, and trends of the theory of social metabolism, and a brief review of the related literature.

M. González de Molina and V. M. Toledo, *The Social Metabolism*,
Environmental History 3, DOI: 10.1007/978-3-319-06358-4_3,

3.2 A Starring Concept

Social metabolism is a concept that gained extraordinary strength in the field of socioenvironmental studies since the 1990's. A general or standard definition of social metabolism was stated by Fisher-Kowalski and Haberl (1997). They define it as the particular form in which societies establish and maintain their material input from and output to nature and as the way in which they organize the exchange of matter and energy with their natural environment. Social metabolism has also occurred as a theory explaining socioenvironmental change (Fisher-Kowalsky and Haberl 1997, 2007; Sieferle 2001, 2011; González de Molina and Toledo 2011), or it has been used as a kit of methodological tools useful for analyzing the biophysical behavior of economies (Matthews et al. 2000; Haberl 2001a, b; Weisz 2007). In all its appearances, social metabolism is a new perspective for analyzing the relations between society and nature from its material bases, mainly through the study of flows of energy and materials. The concept was derived form its analogy with the concept of biological metabolism, and recognizes that for their function and reproduction, societies need flows of energy and materials; flows that were amplified throughout the process of industrialization. That growing need implies one of the main challenges in terms of sustainability (Fisher Kowalski 1997; Fisher-Kowalski et al. 2014; Giampietro and Mayumi 2000; Giampietro et al. 2012).

Since the 1990's, the metaphor of social metabolism has undoubtedly been successful, methodologies for it having been formalized, and being applied in tens of case studies, many of them with deep time perspectives. As a consequence, we currently have detailed evidence available allowing for better understanding the biophysical dynamics of societies, especially industrialized societies.

3.3 The Origins

The use of the concept of social metabolism peaked during the present century, however its origin dates back to the nineteenth century (see further below). In order to be able to entirely understand the birth of the concept of social metabolism—which expresses a whole new worldview– one needs to know the intellectual atmosphere dominating the scientific thought of the nineteenth century. Science originated from European scientific societies since the seventeenth century, but it was during the nineteenth century when science's largest synthesis were prepared and achieved. Unlike what is seen in current specialization and partition of scientific knowledge, that frequently impedes an integrative vision, during the nineteenth century there was reciprocity in the interests of naturalists and social scholars of the time, and a genuine desire—rare in present times—for discovering universal patterns, principles, and laws that applied to all orders of matter organization.

The evolutionary perspective, in particular analogical reasoning, framed a large part of the scientific advances of the nineteenth century providing crossties between natural and social sciences. In terms of Padovan: "The theoretical systems of the early sociologists were deeply influenced by contemporary interpretations of nature, both because they thought that the sciences of nature and of the biological body, such as biology and medicine, were becoming more and more accurate and scientifically objective, and because these early sociologists thought that the nature of society itself depended, in many ways on relations with nature that surrounded it, with the environment. The conviction that there was an indisputable interdependence between social evolution and evolution within nature was due to the analogical cognitive structures which predominated (Padovan 2000, p. 2)."

The metaphor of social metabolism arises from the analogical thesis stating that two systems can be obviously different, yet structurally similar. The idea of societies being similar to living organisms was accompanied by still another analogy: the laws of behavior and evolution ruling living organisms also apply to human societies. From this notion derives the need for studying the interchanges of energy and mater occurring between society and the natural world. Quoting Padovan: "In the eyes of positivist and organicist sociology, society was not separate from nature: the two could perhaps compete or struggle or, more often, co-operate and collaborate, but they were never considered in different ways. Human beings, like society, were part of nature and were linked, both mechanically and dialectically, to the same laws that govern natural evolution. Furthermore, society was more complex and more differentiated than any other living organism. But both the ends and the function of society and nature were very similar (Padovan 2000, p. 10)." Amidst such intellectual turmoil agitating the brains of the thinkers of that time, it was frequent that sociologists imbibed from the contributions of natural science, and also that all sorts of naturalists—including zoologists, botanists, geologists, and geographers—rummaged through the thesis of social scientists. Among the latter, Ernst Haeckel is noticeable for coining the term *oekologie* in 1866 and for developing numerous analogical comparisons between social and biological organisms; cells and individual human beings operate as units that build organisms. Haeckel even outlined a comparative anatomy of plants and animals based on a succession of forms of political organization that had been suggested by other authors. In the camp of social science, organicist sociologists such as Herbert Spencer, Paul Lilienfield, Auguste Comte, and Adam Schâffle made contributions that were mostly retaken by present socioecological analyses (Padovan 2000). Such is the case of the concepts of resilience, inputs and outputs, evolution and its derivatives (integration, differentiation, and specialization), diversity, and heterogeneity, among many others. Spencer's thesis of nature, being a mirror for society to organize, transform, and evolve, preceded biomimetics for over a century.

Despite these developments, the analogical exercises faded out as the fields of science became delimited and gained autonomy, the comprehensive approach dominating most of nineteenth century science being lost. Specialization increased as each field of the study of reality gained in depth, ending in the establishment of modern scientific disciplines. The current scenario presents a fragmented and overspecialized knowledge generated by tens of thousands of researchers throughout the world. In the case of sociology, criticism of organicist conceptions came more frequently from those who decades later would be recognized as its legitimate founders: Emile Durkheim, Max Weber, Célestine Bouglé, and Talcott Parsons. Sociologists pulled down the curtains and proclaimed that social processes could only be explained by social factors themselves. The study of society remained captive of that exclusion principle for decades, until in the late 1970's three authors from the US rigorously questioned this human exceptionalism paradigm: W.R. Catton, R.E. Dunlap and F.H. Buttel (see Catton and Dunlap 1978; Dunlap 1997; Buttel 1987, 1978). The result was the birth of the new discipline of environmental sociology, whose followers have multiplied, especially in English speaking countries (Redclift and Woodgate 1997). Paradoxically, only one student of society, and the most critical of them, explicitly used the concept of metabolism as the base and trigger of the construction of his social theory: Karl Marx.

3.4 Darwin and Marx in London

The nineteenth century was the era of the British Empire and London was not only the largest city in the world (in one century reaching to a population of 6.7 million inhabitants), but also the world capital of finances, commerce, politics, and intellectual creation. Numerous scholars and researchers from the most advanced intellectuality of the epoch lived in London, including among them two of the giants of thought of the century: Charles Darwin (1809–1892) and Karl Marx (1818–1883). Darwin established his home in a town near London in 1842 after returning from his exploration voyage to the southern hemisphere. Marx arrived to London 7 years after during his itinerary through several European cities, and remained there until his death. While living within sixteen miles from each other, Darwin and Marx never met personally. Their contact was limited to correspondence started by Marx, who was an admirer of Darwin's work to the extreme of wanting to dedicate him the second volume of Capital: Critique of Political Economy. After the publication in November of 1859 of Darwin's long expected book The Origin of Species, F. Engels wrote to Marx: "Darwin, whom I am just now reading, is absolutely splendid. His book has achieved the demolishment of a certain theology upheld since some time ago." In response, on December 19 of 1860, Marx wrote to Engels: "This book contains the natural historical foundations of our conception."

3.5 The Key Writings of Alfred Schmidt

Although the intellectual links between Darwin and Marx were recurrently studied both by historians of science (e.g., Gerratana 1973; Colp 1974) and by Marxist analysts (Foster 2000), we owe to Alfred Schmidt (1962) what ended up being a crucial revelation. During the spring of 1973, one of us (VMT) discovered in a bookstore in Harvard Square in Cambridge, Massachusetts, US a 1973 edition of the English version of Alfred Schmidt's book The Concept of Nature in Marx. This book is a translation from German of the doctoral dissertation of Schmidt—a philosopher of the Frankfurt School—that was published as a book in 1962. As years passed, this book that has been translated to 18 languages has become an obligatory source for those interested in the articulations between Marxism and ecology. Alfred Schmidt died recently on August 28 of 2012 in Frankfurt at the age of 81 years (Gandler 2012).

Marx had not only extensively read the works of naturalists of his time, but he had also perused the work of a key author from the Netherlands, Jacob Moleschott (1822–1893), who was amply recognized in the natural science circles of Europe. Moleschott wrote several books, among which is Der Kreislauf des Lebens (The Cycle of Life) published in 1852 containing a true nineteenth century treatise of ecology. From The Cycle of Life, Marx derived the key concept that allowed him to build his critical theory of capitalism: Stoffwechsel, translated as metabolism or organic exchange. The term Stoffwechsel was used by Marx in the manuscripts he wrote in the late 1850's and in volume one of Capital: Critique of Political Economy published in Hamburg in 1867 (see also Martínez-Alier 1987, pp. 200–226).

Marx used metabolism as having two main meanings: as an analogy or a biological metaphor to illustrate flow of commodities, and in a more general way as an exchange between man and land or between society and nature (Martínez-Alier 2004). Schmidt (1971) devoted a large part of his book to provide a detailed interpretation of the use of the concept of metabolism and to a reflection about the social, historical, ecological, and cosmic implications of the concept, which he synthesized in a key premise: "Marx conceived labor as a process of progressive humanization of nature, an act which is coincident with the gradual naturalization of humans (Schmidt 1971, p. 81). "Nature is thus thought by Marx as the material substrate of work, as the primary source of all instruments and subjects of labor (Schmidt 1971)." Schmidt states: "All act of giving form to a natural substance must obey to the peculiar laws of mater (Schmidt 1971, p. 84)." Therefore, "…man can only proceed in his production in the same way as nature itself, that is he can only alter the *forms of the material* (Marx 1965, p. 43)."

The connection of Marx's economic theory and natural processes derives from a key distinction between use value and exchange value: In Marx's terms, "…as labor is a creator of use-value, is useful labor, it is a necessary condition, independent of all forms of society, for the existence of the human race; it is an eternal nature-imposed necessity, without which there can be no material exchanges between man and Nature, and therefore no life (Marx 1965, p. 54)". Because of this, Marx calls use value to the natural, vulgar, concrete form of labor, and exchange value to the supra natural, abstract, and general form of labor. This distinction will in turn allow for establishing a tacit difference between ecological exchange and economic exchange (Toledo 1981), which is crucial for building a theory of appropriation of nature (see Chap. 5).

What follows is an assumption that preceded the present interdisciplinary proposals as an epistemological forecast: "The sciences of Nature will engulf in the future the sciences of man, as will the sciences of man do with the sciences of nature; there will but a single science (Marx 1975, p. 355)." The relevance in Marx's thought of the concept of metabolism was certified in letter he wrote to his wife on June 21 of 1856: "…it is not the love for man of Feuerbach, nor that for metabolism of Moleschott, or for the proletariat, but love for the cherished woman, in this case for you, what makes a man become once more a man (see Annali del Instituto Giancgiacomo Feltrinelli, Milan, Italy, 1959)."

3.6 Marx and Energy Flows

Despite his interest for the contributions of naturalist of the time—lead by Darwin—and the adoption of the concept of Stoffwechsel, Marx could not establish the connection between economic and energetic flows that more than a century later would give place to numerous proposals (led by Georgescu-Roegen and his Economy and Entropy), which would crystalize in what was named ecological economy (Martínez-Alier 1987).

Quoting Martínez-Alier "Marx was a historian and economist, also interested in agricultural chemistry. He wrote that the metabolic flow of materials between human society and Nature was mobilized by human labor except in primitive gathering societies. Tool development by humans was essential for the metabolism. Marx did not consider energy flow (unless he did so in unpublished writings). He did not trace the distinction (as Lotka was to do in 1911) between endosomatic use of energy in nutrition (bio-metabolism) and the exosomatic use of energy by tools (techno-metabolism). Humans have genetic instructions on bio-metabolism but not on techno-metabolism, which is very different between rich and poor, and is explained by history, politics, economics, technology, culture…The link between material metabolism (Stoffwechsel, exchanges of materials) and the flow of energy at the level of cells and organisms was made in the 1840s. It was then also understood that agriculture implied changes in the flow of energy and not only in the cycling of plants nutrients (Mayer 1845, used Stoffwechsel or energy flow). Metabolism was used then not only for materials but also for energy. Of course, materials could to some extent be recycled, but energy could not. The theory of the direction of the flow of energy was developed after the Second Law was established in 1850 (Martínez-Alier 2006, p. 5)."

A relevant case is that of the Ukrainian medic and philosopher S. Podolinsky (1850–1891), who made bold new contributions regarding agricultural energy, being the first to establish links between agriculture, agricultural production and productivity, and energy dissipation. On April 8 of 1880 Podolinsky wrote a letter to Marx, to which he attached one of his articles, in which he stated: "With particular impatience I wait for your opinion on my attempt to bring surplus labor and current physical theories into harmony (for details, see Martínez-Alier and

Naredo 1982)." Marx skepticism, which Engels nourished and shared, left unaccomplished the development of a research line that has today become strategic. The insight achieved by Podolinsky is described by Martínez-Alier in the following paragraph: "Podolinsky looked at the energy return to energy input in a framework of reproduction of the social system. He thought that he had reconciled the Physiocrats with the labor theory of value, although the Physiocrats (in the eighteenth century) could not have seen the economy in terms of energy flow. He interpreted capital accumulation not as increasing the produced means of production or even less in financial terms, but as increasing the availability of energy (and certainly also its dissipation) (Martínez-Alier 2006, p. 9)."

It is surprising that nearly a century later none of the main essays written about Marxism and ecology documented the pivotal character of the concept of social metabolism (Moscovici 1969; Skirbek 1974; Lefevre 1978), and that the concept was also overlooked in the detailed compilation of Marx and Engel's ecological ideas made by Parsons (1977).

3.7 The Rediscovery of the Concept of Social Metabolism

The concept of social metabolism remained virtually dormant during decades until the 1960's, when Wolman (1965) applied it for the biophysical analysis of cities, as did Boulding (1966), and by the economists Ayres and Kneese (1969) for industrial countries. But Marina Fisher-Kowalski was who formally re-launched the concept in a chapter of her book Handbook of Environmental Sociology published in 1997 (Radclife and Woodgate 1997), presenting it as a stellar concept useful for analyzing flows of materials. The same author also wrote accounts of the historical trajectory of the concept (Fisher-Kowalski 1998; Fisher-Kowalski and Huberl 1999). By that time, other concepts had appeared such as industrial metabolism, societary metabolism, socioeconomic metabolism, urban metabolism, and more recently, agrarian or rural metabolism, and hydraulic metabolism. These terms correspond to the study of fractions or dimensions of the general metabolic process (see Chaps. 5 to 8). In the context of birth and development of new hybrid disciplines that predicate and practice interdisciplinarity, the concept of social metabolism and its equivalents was placed predominantly—but not exclusively—as a tool and method of ecological economy and industrial economy.

3.8 A Bibliometric Analysis

The best way of finding out how much is a recent discipline developing is by making a bibliometric analysis, which is based on searching bibliographic databases for concepts, terms or key words, and obtaining the number of corresponding publications along time. Bibliometric studies have been made of recently developed fields of science as Agroecology (Wezel and Soldat 2009), Ethnoecology (Toledo and Alarcón-Cháires 2012), and Sustainability Science (Bettencourt and Kaur 2011). Recently, Infante and collaborators (2014) used Google Scholar as a web search engine for creating a database with the results of a detailed bibliometric analysis of the concept of social metabolism (Table 3.1 and Figs. 3.1, 3.2).

Table 3.1 shows that over 5,000 publications about social metabolism have been produced between 1980 and 2013, including peer-reviewed and not peer-reviewed papers, books, thesis, reports, and other types of publications. The field's takeoff occurred during the 1990's, about 90 % of the total publications occurring between 2000 and 2013. The more common languages are English and Spanish or Portuguese (Fig. 3.1, 3.2), all other languages accounting for only 6.6 % of the total published works. The number of publications in Spanish and Portuguese is increasing at a high rate, already being nearly the same as that of English publications, and probably surpassing them in the near future. Such trend reveals the interest for the topic in countries such as Spain, Brazil, and Mexico, among other Latin American countries (Fig. 3.1, 3.2).

Beyond these figures, the adoption and use of the concept of social metabolism has been extending as authors began to retake analogical reasoning and dared to propose a metaphor of society as an organism. However, nearly without exceptions, the use of the term metabolism was made without any reference to its origins in the nineteenth century, because of which it was always associated to qualifiers different from social: industrial metabolism, urban metabolism, metabolism of the anthroposphere, etc. Three decades went by before an official letter of presentation made its appearance in the form of the theoretical and historical essay of Fisher-Kowalski (1997), and the many subsequent studies made since then by the Socio Ecological Institute of Vienna. To date, a dozen key works can be selected from the universe of publications on the topic (Table 3.2), and a preliminary classification can be made of at least five groups of themes focusing on fractions or dimensions of the general process of metabolism, which we present in the following paragraphs: Industrial Metabolism, Urban Metabolism, Agrarian or Rural Metabolism, Regional metabolism, and National metabolism.

3.9 Industrial Metabolism

The first works made about industrial metabolism were part of the heritage of the groups linked to Industrial Ecology (Ayres and Kneese 1969; Ayres and Simonis 1994). Research in that field has focused on studying the flows of materials in industrial societies, aiming at reconstructing the biophysical base of territories at the national and global scales. The main publications come from a recognizable group of institutes and research centers including the World Resources Institute (WRI) and the Sustainable Europe Research Institute (SERI). The foremost products of this group have been the reconstruction of the Economy-wide Material

Table 3.1 Numbers of publications by language about social metabolism searched by means of Google Scholar between 1880 and 2013

	English	English or Portuguese	German	French or Catalonian	Italian	Total
1880–1890			1			
1891–1800						
1901–1910	3		1			4
1911–1920	2					2
1921–1930	8					8
1931–1940	7			1	2	10
1941–1950	7			1	1	9
1951–1960	4	2		2	3	11
1961–1970	16	1		6	1	24
1971–1980	36	11	2	6	1	56
1981–1990	49	13	5	10	1	78
1991–1900	249	60	20	7	3	339
2001–2010	1290	1180	104	66	22	2662
2011–2013	793	995	45	35	11	1879
Total	2464	2262	178	134	45	5082

Publications were found in English (search terms: social metabolism, societal metabolism, socioecological metabolism, and socioeconomic metabolism), German (Soziale Metabolismus and Gesellschaftlichen Stoffwechsel), and Italian (metabolismo sociale), and in languages for which the term is the same, such as Spanish and Portuguese (metabolismo social), and French and Catalan (métabolisme social, métabolisme socio-économique, and métabolisme socio-écologique). Duplication of terms because of Spanish and Portuguese papers usually having English abstracts was avoided by exclusion of appropriate terms
Source Infante et al. 2014

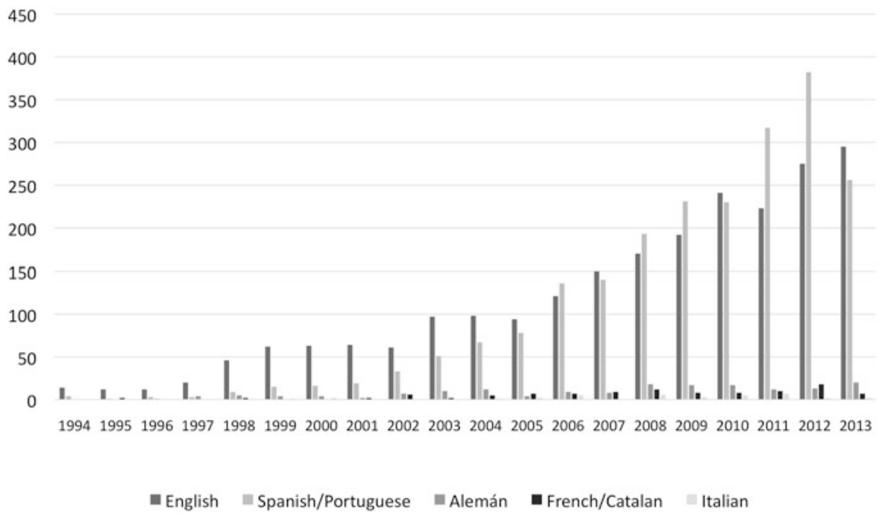

Fig. 3.1 Number of publications by year (1994–2013) on social metabolism in English, Spanish, Portuguese, Germany, French, Catalan and Italian

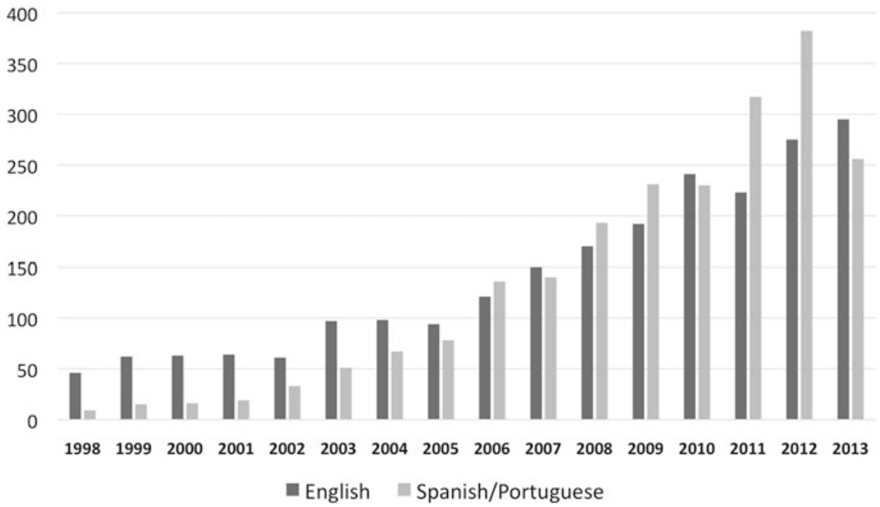

Fig. 3.2 Number of annual publications (1998–2013) on social metabolism in English, Spanish and Portuguese

Table 3.2 Twelve key works about social metabolism published from 1965 to 2013 listed in chronological order

Title	References
The metabolism of the cities	Wolman (1965)
Industrial metabolism	Ayres (1989)
Metabolism of the anthroposphere	Baccini y Brunner (1991)
Society's metabolism: on the childhood and adolescence of a rising conceptual star	Fisher-Kowalski (1997)
Industrial metabolism: restructuring for sustainable development	Ayres and Simonis 1994
The weight of nations	Matthews et al. (2000)
Economy-wide material flow accounts and derived indicators: a methodological guide	Eurostat (2001)
Socio-ecological transitions and global change: trajectories of social metabolism and land use	Fischer-Kowalski and Haberl (2007)
Metabolismos Rurales	Toledo y García-Frapolli (2008)
Metabolismos, Naturaleza e Historia. Hacia Una teoría de las transformaciones socio-ecológicas	González de Molina y Toledo (2011)
The metabolic pattern of societies: where economists fall short	Giampietro et al. (2012)
Sustainable urban metabolism	Ferrao and Fernández (2013)

Flow Accounts (EW-MFA) for most of the countries of the world, detailing and analyzing the associated indicators of production, consumption, and commerce, attempting to stand as a tool for environmental policy aiding in planning scenarios of resource consumption. The kind of efforts made in this series of studies of flows of materials in industrial societies are represented in the report on the subject prepared by a selected group of researchers from the World Resources Institute in 2000 (Mathews et al. 2000).

3.10 Urban Metabolism

The first explicit mention of urban metabolism was made in the 1960's in an article of Wolman (1965) published in Scientific American with the title The Metabolism of Cities. But the metabolic approach to cities developed at a much slower pace than that of the vertiginous expansion of the concept of industrial metabolism. The field of urban metabolism became consolidated until the present century (Kennedy et al. 2007, 2011), as reaffirmed by two key publications: a special issue of the Journal of Industrial Ecology (Vol. 16, Issue 6, 2012) dedicated to sustainable urban systems, and the book Sustainable Urban Metabolism written by Ferrao and Fernández (2013). This latter book addresses urban metabolism attempting to arrive to a theoretical and methodological unification, reviews the criteria for sustainability of cities, and provides a platform assisting ecological urban planning, as stated by the authors: "Cities at present are mainly linear reactors: their metabolism consists of consuming materials and goods from elsewhere, transforming them in buildings, technical infrastructures for energy or water supply, communications or mobility, and wastes, which are summarily discarded, typically involving very limited reuse or recycling (Ferrao and Fernández 2013, p. xi)."

3.11 Agrarian or Rural Metabolism

Later in appearance were studies of the metabolism of rural communities, municipalities, and regions focused on agrarian processes and particularly on direct interaction between nature and humans. These studies—made at the local or micro-regional scale—analyze in detail the relations that human communities have with both the natural environment and other sectors with which they hold trade (exchange of goods, commodities, and services), thus comprehensibly revealing the networks between ecological and economic exchanges existing in a determined territory. Using dissimilar methodologies, these studies offer insights of both contemporary (Singh et al. 2001; Grau-Satorras 2010; García-Frapolli et al. 2008; Cordón and Toledo 2008; Ortiz and Masera 2008) and historical (González de Molina 2002; González de Molina and Guzmán-Casado 2006, 2009; Tello et al. 2008; Krausmann 2001, 2004; Krausmann and Haberl 2002) metabolic processes.

3.12 Regional Metabolism

Nor rural nor urban and industrial centers perform their metabolism in isolation from each other, being thus necessary to study metabolism from the spatial (territorial) perspective that integrates centers, territories, and regions. Such a requirement defining a different approach was recognized in the pioneer book of Baccini and Brunner, Metabolism of the Anthroposphere published in 1991, and reedited in a revised edition in 2012. The authors using the systemic approach make a metaphor between cities and organisms, defining urban metabolism as a general framework. The metabolic study of regions by Baccini and Brunner (1991) introduced the new category of substance flow—denoting flows of materials formed by uniform units that can be either pure chemical elements or compounds—that adds to the category of flows of materials—which includes substances and goods made up of one or more substances. During the past decade Tello and collaborators have made innovating contributions to the study of metabolism of territories and regions, developing an original methodology "which combines the energy and material flow analysis from an agroecology or an ecological economics standpoint with the study of land cover and land-use changes environmentally evaluated using the metrics and indices of landscape ecology (Tello 2013, p. 196)". The results of Tello's studies, centered in the Spanish Catalonian region, are methodologically robust given they integrate under the conceptual framework of social metabolism three traditions of the analysis of socioecological processes of concrete territories: land use change, landscape ecology, and environmental history (see Cussó et al. 2006; Tello et al. 2008; Marull and Tello 2010; Marull et al. 2010).

3.13 National Metabolism

Studies made of social metabolism at the scale of countries have noticeable multiplied along the past few years. At present, methods, indicators, and sources of statistical information are available, allowing for a detailed estimation of national-scale flows of materials and energy, from which the energetic and material metabolisms of countries can be quantified (Matthews et al. 2000; Haberl 2001b), and its changes along time be recorded (e.g., Krausman and Haberl 2002). Most of these studies offer contemporaneous diagnoses and almost without exception are limited to analyzing flows of energy and mater in correlation with economic parameters of interest (Haberl 2001a, b; Opschoor 1997). Currently, the metabolic profiles of nearly thirty countries are available, including countries of the EU, Latin America (Chile, Ecuador, México, Peru, and Venezuela), and Asia (China, Laos, the Philippines, and Thailand) (Eisenmenger and Giljum 2007; Russi et al. 2006).

In recent years, studies of national metabolism have begun to be analyzed comparatively (Eisenmenger and Giljum 2007; Russi et al. 2006; Muradian and Giljum 2007; Muradian et al. 2002) attempting to reach to historical diagnoses, such as those for Spain (Carpintero 1995) and Austria (Krausmann and Haberl 2002). By means of the ecological footprint of the human appropriation of net primary productivity, these studies assess the impacts on natural resources of human activities (Krausman et al. 2009). In all cases, the use of the concept of social metabolism in these works is circumscribed to the simple calculation of the flow of inputs (appropriation), outputs (excretion), imports, and exports.

3.14 Two Problems to be Solved

A shallow analysis of the current perspective of studies of social metabolism and its conceptual equivalents allows for observing two interesting facts. The first fact is that most of the literature contains analyses exclusively of material interactions of societies with nature and that the concept of social metabolism is seen as a mere methodological tool or a new form of environmental accountancy. The result is the proliferation of multiple interpretations and the consequent absence of a theoretical conceptual framework. With very few exceptions (Fisher-Kowalski and Weisz 1999; Giampietro 2006), most works are lacking theoretical or methodological reflections. What this means is that most studies belong to a version of social metabolism falling within engineering, energetics, and cybernetics that simply analyzes the flows of materials, energy, substances, water, or services, at the most assigning them a monetary value. In consequence, the conception of metabolism as a black box continues to prevail.

The second fact is the disappearance in the analyses—pretended to be holistic or interdisciplinary—of the social dimension in strict sense (among others, including the cultural, cognitive, juridical, political, and property dimensions), social dimension being rooted in exchanges of information, institutions, rules, values, knowledge, cosmovisions, and the forms of tenure and access to resources from nature that are not covered by most studies of social metabolism. The above-mentioned fact means leaving out the sociological dimension from the supposedly socioecological analysis, to concentrate exclusively on the material exchange between society and environment. It is an incomplete, partial view reduced to the analysis of flows of energy and mater, forgetting to investigate information flows that order or organize energy and mater flows. In the remaining of this book we attempt to overcome the above-mentioned limitations by proposing a basic model of social metabolism, providing a corresponding theoretical and methodological framework, and drafting a theory of socioecological transformations through history.

References

Ayres RU (1989) Energy inefficiency in the US economy: a new case for conservation. IIASA Research Report RR-89-012

Ayres RU, Kneese AV (1969) Production, consumption and externalities. Am Econ Rev 59:282–297

Ayres RU, Simonis UE (eds) (1994) Industrial metabolism: restructuring for sustainable development. UNU Press, NewYork

Baccini P, Brunner PH (1991) Metabolism of the anthroposphere. The MIT Press, Cambridge

Bettencourt LMA, Kaur J (2011) Evolution and structure of sustainability science. PNAS 108(49):19540–19545

Boulding K (1966) The economics of the coming spaceship Earth. In: Boulding K et al (eds) Environmental quality in a growing economy. John Hopkins University Press, Baltimore, pp 3–14

Buttel FH (1978) Environmental socioloogy: a new paradigm. Am Sociol 13:252–256

Buttel FH (1987) New directions in environmental sociology. Annu Rev Sociol 13:465–488

Catton WR, Dunlap RE (1978) Environmental sociology: a new paradigm? Am Sociol 13:41–49

Colp R (1974) The contacts between Karl Marx and Charles Darwin. J Hist Ideas 35:329–336

Cordón MR, Toledo VM (2008) La importancia conservacionista de las comunidades indígenas de la reserva de Bosawás, Nicaragua: un modelo de flujos. Revista Iberoamericana de Economía Ecológica 7:43–60

Cussó X, Garrabou R, Tello E (2006) Social metabolism in an agrarian region of Catalonia (Spain) in 1860–1870: flows, energy balance and land use. Ecol Econ 58(1):49–65

Dunlap RE (1997) The evolution of environmental sociology: a brief history and assessment od the American experience. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Edward Elgar, Cheltenham, pp 21–39

Eisenmenger NY, Giljum S (2007) Evidence from societal metabolism studies for ecological unequal trade. In: Hornborg A, Crumley YC (eds) The world system and the earth system: global socio-environmental change and sustainability since the neolithic. Left Coast Press, Walnut Creek, CA, pp 288–302

Eurostat (2001) Economy-wide matrial flows accounts and derived indicators: a methodological guide. European Communities, Luxembourg

Ferrão P, Fernández JE (2013) Sustainable urban metabolism. MIT Press, Massachusetts

Fischer-Kowalski M (1997) Society's metabolism: on the childhood and adolescence of a rising conceptual star. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Edward Elgar, Cheltenham, pp 119–137

Fischer-Kowalski M (1998) Society's metabolism: the intellectual history of materials flow analysis, part I, 1860–1970. J Ind Ecol 2:61–77

Fisher-Kowalski M, Haberl H (1997) Tons, Joules, and money: modes of production and their sustainability problems. Soc Nat Resour 10:61–85

Fischer-Kowalski M, Haberl H (eds) (2007) Socioecological transitions and global change: trajectories of social metabolism and land use. Edward Elgar, Cheltenham

Fisher-Kowalski M, Hûttler W (1999) Society's metabolism: the intellectual history of materials flow analysis, part II, 1970–1998. J Ind Ecol 2:107–129

Fisher-Kowalski M, Krausmann F, Pallua I (2014) A sociometabolic reading of the Anthropocene. Anthropocene Rev 1:1–26. http://anthropocenerev.blogspot.co.uk/p/about-journal.html

Foster JB (2000) Marx's ecology. Monthly Review Press, New York

Gandler S (2012) Alfred Schmidt. La Jornada Semanal 916:16

García-Frapolli E, Martínez-Alier J, Toledo VM (2008) Apropiación de la naturaleza por una comunidad maya yucateca. Revista Iberoamericana de Economía Ecologica 7:27–42

Gerratana V (1973) Marx and Darwin. New Left Rev 82:60–82

Giampietro M (2006) Comments on the energetic metabolism of EU and USA by Haberl and colleagues. J Ind Ecol 10:173–185

Giampietro M, Mayumi K (2000) Multiple-scale integrated assessment of societal metabolism: introducing the approach. Popul Environ 22:109–154

Giampietro M, Mayumi K, Sorma AH (2012) The metabolic pattern of society. Routledge, New York

González de Molina (2002) Environmental constraints on agricultural growth in 19th cenntury, Granada, Spain. Ecol Econ 41:257–270

González de Molina M, Guzmán-Casado G (2006) Tras los Pasos de la Insustentabilidad: Agricultura y Medio Ambiente en perspectiva Histórica (Siglo XVIII-XX). Icaria, Barcelona

González de Molina M, Toledo VM (2011) Metabolismos. Naturaleza e Historia. Icaria editorial, Barcelona

Grau-Satorras M (2010) Ecological knowledge and use of natural resources, are they related? A study case among tribal communities in Kodagu, India. Bsc 'Environmental Sciences' Universitat Autónoma de Barcelona. http://ddd.uab.cat/pub/trerecpro/2010/hdl_2072_94000/PFC_MarGrauSatorras.txt

Guzmán-Casado G, Gonzalez de Molina M (2009) Preindustrial agriculture versus organic agriculture: the land cost of sustainability. Land Use Policy 26:502–506

Haberl H (2001a) The energetic metabolism of societies I: accounting concepts. J Ind Ecol 5:11–33

Haberl H (2001b) The energetic metabolism of societies II: empirical examples. J Ind Ecol 5:53–70

Infante J, Toledo VM, Gonzalez de Molina M (2014) El concepto de metabolismo social: un análisis bibliométrico. Sended to *Revista Iberoamericana de Economía Ecológica*

Kennedy C, Cuddihy J, Engel-Yan J (2007) The changing metabolism of cities. J Ind Ecol 11(2):43–59

Kennedy C, Pincetl S, Bunje P (2011) The study of urban metabolism and its applications to urban planning and design. Environ Pollut 159:1965–1973

Krausmann F (2001) Land use and industrial modernization: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830–1995. Land Use Policy 18:17–26

Krausmann F (2004) Milk, manure and muscle power. Livestock and transformation of pre-industrial agriculture in Central Europe. Human Ecol. 32(6):735–772

Krausmann F, Haberl H (2002) The process of industrialization from the perspective of energetic metabolism: socio-economic energy flows in Austria 1830-1995. Ecol Econ 41:177–201

Krausmann F, Haberl H, Erb K-H, Wiesinger M, Gaube V, Gingrich S (2009) What determines geographical patterns of the global human appropriation of net primary production? J Land Use Sci 4:15–33

Lefevre H (1978) Marx et la Nature. La Pensée 198:51–62

Martínez-Alier J (1987) Economía Ecológica. Fondo de Cultura Económica, México

Martínez-Alier J (2004) Marx, energy and social metabolism. Encycl Energy 3:825–834

Martínez-Alier J (2006) Social metabolism and ecological distribution conflicts. Paper presented at the Australian and New Zealand Society for Ecological Economics, Massey University, Palmerston North, 11–13 Dec 2005 and Queen Elizabeth House & Wolfson College, Oxford, 17–19 Feb 2006. http://www.lucsus.lu.se/Joan_Martinez_Alier_2006_02_15.pdf

Marull J, Tello E (2010) Eficiència territorial: la sinergia entre energia y paisatge. Medi Ambient. Tecnologia i Cultura 46:75–80

Marull J, Pino J, Tello E, Cordobilla MJ (2010) Social metabolism, landscape change and land-use planning in the Barcelona Metropolitan Region. Land Use Policy 27(2):497–510

Marx, K. (1965) Capital: A Critical Analysis of Capitalist production, vol. I. Progress Publishers, Moscow

Marx K (1975) Early writings. Vintage, New York

Matthews E et al (2000) The weight of nations: material outflows from industrial economies. World Resources Institute, Washington, DC

Mayer JRB (1845) Die Organische Bewegung in Ihrem Zusammenhange Mit Dem Stoffwechsel. Kessinger Pub Co, Germany

Moscovici S (1969) Le marxisme et la question naturelle. ĹHomme et la Societé 13:59–109

Muradian RY, Giljum S (2007) Physical trade flows of pollution-intensive products: historical trend in Europe and the World. In: Hornborg A et al (eds) Rethinking environmental history. Altamira Press, USA, pp 307–326

Muradian R, O'Connor M, Martínez-Alier J (2002) Embodied pollution in trade: estimating the environmental load displacement of industrialized countries. Ecol Econ 36:281–297

Opschoor JB (1997) Industrial metabolism, economic growth and institutional change. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Edward Elgar, UK, pp 274–286

Ortiz T, Masera O (2008) Subsidios y estrategias de producción campesina: el caso de estudio de Casas Blancas, México. Revista Iberoamericana de Economía Ecológica 7:61–80

Padovan D (2000) The concept of social metabolism in classical sociology. Theomai J 2:1–36

Parsons HL (1977) Marx and engels on ecology. Greenwood Press, USA

Redclift M, Woodgate G (eds) (1997) The international handbook of environmental sociology. Edward Elgar, Cheltenham

Russi D, González AC, Silva JC et al (2006) Material flow accounting in Chile, Ecuador, Mexico and Peru (1980-2000). ICTA, Universidad Autónoma de Barcelona, Mecanoscrito

Schmidt A (1971) The Concept of Nature in Marx. New Left Books, London

Sieferle RF (2001) The subterranean forest: energy systems and the industrial revolution. The White Horse Press, Cambridge

Sieferle RF (2011) Cultural evolution and social metabolism. Geografiska Annaler Series B, Human Geography 93:315–324

Singh SJ, Grûnbuhel C, Schandl MH, Schulz N (2001) Social metabolism and labour in a local context: changing environmental relations on Trinket Island. Popul Environ 23:71–103

Skirbek G (1974) Marxisme et ecologie. Espirit 440:643–652

Spangenberg JH (2011) Sustainability science: a review, an analysis and some empirical lessons. Environ Conserv 38:275–287

Tello E (2013) La transformació històrica del paisatge entre l'economia, l'ecologia i la història: podem posar a prova la hipòtesi de Margalef? Treballs de la Societat Catalana de Geografia 2190:195–221

Tello E, Garrabou R, Cussó X, Olarieta JR (2008) Una interpretación de los cambios de uso del suelo desde el punto de vista del metabolismo social agrario. La comarca catalana del Vallès, 1853-2004. Revista Iberoamericana de Economía Ecológica 7:97–115

Toledo VM (1981) Intercambio ecológico e intercambio económico. In: Leff E (ed) Biosociología y Articulación de las Ciencias. UNAM, México, pp 114–147

Toledo VM (2011) La crisis de civilización es una crisis de las relaciones de la sociedad industrial con los procesos naturales. Papeles 110:171–177. http://www.fuhem.es/media/ecosocial/File/Entrevistas/entrevista%20a%20Victor%20Toledo_b_M.%20DI%20DONATO.pdf

Toledo VM, Alarcón-Cháires P (2012) Ethnoecology today: overview, advancements and challenges. Etnoecológica 9:1–16

Weisz H (2007) Combining social metabolism and input-output analyses to account for ecologically unequal trade. In: Hornborg A, McNeill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 289–306

Wezel A, Soldat V (2009) A quantitative and qualitative historical analysis of the scientific discipline of agroecology. Int J Agric Sustain 7(1):3–18

Wolman A (1965) The metabolism of cities. Sci Am 213(3):178–193

Chapter 4
The Basic Model

4.1 Introduction

Our first task is to generate a basic model of social metabolism. For that, and for the created model to be suitable and coherent, we must start by identifying and recognizing the foundational totalities: "The world is the everyday existential totality. The world is intentionally expressed as an interpreted totality… The interpreted totality represents the world and language expresses the representation (Dussel 1977, p. 187)." In order not to miss the course through common detours, we must first recognize two totalities in permanent interaction: Nature, which is "…the non-culturalized of the cosmos within the world (Dussel 1977, p. 187)," and Society, which is the structure receiving the end products of sociability and culturallity of the human species or humanity. In consequence, societies in any condition, having any characteristics, features, and levels of complexity, do not exist in an ecological vacuum, but affect and are affected by the dynamics, cycles, and pulses of nature. Nature is defined as "…that which exists and reproduces independently of human activity, but at the same time represents a superior order to that of mater (Rousset 1974)."

The above definitions involve recognizing that human beings organized in society not only respond to phenomena and processes of an exclusively social character, but are also determined by natural phenomena. In the words of Kosik, "…man does not live in two different spheres: a part of it does not occupy a place in history and another one in nature. As a human being man is always and at the same time in nature and in history. As a historical, and hence social being, man humanizes nature, but also recognizes it as an absolute totality, as a self-sufficient causa sui, as condition and premise of humanization (Kosik 1967, p. 9)."

Therefore, human societies produce and reproduce their material conditions of existence by their interchanges with nature, a condition that appears as pre-social, natural, and eternal (Schmidt 1976). In other words…"the metabolism between man and nature is thus independent of any historical form because it can be traced back into pre-social natural-historical conditions… (Schmidt 1976, p. 136)." Such metabolism implies the diversity of processes by means of which human beings

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organized in society, independently of their situation in space (social formation) and in time (historical moment), appropriate, circulate, transform, consume, and excrete materials and energy from the natural universe.

Because "…the whole of nature is socially mediated and, inversely, society is mediated through nature as a component of total reality (Schmidt 1976, p. 79)," human beings consumate two acts: on one side they socialize fractions or parts of nature, and on the other side, they naturalize society by producing and reproducing their links with the natural world. Likewise, along that general metabolic process a situation of reciprocal determination between Society and Nature is generated, because the form in which human beings are organized in society will determine the way in which they affect, transform, and appropriate nature, which in turn conditions the way in which societies become configured. In consequence, there is a permanent reciprocity between both realities, which some scholars consider to be of a dialectic (Schmidt 1976), or co-evolutionary (Noorgard 1994) character.

The result of this double mediation (ecological of society and social of nature) embodies a qualitatively higher order view of nature because of two facts: first, it derives from an approach that transcends parceled knowledge and the customary separation between natural and social sciences, and humanities, to which we are condemned by the dominant practice of scientific activity, i.e., an approach allowing for recognizing and adopting a complex thought (Funtowicz and Ravetz 1993; Morin 2001; Leff 2000); and second, because it introduces this abstract view into the concrete dimension of space (planetary), i.e., it places each social and natural phenomenon in a context where position, scale, and temporality also become determinant factors.

As complex systems, the totalities of Nature and Society meet at two instances: during the appropriation or extraction of resources (input), and during excretion or expulsion of wastes (output), thus giving place to a new system (natural-social or social-natural) having a further higher complexity. Nature and science constitute a two-way interrelation of mater and energy exchange accompanied by a permanent dissipation of heat that generates entropy, revealing the existence of a permanent, unidirectional flow of mater and energy. Flow begins with appropriation, it then follows several courses within society, and it ends with excretion. This double metabolic connection can at the same time be individual or biological, and collective or social. At the individual level human beings extract from nature enough amounts of oxygen, water, and biomass per unit of time in order to survive as organisms, and excrete heat, water, carbon dioxide, and mineral and organic substances. At the social level, the collectivity of individuals articulated through a diversity of relations or links organize themselves in order to guarantee their subsistence and reproduction, also extracting mater and energy from nature by means of meta-individual structures or artifacts, excreting heat and a range of residues or wastes.

These two levels, the individuals and the social groups, correspond to what Lotka (1956), Georgescu-Roegen (1975), and afterwards Margalef (1993) called **endosomatic energy** and **exosomatic energy**, a distinction having an axiomatic value for the foundations of ecological economy (Martinez-Alier and Roca-Jusmet 2013).

These two flows also represent the biometabolic and sociometabolic energy flows, respectively, which together make up the general process of metabolism between nature and society. “The flow of endosomatic metabolism is fairly constant in time, and especially when considered per capita, and is directly related to population size. On the contrary, the exosomatic metabolism is highly variable and depends on the amount of technological capital present in society and its usually heterogeneous distribution across the various compartments distinguished within the society (Giampietro et al. 2012, p. 187).” A detailed discussion of these concepts and their application can also be found in Giampietro (2004).

The history of humanity is then but the history of the expansion of socio-metabolism beyond the addition of the bio-metabolisms of all its members. In other terms, human societies along time have been obliged to increase exosomatic energy over endosomatic energy, so that the exo/endo ratio can be used as an indicator of the level of material complexity of societies (Giampietro2004). During the early societary stages endosomatic energy was nearly the only class of energy reaped off from nature—with only a minimal amount of energy transformed into instruments for domestic use, clothing, and housing materials—but in the present time industrial societies, the exosomatic energy is thirty or forty times larger than the overall energy used by the individuals that conform them (Naredo1999, 2000). At the global scale, the extraction of mineral resources (fossil fuels, metallic and non metallic minerals) measured in tons, triples the extraction of biomass (photosynthetic products) obtained through agriculture, livestock raising, fisheries, gathering, and extraction (Naredo2000).

As was shown in Chap. 3, nearly without exception all researchers devoted to study social metabolism have narrowed their analyses to the sole quantification of materials and energy flows exchanged by a given society with its natural surroundings during the appropriation or extraction of resources and services (inputs), and during the recycling of residues or wastes (outputs). This simplified or rudimentary version of social metabolism becomes useful to a certain point, but it lacks of any perspective given that it oversees or ignores two aspects: (a) the processes occurring inside society (the black box) that make up the internal part of the metabolic phenomenon; and (b) the immaterial or intangible processes occurring in all societies, and which in an invisible but effective way interact through reciprocal mechanisms with the material processes (as will be seen below).

4.2 The Five Metabolic Processes

Metabolism between nature and society begins when socially grouped human beings appropriate materials and energy from nature (input), and ends when they dispose off their wastes, emissions, or residues in natural spaces (output). But between these two phenomena other processes take place in the entrails of society by means of which the appropriated materials and energy circulate, become transformed, and end up being consumed (Fig. 4.1). Because of that, the general

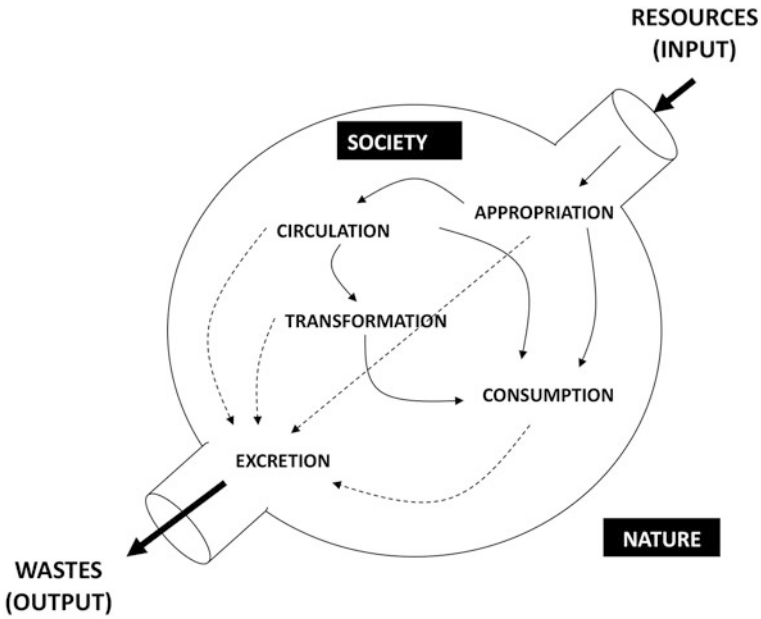

Fig. 4.1 General diagram showing the metabolic processes and the relation between society and nature

process of social metabolism involves three types of material and energy flows: input flows, inner flows, and output flows. The metabolic process is then represented by five phenomena that are theoretically and practically distinct, and that represent the five main functions of social metabolism: appropriation (Apr), transformation(Tr), circulation (Cir), consumption (Con), and excretion (Exc) (Fig. 4.2).

The act of appropriation (Apr) is in strict sense the primary mode of exchange between human societies and nature. Through Apr, society is nourished from all those materials, energies, water, and services that are required for sustaining and reproducing both human beings and their artifacts (endosomatically and exosomatically).

The Apr process is always carried out by an appropriation unit, which can be a company (owned by the state or private), a cooperative, a family, a community, or a single individual (e.g., the capturer of solar energy).

The process of transformation (Tr) implies all changes induced on the products extracted from nature, which after being modified are no longer consumed in their original form. In its simplest forms, Tr includes the most elementary modalities of food preparation (e.g., cooking of plant and animal parts by the use of fire), and in its most elaborate forms, in the elaborate transformation of materials (e.g., metallurgy, the nuclear industry, biotechnology, petrochemistry, nanotechnology, etc.). Through time, Tr activities have been gradually increasing in complexity,

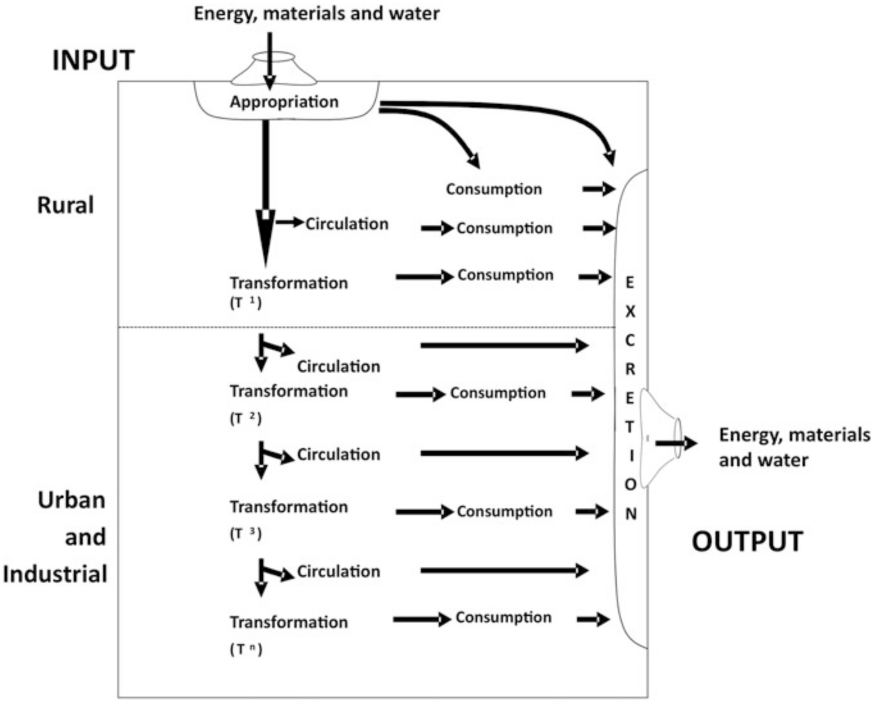

Fig. 4.2 Diagram showing the relations of the five main functions of social metabolism in rural, urban and industrial sectors

and the process becoming less labor intensive and more energy intensive. It goes from craftsmanship, to manufacture, and to the production of increasingly more elaborate commodities. The transformation chains or sequences in many instances make the raw materials obtained from nature to become unrecognizable.

The process of Circulation (Cir) appears when appropriation units stop consuming all they produce, and producing all they consume. At that moment, the phenomenon of economic exchange in strict sense becomes inaugurated (Toledo1981). From there on, those elements that were extracted from nature begin to circulate—either being transformed or not—and along time the volumes of what is circulated have become larger, while the distances they travel before being consumed have also increased. The changes in the patterns of territorial communication that were brought about by more efficient means of transportation (human, animal, fluvial, maritime, aerial, etc.) amplified the range of distribution, until the present when what is circulated does it in an increasingly faster and more efficient way. The magnitude of Cir has evolved from the non-commercial, non-monetary consignment (or trade), to financially mediated exchange, private property, and markets. The result has been an intricate network of exchanges that is intimately linked to transformations, in which the longstanding direct and almost immediate relation between appropriation and consumption becomes blurred (Fig. 4.3).

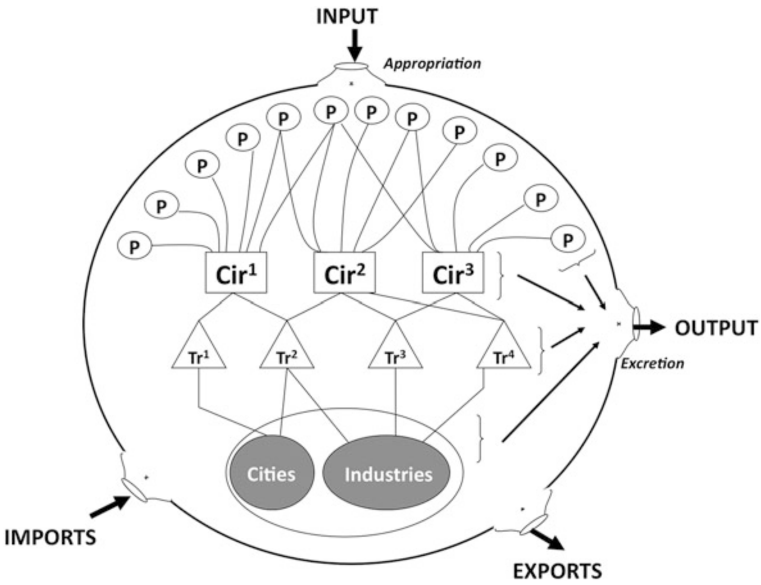

Fig. 4.3 Diagram showing the appropriation act in current societies, which is performed by a series of appropriation units (P). The appropriated materials and energy are later circulated (Cir) by different routes, in some cases transformed (Tr), and finally consumed by industry and cities. All these processes, in turn, generate a flow of wastes towards nature, or excretion (Exc). Along with domestic metabolic relations with nature (input and output), societies also import and export commodities to and from other societies

Society as a whole becomes involved in the metabolic process of consumption (Con), regardless of placing within the metabolic chain. This process can be understood from the existing relation between human needs, which are socially and historically determined, and the commodities provided by means of the three preceding processes (Apr + Tr + Cir). Nevertheless, in many societies—mainly in societies with an organic energy base—the level of consumption has determined the efforts of Apr, Tr, and Cir (agrarian societies), and especially so in the current functioning of industrial metabolism. Consumption can become a powerful factor of demand that incentives, and somehow, subordinates all other metabolic processes. As stated above, two large classes of consumption can be distinguished, one of them being the endosomatic consumption, and the second the exosomatic consumption pertaining to all those artifacts (devices, apparatuses, machines, buildings) created by human beings in a way that resembles an external carapace or envelope.

Once again, during the process of excretion—the actions by means of which societies dispose off materials and energy towards nature, including wastes, emissions, gases, substances, and heat—society as a whole and all the metabolic processes become involved. The two basic issues to consider in this regard are: the quality of the excreted residues (if they are intrinsically recyclable or not), and their quantity (if it surpasses the natural capacity for recycling). To these residues must be added the heat generated by all human activities, and which is a physical response to all transformations or movements. Maybe Exc is the metabolic process that is most dependent on other metabolic processes, but the scenario that begins to appear is speaking about the volumes of generated waste turning Exc into a phenomenon requiring—for its treatment, final disposal, or storage—of novel metabolic processes (capture, transformation, transportation, and storage of wastes), which in many cases end up conditioning Apr + Tr + Cir + Con. Summarizing, it will be the modalities adopted by each process, combined in many possible ways, what will give rise to multiple concrete configurations thus revealing the existence of highly complex phenomena.

4.3 Metabolic Processes: Funds and Flows

Encouraged by the Systems Theory, it has become commonplace to design models from the essential components: structures (in the most elementary version represented by boxes), and flows of mater, energy, and information (in the most elementary version represented by arrows). It is beyond the scope of the present Section to abound about the ingenuity, superficiality, or banality of most of these modeling efforts, which generates confusion regarding the terminology adopted in different analytical frameworks. Instead, in order to overcome the above-mentioned limitations, we have adopted in this book the theoretical formulation introduced by Georgescu-Roegen (1971, 1975) for the joint analysis of economic and biophysical processes. According to the latter author, two fundamental elements must be distinguished for representing social-natural metabolic processes: **funds** and **flows**. Following Giampietro et al., "… funds refer to agents that are responsible for energy transformations and are able to preserve their identity over the duration of representation (time horizon of the analysis). They are the ones transforming input flows into output flows on the time scale of the representation (Giampietro et al. 2012, p. 184)." On the other side, "…flows refer to elements disappearing and/or appearing over the duration of representation, that enter but do not exit or that exit but without having entered…Hence, flows include matter and energy in situ, controlled matter and energy, and dissipated matter and energy (Giampietro et al. 2012, p. 184)." In brief, fund is "what the system is and what has to be sustained", and flow is "what the system does in its interaction with the context (Giampietro et al. 2012, p. 185)." Restating the above in biological terms, these elements are analogous to the anatomy and the physiology of society in relation with nature.

Given the above, the five processes conforming the general process of social metabolism (appropriation, transformation, circulation, consumption, and excretion), which operate as the five modalities adopted by flow of mater and energy through the social network, will determine the functions performed by the fund. In consequence it is a task of the analyst to construct the corresponding structures, the social agents and their artifacts that function as the operative units of these five processes, and to identify the dynamics or synergies derived from the interaction of these operative units at different space-time scales. It is needless to mention the enormous complexity involved in such an analysis.

4.4 Metabolic Flows: Energy, Emergy, and Exergy

All natural processes and all human activities involve energy transformations. In general terms, civilizatory evolution of human societies can be visualized as a continual increase in the use of energy, expressed as larger volumes of foodstuffs, the mobilization of further sophisticated and complex artifacts, and more efficient transformation of materials, commodities, and people (Adams1975; Smil 1994; Debeir et al. 1991). Because of this trend, the tangible or visible material flows from and towards nature are frequently expressed in energetic terms, and quantified by means of several indexes using units of energy. Almost without exception, researchers using the concept of social metabolism commonly make their quantitative analyses by measuring material flows in terms of energy.

The obsession for caloric or energetic assessments is not exclusive of metabolic studies, and it exists since before their arrival as a method for studying societies (White 1959; Moran 1990; Pimentel and Pimentel 1979), a duty that was predominantly assumed by scholars belonging to the field of cultural ecology. What is interesting is that the debate and theoretical reflection regarding the energetic analysis of societies that took place along the past three decades have arrived to the use of new theoretical frameworks, concepts, indexes, and measuring units resulting more robust and precise. In fact, theoretically, the use of the concept of energy—which is usually defined as the ability to do work, and which is based on the physical principles of work requiring energy inputs and of energy being measured in units of heat (or molecular motion)—can result limited or even reductionist when being used in the quantitative analysis of more complex work processes, such as the interchange between nature and society. In other words, it is logically incoherent to quantify complex process, such as the material flows transiting from nature to societies only in caloric terms: "…converting all energies of the biosphere to their heat equivalents reduces all work processes of the biosphere to heat engines. Human beings, then, become heat engines and the value of their services and information would be nothing more than a few thousand calories per day. Obviously not all the energies are the same…(Brown and Ulgiati 1999, p. 487)." As a result, the human ecologist Odum (1971, 1996) developed the idea of **emergy**, or embodied energy analysis, which distinguishes different kinds of energy proceeding from the natural environment (biosphere, geosphere, atmosphere). This new method of analysis uses the thermodynamic basis of all forms of energy and materials, but converts them into equivalents of one form of energy: sunlight. Emergy is the amount of potential energy that is required to do something, and therefore it is in some sense the memory of energy. The approach known as Emergy Accounting has been frequently used during the past two decades in studies going from the family farm level (Souza and Ortega 2007), to those evaluating national (Siche and Ortega 2007) and global (Brown and Ugiati 1999) processes.

Another theoretical innovation in the analysis of energy flows is the concept of **exergy**, defined as the maximum useful work that can be developed during the process of thermodynamic equilibration between one or more systems (Dincer and Rosen 2007). Exergy quantifies the ratio between the available resources for performing a thermodynamic task, and the resources that are actually consumed for accomplishing such task; i.e., it evaluates the energetic efficiency of a system in terms of the energy that is actually used. Although less generalized than emergy as a conceptual framework, exergy has also been used for evaluating cases at different scales. Noticeable cases are the exergetic profile of China (Chen et al. 2006), and the detailed evaluation of an indigenous community in Mexico (Martínez-Negrete et al. 2013).

Because, as we have shown, the model of social metabolism offers a given architecture in funds and flows, these three evaluation methodologies of the flows of materials: energy, emergy, and exergy, can be applied simultaneously in the analysis of concrete cases, even for comparative means, using as referents the five above-described social metabolic functions.

4.5 The Tangible and the Intangible

Human beings grouped in societies do more than eating, drinking, sweating, growing, copulating, excreting, and dying. They are also not exclusively dedicated to building structures or manufacturing utensils, instruments, weapons, mechanisms, or machines. They also dream, imagine, believe, know, invent signs and languages for communicating, establish relations between them, make regulations, norms and laws, design technologies, make transactions, and build institutions with different goals and at different scales. This other immaterial dimension of metabolism is, in a certain way, an emergent property characterized not by flows of mater or energy, but by flows of information. And it is this intangible dimension of societies that operates as a framework for the material processes of metabolism.

Until nowadays, the general process of metabolism has been approached as a merely material phenomenon (which explains why its main analysts have commonly been economists from the new field of Ecological Economy). However, a comprehensive approach obliges to consider those immaterial instances and mechanisms with and within which the five metabolic processes take place. From the technologically simplest societies the material dimension of the metabolic process have always occurred and have been embedded in determined social relations, i.e., metabolic processes have always been conditioned by diverse forms of institutions, knowledge, cosmovisions, regulations, norms and agreements, technological know-hows, forms of property, and modes of communication and government.

The five metabolic functions articulate in specific, particular, and more or less permanent ways, which allow us to talk about specific forms of articulation between humans and of these with nature. And it is these superstructures or institutions the ones that—together with other equally intangible dimensions—express strictly determined social relations such as family, market, resource access rules, forms of property, political power, taxing, kinship, reciprocal aid, etc., and which socially organize the articulation of the metabolic processes. In other words, the flows of mater and energy that are the material or tangible part of the metabolism between nature and society, are always conditioned, regulated, and articulated by these intangible super-structures that exist and persist by means of flows of information.

The five metabolic functions operate as the **hardware** of social metabolism, they are the material and energetic crust, and the tangible part of human societies, but the institutions and their corresponding symbolic systems—juridical, economic and social regulations—are the immaterial, invisible parts organized by flows of information that function as the **software** of social metabolism. The hardware and software of social metabolism are reciprocally determined throughout history by means of processes that remain to be incomprehensible and that need to be studied, discovered, and analyzed.

Therefore, in every society there is a particular articulation of the five metabolic functions that is commanded by a corresponding set of social relations configuring each one of the functions. These particular social relations tend to the reproduction and permanence through time of societies by displaying a collective consensus when satisfying the basic needs of all sectors of the social group. Unlike the visible or material processes that can be identified and analyzed, social relation processes, having a greater complexity and less conspicuousness, are almost impossible to characterize. Provisionally we distinguish eight groups of elements in the societary software, i.e., the group of combined elements that operate as conditional factors of metabolic functions: cosmovision—or ideology, knowledge, technology, juridical regulations—norms and implicit or explicit agreements, political rules, cultural rules, economic rules, and property rules. A caveat must be considered; all the latter elements must be contemplated as incommensurable, i.e., associated to a high degree of difficulty in their quantification, and their relative importance or dominance must be weighted during the analysis of each individual case.

We then arrive to a basic model from which we believe more or less stable forms of configuration or articulation of the five metabolic processes can be singularized—without any ontological pretension—that we tentatively call social stages or metabolic configurations. Such designations could in no case go beyond being merely descriptive characterizations referring to a concrete territory and time, never being prescriptive categories.

A full view of social metabolism as a model and conceptual framework for the study of the relations between the diverse societies and nature, and of their transformation through time, therefore crystallizes as a polyhedral structure formed by two—one immaterial and one material—indissolubly assembled parts (Fig. 4.4), a totality that in turn has reciprocal, dynamic, and complex relations

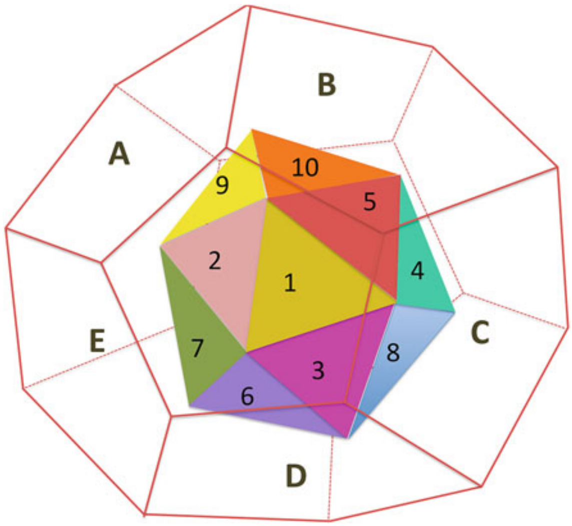

Fig. 4.4 Diagram of the metabolic structure appearing as two coupled polyhedral bodies (one inside the other): an external one formed by the five metabolic processes (A through E), and an internal one formed by the intangible elements (1 through 10). The challenge is to find the rules determining the synergies within and between both dimensions and in their interaction with the natural universe

with the natural world and its processes (Fig. 4.5). In this model or structure the material moiety operates as the content and the immaterial or invisible part, as the container. While visible, identifiable, and quantifiable processes represent the former part, the essentially informational processes (cognitive, symbolic, institutional, juridical, technological, political, etc.) form the latter. It will be the turn for researchers to unravel how these set of highly complex determinants generate the transformations through time, and which are the rules operating during these transformations (see final chapters). This basic structure or model therefore integrates the unity-totality that becomes transformed along time, but that also collapses or becomes disorganized, reconstructed or fossilized, stationary or unstable, changing or decadent.

4.6 The Structure of Nature: Ecosystems and Landscapes

Until now we have established and identified concepts and categories about the human or social portion of social metabolism, it remains to deepen into the realms of natural systems or ecosystems. Along the interaction of human beings with nature, the former appropriate two types of resources: commodities (renewable and exhaustible or not renewable), and services. The solar energy captured either directly (photosynthetically) or indirectly (through wind, currents or tides), besides some compounds (such as oxygen) belong to the renewable resources. Minerals (metallic and non metallic), fossil water, and other materials (such as soils or materials) are exhaustible resources.

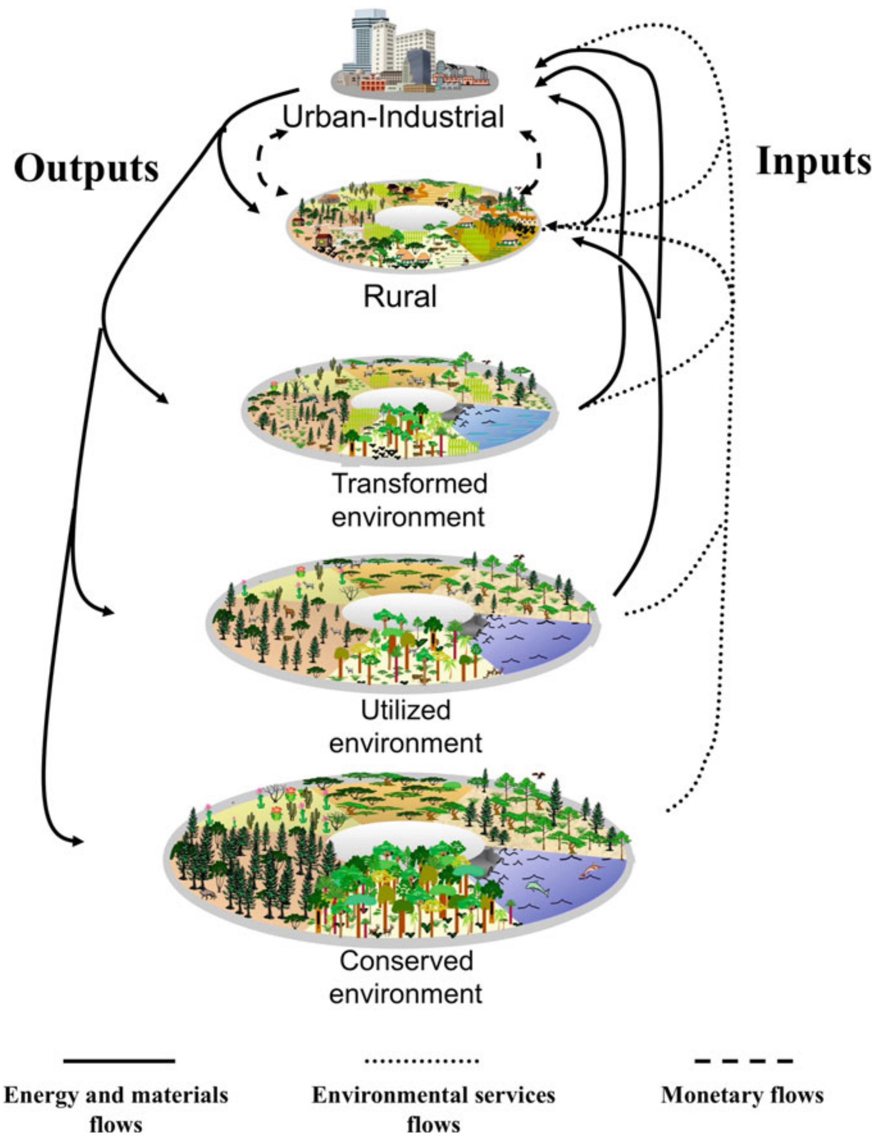

Fig. 4.5 General diagram showing the metabolism between society and nature representing the main mega-environments (see text for explanation)

Besides commodities (energy, materials and water), human beings also appropriate environmental or ecological services, which although intangible and immaterial offer conditions for production and for the reproduction of their existence (e.g., climate, atmospheric oxygen, ecological equilibriums, biodiversity per se, the aesthetic value of landscapes, etc.). Ecosystems provide human beings with environmental services such as an appropriate environment for the survival of the human species, temperature and humidity regulation mechanisms, atmospheric equilibriums through geochemical and physical balances, spaces for recreation, education or contemplation, and realms for nourishing spiritual or aesthetic values. While commodities are visible, tangible natural objects that are readily perceived by humans, services provided by nature are commonly useful processes with variable complexity, which operate at several scales of space and time, and are difficult to recognize. In strict sense, commodities conform flows of mater (including water), and of energy, while services are invisible flows of individual and collective wellbeing.

All commodities and services appropriated from nature by the human species satisfy the needs of people as individuals (endosomatic energy) and of their artifacts, such as clothing, buildings, instruments, machines, factories, devices, etc. (exosomatic energy). However, all these resources exist only as parts or fractions of the totality existing in nature, because in real terms all natural spaces are an assembly of unties-totalities having architectural, compositional, and functional structures. Nature is an heterogeneous matrix formed by uncountable assemblies with a given structure and dynamic allowing reproduction or renovation through time. All these assemblies are unique arrays or combinations of biotic and abiotic elements having their own histories making them different from all others.

These unities-totalities have been defined as ecosystems that once located in space acquire a concrete expression as landscapes—landscape systems formed by landscape units. While the concept of ecosystem became the most relevant theoretical contribution of Ecology, the units of landscape derive from several fields of Ecogeography and Landscape Ecology (e.g., Tricart and Killian 1982; Zonneveld 1995; Turner 2005). Ecosystem and landscapes are two theoretical expressions of the same phenomenon leading to two different concepts: the heterogeneity of natural spaces. Ecosystems are non-spatial, abstract entities, while landscapes are concrete and are determined by location and scale.

These concepts were the product of more than a century of scientific research having the goal of integrating the biological, physicochemical, and geological processes. In that sense, both Ecology and Ecogeography assumed similar and parallel tasks unveiling an integrated vision of the natural world, crystalizing in a concept the diverse contributions from different sciences devoted to the study of phenomena occurring in the Earth's crust, the atmosphere, the hydrosphere, and the living organisms.

Further yet, the scientific demonstration of ecosystems being identifiable entities in the planetary space in which organisms, their interactions, the flows of mater and energy, and the biogeochemical cycles are in a dynamic equilibrium—i.e., ecosystems are entities capable of self maintenance, self regulation, and self reproduction independently of human beings and their societary groups, and following meta-social laws and principles—also reveals the mechanism by which nature constantly renovates itself. The recognition of the dynamics of ecosystems acting as the object of human appropriation and as the ultimate pool of the wastes generated by excretion is thus vital for maintenance of an appropriate social metabolism, because any society can only subsist when the reproduction of its material base remains unaffected.

By creating the concept of ecosystem, Ecology not only discovered the internal structure of nature by identifying unity within the complex and intricate diversity of natural landscapes, but it also made evident that the so-called natural resources (air, water, soil, solar energy, minerals, and biological species) are reciprocally integrated elements forming units having a real presence through the various scales of space.

The consequences of these theoretical developments for the study and analyses of metabolism between society and nature are immediate, because societies are not appropriating of isolated and disarticulated elements, or stocks of resources, but of ensembles or totalities with a systemic and holistic character. This fact obliges to recognize that any theory of the management of natural resources—ultimately, the analysis of appropriation and excretion—can only be effective when talking into account the structures, dynamics, capacities, and thresholds of the ecosystems that from the material basis of production, i.e., metabolism, themselves manifest as visible, recognizable, and appropriable landscape units (Toledo 2006a, b; Holling 2001).

The same applies to excretion, the second major interaction between society and nature after appropriation, which has to do with the regulation by society of waste expulsion in a way that the volume and composition of wastes excreted to ecosystems does not surpass their capacity for absorption and recycling. Given that every ecosystem (terrestrial, aquatic or oceanic) has a determined structure and a given capacity for assimilation, the process of social excretion must be regulated based on these characteristics of the ecosystem. As will be seen in Chap. 11, the events of pollution have not only been multiplied, but have also been potentiated and scaled at several magnitudes. At present, excretion phenomena in their different modalities are the main cause of the global disequilibrium afflicting Earth.

There are at least three assumptions derived from ecological theory that delineate the patterns that need to be adopted for an adequate appropriation of natural resources. First, the landscapes or environmental units conforming the property, plot, area, or space—either terrestrial or aquatic—that is to be appropriated. This is achieved by identifying certain factors (climate, geology, geomorphology, soils, vegetation) over a given scale. This first step allows for a second one consistent of recognizing the ecological potentiality of each one of these previously recognized units. The ecological potentiality is given by the particularities of each recognized unit, and operates by means of their diversity, flexibility, and resilience. In practice, the ecosystemic potential reveals the capacity for renovation and recycling of these units during their material relations with societies, i.e., their capacity for responding to resource extraction and waste excretion. If we admit that ever particular ecosystem has a determined resistance to human use that is derived from its structure, functioning, and history, then it must be recognized that identifying its limitations, thresholds, and potentialities is a crucial task. Eventually, this leads to recognizing what geographers call the suitability of natural spaces. The final assumption includes optimizing appropriation based on the previous assumptions. That implies obtaining the maximum flow of energy or materials from the adequate ecosystem by investing the minimal effort, and without threatening the renovation capacity of the ecosystem (appropriation function), and to dispose off a maximum volume of wastes or residues through a minimal effort and without affecting the ecosystem's capacity for recycling (excretion function).

From the above said it is concluded that any appropriation-excretion process that for any reason is made above the threshold of resilience capacity of the involved ecosystems would result in a certain degree of ecological restriction. This constrain implies a cost that ends up being expressed by low productivity in the short, medium or long terms, be it either from direct or indirect mechanisms applied for avoiding the decrease of productivity, e.g., the use of agrochemicals seeking to attenuate the natural decrease in soil fertility.

In both cases these effects are expressing the penalty imposed by nature to wrong decisions made by the producer. It is the accumulation in space and time of wrong decisions what leads to the collapse of the material basis of social metabolism, and eventually to the decay and even disappearance of social systems (i.e., peoples, states, civilizations).

The magnitude of this cost will of course depend on each concrete and particular situation, so it becomes theoretically possible to establish the thresholds or limits of ecosystems, and consequently, to exert an adequate modality of appropriation and excretion in a way that self-regulation (adaptive management) is enabled, or in other terms, to adjust the magnitude, duration, and intensity of the acts of appropriation and excretion to the limits and capacities of ecosystems operating as the material basis of such activities (Holling 1978). In short, each portion of the natural space has a limit (which can be theoretically established) for its adequate appropriation, beyond which its renewal and recycling capacity becomes endangered, and thus, its own permanence is threatened.

In summary, the processes performed by human beings grouped in societies involve the appropriation of unities-totalities: the ecosystems (in the non-spatial, non-temporal, invisible plane) and the landscapes (in the pragmatic, visible, and immediate plane). By that means it is possible to arrive to a classification and typology of commodities and services provided by nature and which humans appropriate, which are derived from pre-existent or existent ecosystemic functions independently of human presence (Daily 1997; de Groot et al. 2002). Because of that, 23 main commodities and services can be recognized that derive from four well-delimited ecosystemic functions (of regulation, of habitat, of production, and of information) (de Groot et al. 2002) operating as a matrix of what society obtains from nature (Table 4.1).

Table 4.1 Functions, products and services of ecosystems

Functions	Processes and components of ecosystems
	Regulatory functions
Regulation of gases	Ecosystem role in biogeochemical cycles (e.g., $CO_2/0_2$ balance, ozone layer, etc.)
Climatic regulation	Influence of biological and abiotic processes on climate (e.g., prodution of dimethyl sulphur or DMS)
Prevention of perturbations	Influence of ecosystem's structure in environmental perturbations
Regulation of hydrology	Influence of ecosystem on water flow and discharge of water currents
Water supply	Filtration, retention, and storage of fresh water
Soil conservation	Influence of vegetation and soil fauna on soil retention
Soil formation	Weathering of rocks and accumulation of organic mater
Nutrient regulation	Role of biota in storage and recycling of nutrients
Treatment of wastes	Role of flora and fauna on removal or elimination of waste compounds
Pollination	Role of biota in movement of plant gametes
Biological control	Population control through alimentary relations
Production functions	
Food	Conversion of solar energy into consumable plant and animal parts
Raw materials	Conversion of solar energy into biomass used for construction and other uses
Genetic resources	Genetic material and evolution of wild flora and fauna
Medicinal resources	Biochemical and mineral substances used for medicinal purposes
Ornamental resources	Flora and fauna with ornamental potential
Information functions	
Aesthetic information	Attractive environmental features
Recreation	Landscapes having recreational potential
Cultural and artistic information	Natural environments with cultural and artistic value
Spiritual and historical information	Natural environments with spiritual and historical value
Science and education	Natural environments with scientific and educational value

Source Modified from de Groot et al. 2002

4.7 The Three Basic Forms of Appropriation

Human appropriation is performed through three basic kinds of interventions in natural spaces, each of these varyingly impacting the appropriated ecosystems and landscapes, and each one ending up being territorially expressed. The first of these kinds of intervention is when appropriation is made without causing substantial modifications of the structure, architecture, dynamics, and evolution of appropriated ecosystems and landscapes. This includes all known forms of hunting, fishing, gathering, and pastoralism, and some forms of extraction through foraging in several original vegetation types.

In the second kind, human beings disarticulate or disorganize ecosystems during appropriation acts by introducing domesticated or incipiently domesticated species—or by activating processes of domestication of wild species, such as in all forms of agriculture, livestock raising, plantations, and aquaculture. The main distinction between these kinds of appropriation of nature is that in the first kind of appropriation there is a very low degree of loss of the intrinsic, natural faculties of ecosystems for self-maintenance, self-repair, and self-reproduction, while in the second kind the loss of these capacities of the ecosystem a fortiori require for their maintenance of external energy (from human, animal, or fossil sources).

In the absence of human actions, the latter ecosystems regenerate, become restored to the original forms, or derive to bizarre, atypical, and unpredictable forms. The first kind of appropriation results in utilized nature, the second in domesticated nature.

The third form of appropriation was created by conservationist's efforts for finding ways for preserving or protecting undisturbed or regenerating vegetation covers, in which species, patterns and processes of the ecosystems are protected with conservationist goals, and what is useful due to the services they produce in terms of conservation of genetic and biological diversity, local or global weather regulation, water capture, carbon sequestration, recreation, education, aesthetic contemplation, and scientific research. In this third kind of appropriation, what is practiced is a sort of human inactivity, which suppresses all forms of commodity extraction from the appropriated landscapes with the intention of preserving them for the value of the services they provide.

So far we have differentiated kinds of appropriation of land covers and the services they provide, in other terms, we have restricted our analysis to the appropriation of the products of the photosynthetic net primary productivity. But another form of appropriations also take place—increasingly during more recent times—in which what becomes acquired from nature comes from the subsoil as minerals (soils, rocks, ore) water (groundwater, fossil water), or energy (oil and gas). In the first case what becomes appropriated is organic mater, and in the second, abiotic materials from the Earth's crust. In the apparently particular act of extraction of materials from the subsoil, these extractions would belong to the first kind of appropriation if the character of the material extracted, and the extension of the extraction do not have negative effects on the structure and functioning of the ecosystem (e.g., low-impact, artisanal extraction of water by unelaborate means, or low-intensity soil removal). On the contrary, when extraction of commodities from the subsoil impacts or modifies the ecosystem, they must be placed in the second kind of appropriation. In the later case are large mining and oil operations typically under industrial modalities, in which appropriation immediately transforms nature. These activities are made at the expense of large amounts of supplied energy, and commonly they generate polluting wastes (e.g., extraction of copper from pyrites).

Therefore it may be said that, while we placed extraction of materials from the Earth's crust either in the first or in the second kind of appropriation based on the amount of negative impact, their placing almost without exception depends on if the appropriation is made by industrial or other means. Industrial civilization was essentially born and supported by the increasingly intense utilization of energy, water, and materials that are extracted from the crust of the Earth. An unprecedented event in the history of the human species, as stated by Naredo: "…using iron and carbon for building and feeding steam machines that applied their mechanical force for extracting, transporting, and processing more iron and carbon with which to build and feed more steam machines, proclaimed the spiral of explosive growth characteristic of present civilization by accelerating with the energy and materials derived from these extractions, not only the industrial processes, but all other exploitation processes… (Naredo1999, p. 71)".

4.8 Nature in Space: The Three Mega-Environments

These three modalities of appropriation of ecosystems we have established and defined allow for distinguishing in the planetary space three large types of environments or mega-landscapes, and their corresponding transitional or intermediate formations: the utilized environment (UEN), the transformed environment (TEN), and the conserved environment (CEN). These three landscape expressions together with anthropic rural, urban, and industrial areas—forming villages, towns, cities, and eventually megalopolis—have configured the present topology of the Earth. It is in these six spaces (industrial, urban, rural, UEN, TEN, and CEN) where the metabolism between human societies and nature takes place at the global scale (Fig. 4.5).

4.9 Who Appropriate Nature?

In the origins of human societies everyone during their productive life appropriated from nature. In the contemporary society only some of the human population are involved in appropriation of nature in strict sense, and that fraction is generally considered as the rural social sector. Rural can then be defined as the social space integrated by the units appropriating resources from terrestrial and aquatic—continental and oceanic waters—ecosystems, or if you will, agrarian and fishery production systems.

According to FAO's statistics, by 2010 a total of 2,619 millions of human beings formed the agrarian and fishing portion of the human species defined as depending for their subsistence of agriculture, livestock raising silviculture, hunting, extraction, gathering, and fishing, which is equivalent to 40 % of the global population (Fig. 4.6). Data from the few past decades show that the rural sector of Earth remained majoritarian until 1970, and that despite their relative reduction, the population in charge of appropriating resources from nature almost duplicated, expressing the amount of pressure exerted by human society over the natural systems.

By world region, the appropriating population is distributed mostly in the countries forming what is called the Third World: China, India, Indonesia, and a good

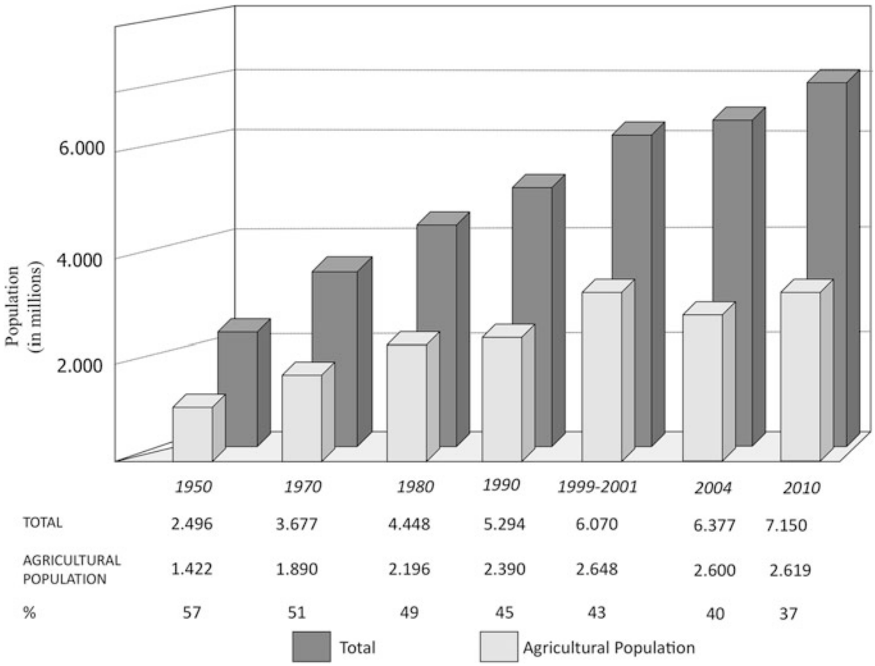

Fig. 4.6 Total and agrarian populations during the period 1950–2010. Source: www.fao.org

number of countries from Asia, Africa, and Latin America. By country, 95 % of the nature extracting population lives in agrarian countries and only 5 % in industrialized countries. An explanation to these numbers is in the process of technological transformation of the past century materialized as advances in industrializing agriculture, livestock raising, fisheries, and other forms of appropriation.

Once more, these figures exclude the population involved in industrialized extraction of non-living commodities from the Earth's crust, which would only slightly modify the shown trends–despite the appropriated volume of rocks, mineral ores, fossil fuel and water by large surpasses the volume of extracted biomass—because the fraction of people involved in the former by large exceeds that in the latter (Naredo and Valero 1999).

4.10 Excretion: What is Excreted to Nature by Human Societies?

As the impacts derived from the processes of appropriation of nature gradually expanded—but not reaching a given threshold of magnitude—the extraction process caused little major problems as long as the endosomatic metabolism was kept below the exosomatic metabolism. However, the accelerated growth of the human population, its concentration in urban centers, and especially the onset of the industrial era along the past one hundred years, turned excretion into an increasingly harmful, dangerous, and incontrollable process that became the number one factor of ecosystem disequilibrium in the planet.

What started as simple organic residues refused from households, cultivated fields, and from activities related to raising livestock, fishing or hunting, turned into wastes that were increasingly less tolerable and more toxic for the terrestrial and aquatic ecosystems. The emergence of the new industrial technologies in the processes of appropriation, transformation, and circulation also made the products of excretion to go beyond the ground surface zone reaching to the deep layers of the subsoil, bodies of water and oceans; and in the atmosphere, to the troposphere and even the stratosphere (Fig. 4.7). The appearance of new non-natural products, such as plastics, created new forms of pollution because nature's incapability for recycling them. The emission of organic solids and liquids, chemical substances, gases, sprays, plastics, and radioactive wastes is reaching levels that not only pose a threat to human life and the biota, but are modifying biogeochemical cycles of global scale—such as those of water, oxygen, carbon, nitrogen, and phosphorous—and even the climatic patterns.

Transformation of excretion into a force of ecological perturbation evolved from diverse causes. For instance, groundwater contamination, defined as the detrimental alteration of the naturally occurring physical, thermal, chemical, or biological quality of groundwater, may result from many sources, including current and past oil and gas production and related practices, agricultural activities, industrial and manufacturing processes, commercial and business endeavors, and domestic activities. The overuse of pesticides in agricultural areas has resulted in widespread occurrence of toxic substances in agricultural runoff and in shallow groundwater. Mining wastes include residues generated during the procedures of extraction, beneficiation, and processing of minerals.

The extraction of ore from the Earth's crust is the first step in hard rock mining. This step is followed by beneficiation, typically achieved by means of crushing, grinding and froth flotation techniques in the attempt to releasing and concentrating the valued mineral from the extracted ore. Mineral processing operations generally follow the beneficiation step, which often includes techniques for changing the chemical composition of the ore or mineral, such as smelting, electrolytic refining, and acid attack.

The old and the new pollutants produced by metabolic excretion from human societies generate interacting effects cascading through the Earth system in complex ways. The cascading effects of human activities interact in multidimensional ways between each other, and with local and regional scale modifications. For example, because living organisms, the carbon cycle, greenhouse effect gas emissions to the atmosphere, and the temperature of the earth's surface are all interrelated, it is not possible to predict the effects on the global ecosystem of the impacts of the metabolic excretion process.

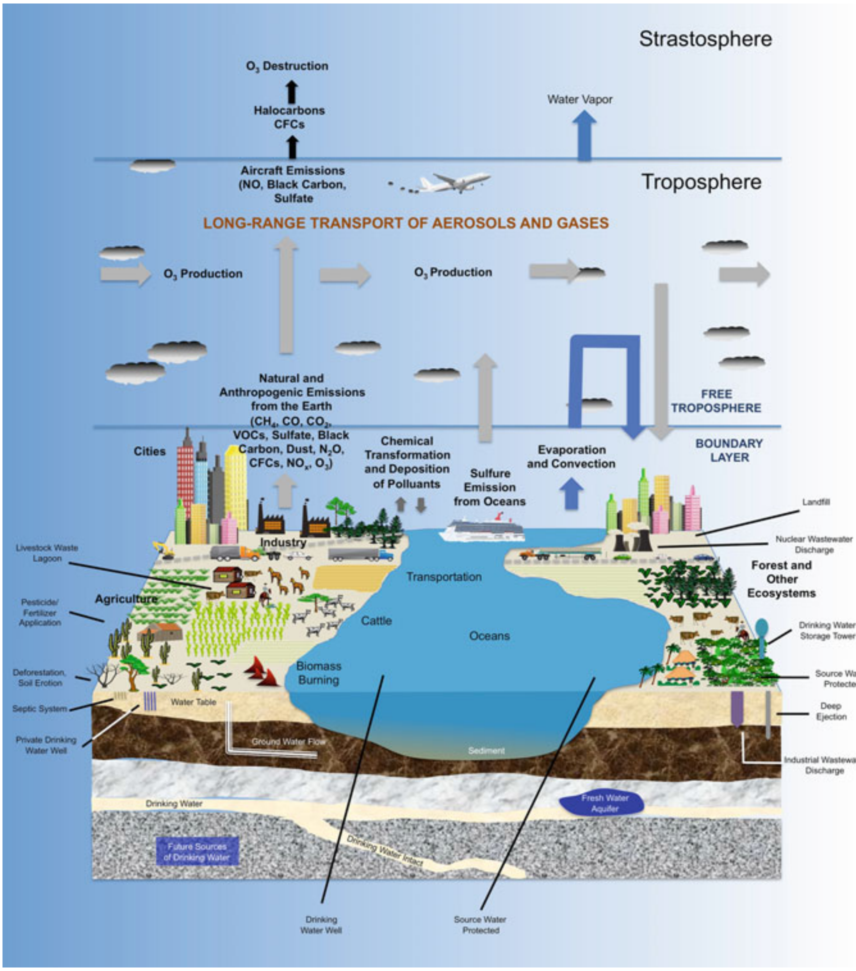

Fig. 4.7 Sources and paths followed by anthropogenic pollutants

In summary, excretion functions are significantly influencing the functioning of the Earth's ecosystem in many ways, and are threatening the survival of human beings (Table 4.2). Anthropogenic changes are clearly identifiable beyond natural variability and their extent and impact are equal to some of the great forces of nature. The modifications are so profound that we are already entering a new geological age, the Anthropocene (see Chap. 1).

Table 4.2 Ten facts about pollution. *Sources* Blacksmith Institute, EPA, Random History. http://www.dosomething.org/tipsandtools/11-facts-about-pollution#

1	Pollution is one of the biggest global killers, affecting over 100 million people. That's comparable to global diseases like malaria and HIV.
2	Over 1 billion people worldwide lack access to safe drinking water. 5,000 people die each day due to dirty drinking water.
3	14 billion pounds of garbage are dumped into the ocean every year. Most of it is plastic.
4	Over 1 million seabirds and 100,000 sea mammals are killed by pollution every year.
5	People who live in places with high levels of air pollutants have a 20 % higher risk of death from lung cancer than people who live in less-polluted areas.
6	The Mississippi River carries an estimated 1.5 million metric tons of nitrogen pollution into the Gulf of Mexico each year, creating a "dead zone" in the Gulf each summer about the size of New Jersey.
7	Approximately 46 % of the lakes in America are too polluted for fishing, aquatic life, or swimming.
8	Americans make up an estimated 5 % of the world's population. However, the U.S. produces an estimated 30 % of the world's waste and uses 25 % of the world's resources.
9	Each year 1.2 trillion gallons of untreated sewage, stormwater, and industrial waste are dumped into U.S. water.
10	While children only make up 10 % of the world's population, over 40 % of the global burden of disease falls on them. More than 3 million children under age five die annually from environmental factors.

4.11 The Analysis of Social Metabolism: Space and Time

The model of social metabolism proposed in the previous sections provides a conceptual framework for the integrative analysis of natural (ecological or bio-physical), and social processes. In this section, we establish the principles and some methodological procedures for the suitable analysis of social metabolism. As defined above, the model of social metabolism is an idealized, abstract, and general representation of the totality of the human society and nature, but with an undefined location in time and space. Therefore, it must be concreted by assigning to it a dimension, and a location in space and time. Once the abstract model of social metabolism is given a concrete expression, analyses can be made either of its entirety as a process, or of its fractions, dimensions, or scales. For example, the model may assume a totalizing dimension, or on the contrary, be focused on parts of this general process. In that regard, it must be keep in mind that the definition of a problem will often delimit the possibilities of its solution. Thus the chosen definition of a problem usually also indicates our preference for its resolution.

As a complex system model, social metabolism can be approached from multiple angles, depending on the partition of reality made by the observer. Such a partition is framed along at least three axes. First, the spatial dimension represented by the global territory, which in its most elementary version includes the atmosphere, biosphere, hydrosphere, cryosphere, lithosphere, and sociosphere. Second, the time dimension spreading nearly 200,000 years since the first

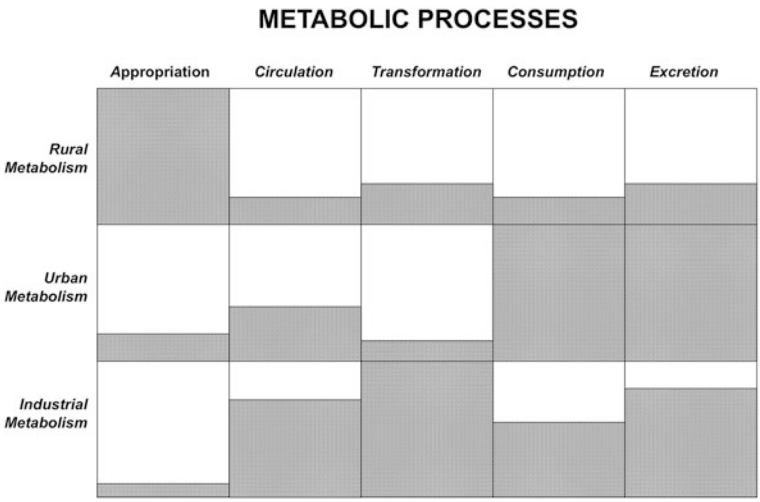

Fig. 4.8 Matrix of the relations between the three main types (*rows*) of the general process of social metabolism, and the five metabolic processes (*columns*)

appearance of Homo sapiens. And third, the axis of the analyzed metabolic process, provided that in some cases the focus is in one or more of the five described processes—appropriation, circulation, transformation, consumption, and excretion (Fig. 4.8). Thus, all social metabolisms occur within a spatiotemporal dimension, i.e., they are enclosed within the territory of the planet and the time spanned by the history of the planet since the origin of the species.

Having a spatial dimension, the general process of social metabolism can be analyzed at several scales. The spatial narrowness or amplitude of the approach defined, or chosen, by the analyst reveals the multi-scalar character of the study of social metabolism. Broadly speaking, up to six scale categories can be identified: appropriation or production unit, community, micro-region (e.g., municipalities or counties), national, international, and planet.

Similarly, when a historical perspective is adopted social metabolism can be approached at different time scales identified by the analyzed time periods. In this case, different temporal extensions, or time scales can be recognized: years, decades, centuries, and millennia. After all, social metabolism exists since the rise of the human species nearly 200,000 years ago.

By that procedure, a matrix is formed having three variables spanning the whole analysis of social metabolism: dimension, scale (spatial extension), and time (temporal extension) (Fig. 4.9). This tridimensional framework at the same time reveals the narrow relation between dimension, scale, and time as three aspects functioning in permanent reciprocity. For example, a totalizing or whole analysis will necessary sacrifice the resolution of details, and is obliged to be limited to a gross spatial scale, and a shallow historical horizon. Likewise, a local analysis—say of appropriation or excretion—will have a finer spatial resolution, and be

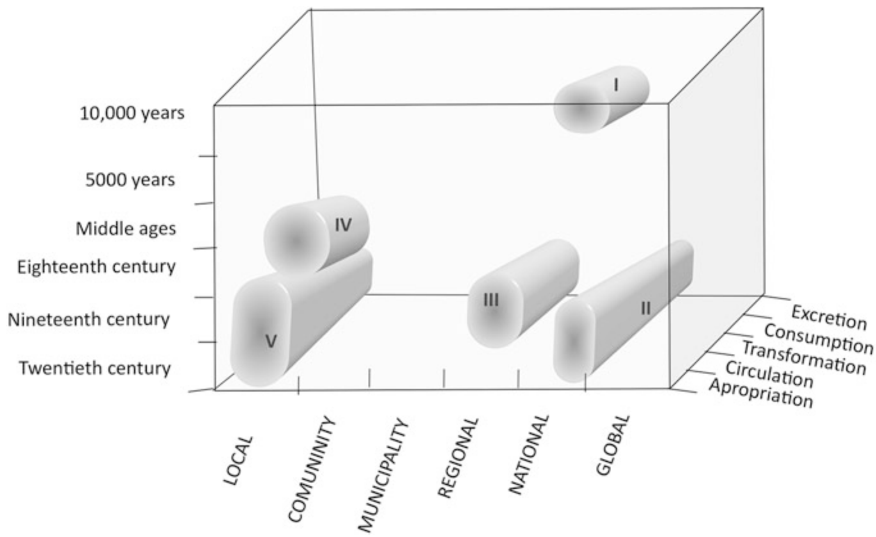

Fig. 4.9 Social metabolism becomes tridimensional because the researcher may approach it from any defined spatial scale, temporality, and dimension (one or more of the five metabolic processes that can be analyzed). The figure illustrates five hypothetical examples, each one with a different position relative to the three above-mentioned aspects (see text for explanation)

appropriate for making more detailed historical analyses. Adoption of a given scale or time will depend not only on the skills of the analyst, but also on the availability of evidence, data, and sources of information.

4.12 Social Metabolism and the Hierarchical Order

Although the search for socio-ecological models became an obsession that reached to most of the hybrid disciplines (see Chap. 2), its highest development happened in the field of ecosystem, or natural resource, management. Such theoretical advances occurred as an epistemological reaction to the concerns for the process of ecological and biological destruction that peaked from the mid twentieth century. During the decade of 1990, an intense debate took place about the models of ecosystemic management, which gave place to new theoretical and methodological proposals rising from the famous idea formulated by Albert Einstein: “We cannot solve the problems we have created, with the same thinking that created them.” Ludwig published an article under the challenging title of The Era of Management is Over, stating that: “The ideologies of our time (economism, scientism and technocracy) support the progressive view that experts, using scientific methods, can manage the World problems by objective and efficient means. These include the notion of an objective and value-free natural science and the idea that economics can be separated from ideology (Ludwig 2001, p. 758)." The recognition of the complexity of socio-ecological systems led Funtowicz and Ravetz (1991) to postulate a "post-normal science" in which normally facts are uncertain, values in dispute, stakes high and decisions urgent.

Among the myriad of new theoretical proposals about human management of ecosystems, those invoking the multi-scalar analysis of socio-ecological systems are noticeable. Such a dimensioning of the analysis originated in the General Systems Theory, particularly in the seminal formulation made by Koestler (1967, 1969) during the decade of 1970 surrounding the concept of the Holon: "Organisms and societies are multi-leveled hierarchies of semi-autonomous sub-wholes branching into sub-wholes of lower order and so on. The term holon has been introduced to refer to these intermediary entities which, relative to their sub-ordinates in the hierarchy, function as self-contained wholes; relative to their super-ordinates as dependent parts. This dichotomy of wholeness and partness, of autonomy and dependence, is inherent in the concept of hierarchy order (Koestler 1967, p. 58)." Because of that, it becomes necessary to explore this new category of the analysis, which has become increasingly more common in the approaches to complex systems, a quality of reality that had been either forgotten or relegated: the hierarchical structure of organization, be this either biological, mental, or social.

Two trends of thought have made substantial advances in multi-scalar analyses: one lead by M. Giampietro and collaborators about what was called the Multi-Scale Integrated Assessment of Society and Ecosystem Metabolism (MUSIASEM), and a second one that has been developing the Panarchy Theory. The theoretical and methodological contributions of Giampietro (2003) during the last decade have merged in a robust proposal known as MUSIASEM, which has been repeatedly applied for analyzing numerous cases in different geographical and economic contexts, and from the level of household to that of countries or nations (see, The Metabolic Pattern of Societies, Giampietro et al. 2012). The epistemological foundations of this Multi-Scale integrated analysis are based on the theory of complexity, and are interlaced with the new paradigm of sustainability (Giampietro and Ramos-Martin2005).

The Panarchy Theory resulted from an international and interdisciplinary research project known as the Resilience Project, which generated numerous papers and books (Berkes and Folke 1998; Berkes 1999), the later of which, with the title of Understanding Transformations in Human and Natural Systems (Gunderson and Holling 2001), founded a new theory based on the integration of concepts such as resilience, hierarchies, adaptive management, and sustainability: "Panarchy is the term we use to describe a concept that explains the evolving nature of complex adaptive systems. Panarchy is the hierarchical structure in which systems of nature and humans, as well as combined human-nature systems and socio-ecological systems are interlinked in never ending adaptive cycles of growth, accumulation, restructuring and renewal. Thus, the idea of panarchy combines the concept of space/time hierarchies with a concept of adaptive cycles (Holling 2001, p. 392)." In this regard, Varey stated: "A panarchy study seeks to transform static definitional hierarchies into a dynamic set of discernable levels of observably nested complexity… It draws from ecological hierarchy theory in recognizing that complex systems are ordered in discernable levels of functions… (Varey 2010, p. 11).” In summary, given the previously established, a spatio-temporal analysis of the metabolic process can be realized across and between scales. Because of cross-scale interactions, the maintenance of a system at a particular focal scale will depend on the influences from states and dynamics placed at scales both above and below.

References

Adams RN (1975) Energy and structure. A theory of social power. University of Texas Press, Austin
Berkes F (1999) Sacred ecology. Taylor and Francis, Philadelphia
Berkes F, Folke C (eds) (1998) Linking social and ecological systems. Cambridge University Press, Cambridge
Brown MT, Ugliati S (1999) Emergy evaluation of the biosphere and natural capital. Ambio 28(6):486–493
Chen GQ, Jiang MMB, Chen YZF, Lin C (2006) Emergy analysis of Chinese agriculture. Agric Ecosyst Environ 115:161–173
Daily GC (ed) (1997) Nature’s services: societal dependence on natural ecosystems. Island Press, Washington, DC
De Groot RS, Wilson MA, Boumans RMJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol Econ 41:393–408
Debeir JC, Deleage JP, Hemery D (1991) In the servitude of power: energy and civilization through the ages. Zed Books Ltd, London
Dincer I, Rosen MA (2007) Exergy: energy, environment and sustainable development. Elsevier, London
Dussel E (1977) Filosofia de la liberacion. Fondo de Cultura Económica, México
Funtowicz S, Ravetz JR (1993) Science for the post-normal age. Futures 25(7):35–38
Funtowicz SO, Ravetz JR (1991) A new scientific methodology for global environmental issues. In: Costanza R (ed) Ecological economics the science and management of sustainability. Columbia University Press, New York
Geogescu-Roegen N (1996) The entropy law and the economic process. Harvard Univerity Press, Massachusetts
Georgescu-Roegen N (1971) The entropy law and the economic process. Harvard University Press, USA
Georgescu-Roegen N (1975) Energy and the economics myths. South Econ J 41(3):347–381
Giampietro M (2003) Multi-scale integrated analysis of agro-ecosystems. In: Edwards C (ed) Series of advances in agroecology. CRC Press, Boca Raton
Giampietro M (2004) Multi-scale integrated analysis of agroecosystems. CRC Press, Boca Raton
Giampietro M, Ramos-Martin J (2005) Multi-scale integrated analysis of sustainability: a methodological tool to improve the quality of narratives. Int J Global Environ Issues 5:119–142
Giampietro M, Mayumi K, Sorma AH (2012) The metabolic pattern of society. Routledge, Abingdon
Gunderson L, Holling CS (eds) (2001) Panarchy: understanding transformations in human and natural systems. Island Press, Washington, DC
Holling CS (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390–405
Holling CS (ed) (1978) Adaptive environmental assessment and management. Wiley, New York
Koestler A (1967) The ghost in the machine. The Macmillan Company, New York

Koestler A (1969) Beyond atomism and holism: the concept of the holon. In: Koestler A, Smythies JR (eds) Beyond reductionism. Beacon Press, Boston, pp 192–232
Kosik K (1967) Dialéctica de lo Concreto. Editorial Grijalbo, México
Leff E (2000) La complejidad ambiental. Siglo XXI Editores, México
Lotka AJ (1956) Elements of mathematical biology. Dover, New York
Ludwig D (2001) The era of management is over. Ecosystems 4:758–764
Margalef R (1993) Teoría de los sistemas ecológicos. Universitat de Barcelona, Barcelona
Martinez-Alier J, Roca-Jusmet J (2013) Economía ecológica y política ambiental. Fondo de Cultura Económica, México
Martínez-Negrete M, Martínez R, Joaquín R, Scheinbaum C, Masera O (2013) Is modernization making villages more energy efficient? A long term comnparative end-use analysis of Cheranatzicurin, Mexico. Energy for sustainable development http://dx.doi.org/10.1016/j.esd.2013.05.004
Moran E (ed) (1990) The concept of ecosystem in anthropology. The University of Michigan, USA
Morin E (2001) Introducción al pensamiento complejo. Gedisa Editores, España
Naredo JM, Valero A (eds) (1999) Desarrollo económico y deterioro ecológico. Visor/Argentaria, Madrid
Naredo JM (1999) El enfoque eco-integrador y su sistema de razonamiento. In: Naredo JM, Valero A (eds) Desarrollo económico y deterioro ecológico. Visor y Fundación Argentaria, Madrid, pp 47–56
Naredo JM (2000) El metabolismo de la sociedad industrial y su incidencia planetaria. In: Naredo JM, Parra F (eds) Economía, ecología y sostenibilidad en la sociedad actual. Siglo XXI Editores, España, pp 193–229
Noorgard RB (1994) Development Betrayed. Routledge, New York
Odum HT (1971) Environment, power and society. Wiley, New York
Odum HT (1996) Environmental accounting: emergy and environmental decision making. Wiley, New York
Pimentel D, Pimentel M (1979) Food, energy and society. Edward Arnold, London
Rousset C (1974) La anti-naturaleza: elementos para una filosofía trágica. Taurus, Spain
Schmidt A (1976) El concepto de naturaleza en Marx. Siglo XXI Editores, México
Siche R, Ortega E (2007) Emergey-based suatainability of the Peruvian economy. In: Emergy Synthesis, pp 111–123. Proceedings from the 4th Biennial Emergy Conference, Gainesville, Florida
Smil V (1994) Energy in world history. Westview Press, Denver
Souza A, Ortega E (2007) Emergy analysis for small farmers. In: Emergy synthesis, pp 325–330. Proceedings from the 4th biennial emergy conference, Gainesville, Florida
Toledo VM (2006a) Ecología, espiritualidad, conocimiento: de la sociedad del riesgo a la sociedad sustentable. Editorial Jitanjáfora, México
Toledo VM (2006) Ecología, sustentabilidad y manejo de recursos naturales: la investigación científica a debate. In: Oyama K, Castillo A (eds) Manejo, conservación y restauración de recursos naturales en México. UNAM/Siglo XXI Editores, México, pp 27–42
Toledo VM (1981) Intercambio ecológico e intercambio económico. In: Leff E (ed) Biosociología y articulación de las ciencias. UNAM, México
Tricart J, Kilian J (1982) La eco-geografía y la ordenación del medio natural. Editorial Anagrama, Barcelona
Turner MG (2005) Landscape ecology: what is the state of the science? Annu Rev Ecol Evol Syst 36:319–344
Varey W (2010) Psychological panarchy: steps to an ecology of thought. Proceedings of the 54th meeting of the international society for the systems sciences ISSS (17–23 July 2010), Waterloo, Ontario
White LA (1959) The evolution of culture. Mc Graw Hill, New York
Zonneveld IS (1995) Land ecology. Academic, Amsterdam

Chapter 5
Social Metabolism at the Local Scale

5.1 Introduction

The best way to fully appreciate the complexity and theoretical potential of the idea of social metabolism is to understand the process of labor (human work) that is the starting point, trigger, key axis, and primeval unit of the historical development and evolution of human society as an emergent phenomenon of the universe. Of all the great thinkers of the nineteenth century opening the breach to the explosive development of science that took place in the following century, Karl Marx was the only one that succeeded in understanding the full meaning of the dual character of the human biological and social phenomenon, all of which was encompassed in his detailed and profound analysis of the process of labor. Marx laid the foundations for the future construction of a socioecological theory, which given the severity of the present crisis has become an urgent need and the main challenge of scientific reflection: "Labor is, first of all, a process between man and nature, a process by which man, through his own actions, mediates, regulates and controls the metabolism between himself and nature. He confronts the materials of nature as a force of nature. He sets in motion the natural forces, which belong to his own body, his arms, legs, head and hands, in order to appropriate the materials of nature in a form adapted to his own needs. Through this movement he acts upon external nature and changes it, and in this way he simultaneously changes his own nature (Marx, Capital, vol. 1 New York: Vintage 1976, 283)."

All of the metabolic processes are triggered and deployed at the very instant in which the most elementary, antique and primordial process of labor takes place: that which performs the act of appropriation of nature, and from whose action all goods needed for reproducing life are *produced*. For that reason and differing from all other current approaches to the concept of social metabolism (see Chap. 3), we give recognition to the need of understanding labor, and place it at the base of the ecological and social processes viewed as an integrated totality.

M. González de Molina and V. M. Toledo, *The Social Metabolism*, Environmental History 3, DOI: 10.1007/978-3-319-06358-4_5,

5.2 The Dual Character of Labor

As stated by Marx, human beings as a biological animal species need of nature for their material sustenance and reproduction, and they achieve that by means of labor: "Man can only proceed in his production in the same way as nature itself, that is he can only alter the forms of the material (Marx 1965, p. 43)." It is the act of production, and at the same time, the act of appropriation . However, given that any form of production is always "…the appropriation of nature by the individual within, and through, the mediation of a definite form of society (Marx 1913, p. 273)," the act of appropriation/production is *also* a social phenomenon. Thus, the dual character of labor expresses the situation in which human beings are simultaneously a member of an animal species, and a part of a given societary configuration. This twofold character of labor becomes essential for concrete analysis–i.e., an analysis that is localized in space and time—of social metabolism , because it allows for uncoupling the natural and the social dimensions, and because it also allows for distinguishing between both fundamental types of material interchanges or flows: the ecological and the economical flows. In order to provide a confirmation of the former statement, we will now begin the analysis of metabolism from the finest scale: that of the units of appropriation of nature, units that are the minimum cell in which the metabolic process begins.

5.3 The Appropriation of Nature

The act of appropriation that initiates all metabolism between society and nature can be defined as "…the process through which all members of a society appropriate and transform ecosystems for satisfying their needs and desires (Cook 1973)," an act that signifies the concrete, particular and specific moment in which human beings materially articulate with nature through the process of labor . It is convenient at this point to distinguish between the material and the intangible appropriation of nature, the latter referring to those actions by means of which human beings articulate themselves with the natural world through beliefs, knowledge, perception, aesthetics, imagination, or intuition.

Hence, appropriation qualifies the act by means of which the social subject becomes the owner of a material *thing*, and in this case it applies to the action by which human beings extract a *fragment of nature* to turn it into a social component; appropriation is the act by which human beings make a certain amount of mater or energy to be transferred from the natural to the social space. In that sense, appropriation of nature is an act of internalization or assimilation of natural elements towards the social *organism*. This action that determines, and is determined by the natural forces is, at the same time, an act that determines, and is determined by the remaining processes conforming the general metabolism: circulation, transformation, consumption, and excretion.

Because of the above, we will here use the term *appropriation of nature* differently from how it is employed by other authors, noticeably those endorsing structural Marxism such as Terray (1972), who has used the term for differentiating technological forms of utilization of nature, or Godelier (1978), who uses it in regards to juridical forms of property and access to resources. Thus, our definition is closer to that of Ingold (1987), who considers it a key concept for differentiating the human from the animal. Vitousek et al. (1986), and other English-speaking authors use the term in an ampler and general sense, usually circumscribed to the extraction of the so-called *products of photosynthesis* (Carpintero 2007).

5.4 The Basic Appropriation Unit: P

Human beings realize the appropriation act through social productive units having different natures, scales, and potencies. Examples of productive units are bands, the communities, cooperatives, families, companies or public corporations, or finally, any private owner buying labor force, i.e., a private entrepreneur hiring workers. Such units are in charge of performing activities for the appropriation of elements from the biosphere (living organisms, water, air) and from the geosphere (materials from the Earth's crust). All appropriation units (P) are real and metaphorically located at the intersection between the Natural and the Social, occupying the outer portion of a given social totality. That fraction of the society is what is conventionally known as the *primary sector*.

Considering the statements made in the previous sections, all unit of appropriation P is articulated to four environmental dominions, each one having a representation in space and time, and each one being materially related: the three environments previously defined in Chap. 4 (TEN, UEN, and CEN) and the social environment (SEN), the latter defined as any part of society other than P with which P materially interacts (i.e., it interchanges materials and energy). The first three types of environments are concrete natural spaces integrated by special units (ecosystems or landscapes), and correspond to the *natural* world, i.e., are located *outside* the social totality. In contrast, the fourth kind of space corresponds to the *social* world, given it is located inside the social totality, and delimits a social space containing all social instances having interchanges with P.

5.5 A Flow Model

In order to approach appropriation from an economical and ecological inclusive perspective obliges us to elaborate the topology of the process (Godelier 1978, p. 764). Appropriation is both a theoretical and a practical category, because of which the process can be empirically reduced to flows of goods, labor, money, services, and information (Cook 1973; Grünbühel 2002). Thus, an adequate way for understanding and explaining the process of appropriation is by describing how these flows are structured and become integrated to a concrete reality. Such a spatial representation of the appropriation process must meet at least three prerequisites: (i) it must have a minimal coherence or conceptual robustness; (ii) it must be as little arbitrary as possible by delimiting the portions of reality it attempts to represent; and (iii) it must be explicit as to the categories, parameters, and variables used in the model, all of which must be identifiable, obtainable, and quantifiable.

As seen above, P performs interchanges with the three main landscape units, and with society. The utilized environment, UEN, is represented by a series of units (generally identified with vegetation types, relief, soils, and other factors in cases of aquatic environments), which as properties of P operate as *working objects*, i.e., the part of nature that is appropriated without disrupting the ecosystemic structure of the appropriated environmental units. The transformed environment, TEN, is formed by those areas that being a property of P are used for agriculture, livestock raising, forest plantations, aquaculture, etc., i.e., the artificial ecosystems representing working means, or nature mediated by human actions. The conserved environment, CEN, includes all the areas consciously and deliberately maintained as *natural reserves*, as untouched areas only offering diverse services. Finally, the social environment, SEN, is made up of all the sectors of the social totality that being beyond the limits of P hold any sort of interchange with the appropriation unit P. These social sectors will be defined in each concrete case by the nature of the interchanges realized by P, which can go from those occurring at a local or regional level (e.g., interchanges between similar communities or in a regional market), to those happening at the national and international levels, when as it currently occurs the unit receives or produces import and export materials.

5.6 The Material Flows

A flow model is created by connecting these four landscape units (UEN, TEN, CEN, and SEN) with the unit P by means of several kinds of material interchanges, which—despite their different natures—flow between the latter five dominions, turning them into parts of a totality, or a system (Fig. 5.1). The flow F_0 represents the total force exerted by the total unit P in order to realize the appropriation, overcoming the intrinsic resistance of ecosystems, and appropriating the potential resources remaining in the landscape units. In that regard, we must recognize that for every particular situation there will be different ecosystemic resistances to that same action, which will be determined by the specific physicochemical, biological, and geological conditions of what is being appropriated. At this point, a rule emerges as a fundamental assumption: the greater the affectation caused in ecosystems by the act of appropriation, the greater will be the effort needed by P for appropriating them. The latter assumption can also be formulated in a different way as the need for creating humanized or useful ecological systems, having structure and dynamics as similar as possible to those in the original modified or removed ecosystem.

Activation of F_0 initiates the process of appropriation, this being a planned human action directed towards obtaining a return flow (goods or useful services). Because of that, the F_0 flow is unfolded into three sub-flows F_{0a}, F_{0b}, and F_{0c}, depending on if it is directed towards appropriating of components or processes of the TEN, UEN, or CEN, respectively. Of all the identified flows, this is the more problematic because it is not easily defined. According to Giampietro (2004, pp. 213–217), the human action triggering the appropriation process can be identified as *energy*, *work*, or *force*, each one having a certain amount of ambiguity as physical categories. Even adopting energy as a parameter for quantifying F_0 implies several contradictions and ambiguities (see Giampietro and Pimentel 1990; Giampietro et al. 1992, 1993).

A central assumption is that the *effort* made during the appropriation made by P—be it either defined as energy, work, or force—most consider the portion of that effort that is needed for construction and maintenance of the structure that allows applying that same effort (Giampietro 2004). This additional effort requirement from the productive structure is inseparable from the type of energy deployed by P in the flow F_0, so that one thing is activating the appropriation using only human power (muscular energy), and another to do it by adding animal power, or using solar energy—either directly (photocells and accumulators, solar heaters) or indirectly (wind, water, or combustion of biomass), or through the use of fossil fuels (machines powered by coal, oil derivatives, or gas) or nuclear energy. Beyond its particular nature, the flow F_0 can be evaluated as a function of the time invested for performing an action with the expectation of a return flow, and the resulting parameter seems to be sufficient for a quantitative assessment of the whole system.

There is three return flows denoted as F_1, F_2, and F_3, each one coming from TEN, UEN, and CEN, respectively. The flows from TEN and UEN can be of goods (materials, energies, water), services (as defined in the former section), or both, while those from CEN are only of services provided by these *untouched* spaces whose sole presence is considered valuable. Each return flow is itself divided in two sub flows, one satisfying the needs of P (F_{1a}, F_{2a}, and F_{3a}) and the second circulating through other social spheres (SEN) different from P (F_{1b}, F_{2b}, and F_{3b}).

Finally, flow F_4 goes from SEN to P, commonly but not exclusively is a flow of return of what P provided (the three sub flows F_{1b}, F_{2b}, and F_{3b}). Flow F_4 can also appear spontaneously, for instance, in the form of subsidies, donations from public, social, or private institutions—banks, beneficence institutions, government agencies, other P—either in commodities , money, or supportive aid.

The flow F_4 is exceptional in that it introduces a new element: the goods needed but not produced by P, and in a second instance, the goods transformed in merchandise (commodities), i.e., goods and services that end up being given monetary significance and valued by markets. F_4 is the flow that introduces the monetization

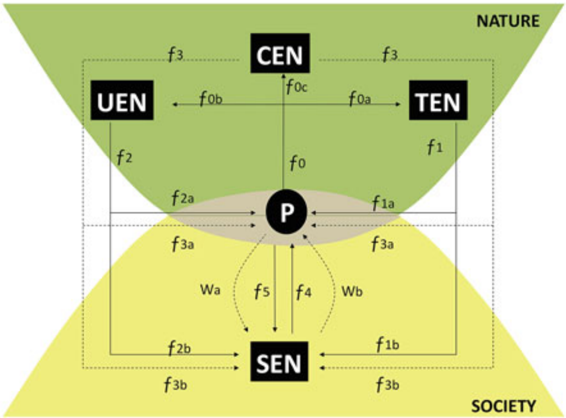

Fig. 5.1 Graphic representation of the flow model synthesizing the interchanges made by P with nature and with the rest of society (see text for explanation)

of the system. As a result, flow F_5 occurs when P uses the acquired money for buying other necessary commodities, prompting the rise of a new range for mercantile exchange between SEN and P that is measured, mediated, and determined by the economic value of what is traded.

The flow model is completed by two last components: the flows of work force (labor power) from P to and from SEN (*Wa* and *Wb*, respectively), and the transformation capacity of P (*t*). *Wa* denotes the work force sold to SEN by P, and *Wb* the work force acquired from SEN by P. In both cases, the flow takes the form of work converted to a commodity or merchandise, i.e., valued by a specific labor market, and is the result of an anomaly occurring at P that forces the appropriation—and reproduction—unit to make use income from a metabolic sphere different from that of appropriation, or to request aid from social actors that are external to P.

The latter aspect involves the capacity of P for transforming into commodities the goods it extracted from either TEN or UEN—e.g., fruit converted to preserves, cured meat or fish preparations, lumber transformed into utensils or furniture, etc.—that is denoted by *t*. In a strict sense, these transformed products are derived through the application of an effort from P that is not strictly correspondent to the flow F_0, an effort that is not a part of the act of appropriation, but belongs to the metabolic process of transformation.

It should be noticed that the flow model shown in Fig. 5.1 excludes generation and emission of wastes because these are considered to be negligible, but these flows can also be incorporated into the model as counter flows of the return flows whenever that is deemed as necessary. The latter need gains particular relevance in cases of industrial appropriation.

Thus, a particular model of the process of appropriation is reached to, which allows for visualizing the different processes that are crucial for gaining a deeper insight into the whole metabolic process.

5.7 Ecological and Economic Interchanges

From the theoretical standpoint, the flow model reveals the existence of a *dynamic equilibrium* allowing for sustenance through time of the appropriation process. It also provides a mean for distinguishing the forces operating as variables, and as stabilizing or disruptive, positive or negative factors of such equilibrium. But above all, the flow model reveals the existence of two different but coupled material interchanges. The two shaded areas intersecting around P that are depicted in Fig. 5.1 are expressing the occurrence of two ranges, spheres or *gravitational fields* in which P exists and reproduces itself. Thus, P behaves as one more biological species in that it consumes all that it produces exclusively for being consumed. In such case, the permanence of P depends on its ability for obtaining from the environment the amount and quality of commodities and services required by the members of P without depleting these commodities and services. These interchange that can be expressed as $F_0/F_{1a} + F_{2a} + F_{3a}$, will then depend upon the efficiency of the work force (F_0) for obtaining enough and constant flows of commodities and services from TEN (F_{1a}), UEN (F_{2a}), and CEN (F_{3a}): a condition that is in turn dependent upon the preservation of the dynamic processes allowing for the continued renovation of the ecosystems being appropriated. We are thus in front of a form of *ecological interchange*.

To the contrary, as soon as P circulates its appropriated products beyond the sphere of its own consumption, P becomes a *social species* so that its permanence and reproduction become further dependent upon the processes and dynamics of the spheres in which its products circulate. This is because its consumption no longer solely depends on what is interchanged with nature (TEN, UEN, and CEN), but also on what is interchanged with SEN. In such cases, those products obtained from the TEN, UEN, and CEN landscape units (F_{1a}, F_{2a}, and F_{3a}, respectively) that are either of no use to P or have a use value for SEN, begin to circulate and are transformed or consumed by individuals not belonging to P but to SEN. In the latter instance, the efficiency of P is determined by its ability for obtaining enough commodities and services flows from SEN, itself dependent upon the type of market with which P interacts. We are then in front of the phenomenon of *economic exchange*.

The overlap, connection, or articulation of these two types of interchanges, the *ecological* and the *economic*, is not only evident, but a preponderant and unavoidable feature of social metabolism because it reveals the transit of material flows through two different spheres: the natural or ecological, and the social. Such juxtaposition implies recognizing in the unfolded process of appropriation the existence of two separate processes, which despite their dissociation, remain being indissoluble parts of one same totality: the *Holon*.

Therefore, the phenomenon of appropriation/production simultaneously obeys to two different spheres or levels, which represent two irreducible, but inseparable aspects of the same process. The above fact places all P units between two forces—with variable degrees of tensions—that determine or force them to act in different ways.

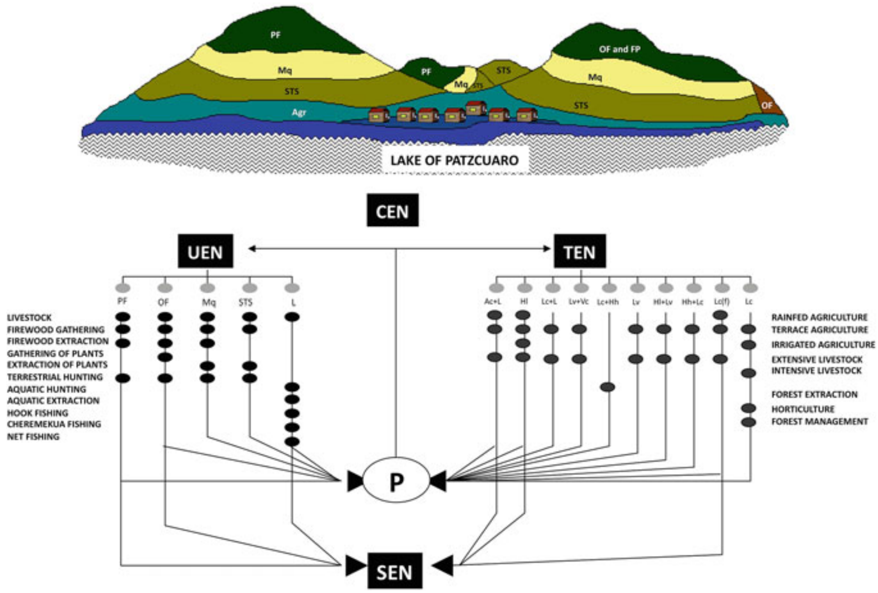

Fig. 5.2 Diagram showing how the flow model allows for ordering the inter-changes sustained by the rural community of Tzintzuntzan (located in the lacus-trine region of Pátzcuaro, México) with the three environments (TEN, UEN, and CEN) and with the rest of the local society (SEN). Each activity is placed within the whole of activities conforming the process of appropriation . In the case shown here, the types of vegetation cover (pine forest: PF; oak forest, OF; and sub-tropical scrubland, STS), and the lake (L) determined the landscape units of UEN. The soil units determine the landscapes units of TEN (Acrisol and Luvisol: Ac + L; Histosol HI; Leptosol and Luvisol: Le + L; Vertic Luvisol and Chromic Vertisol: Lv + Vc; Chromic Luvisol and Histic Histosol: Lc + Hh; Vertic Luvisol: Lv; Histo-sol and Vertic Luvisol; Histic Histosol and Leptosol: Hh + Lc; Ferric Leptosol: Le(f); and Chromic Leptosol: Lc). Notice that the community of Tzintzuntzan lacks CEN. The community scale model is integrated by the sum of interchanges from all households. Elaborated from data of Toledo and Barrera-Bassols (1984)

In societies that produce only what they consume—i.e., when human beings grouped as a society remain to be one more of the biological species in nature—the productive process is fundamentally expressed as a natural process. Through the historical evolution of societies, and after the appearance of economic interchange realized through the circulation of the products appropriated by P, the productive process gains an emergent attribute that is overlapped to its natural character, but without suppressing it. As was stated by Schmidt: "The metabolism between man and nature—a special case of the general interaction of natural things—was placed by Marx in the category of exchange and, inversely, he had recourse to the concept of metabolism when characterizing the process of exchange. In the direct labor-process, i.e. the metabolism between man and nature, the *material side* triumphs over the historically determined form; in the process of exchange, which depends of the labor-process, the *historically determined form* triumphs over the material side (Schmidt 1973, p. 92)."

Admitting that in past or extant relatively simple human societies, such as the band or the domestic community, the process of appropriation is only suitable of being analyzed in purely ecological terms, also implies recognizing that in the realm of material production and reproduction such human groups continue to behave as a biological species, despite that its populations are grouped in societies, possess means for communication in the form of language, and generate cultural expressions in the form of knowledge, art, beliefs, or ideology. The significance of this recognition is that, in a historical perspective, the social, cultural, and economic phenomena do not appear in synchrony, and that the latter phenomenon made its appearance long after the two former ones, i.e., economic processes are more recent than is commonly believed. Apparently thus, the social being separates from the biological being in those features and dimensions that can be considered as ethereal, before that in those of a material nature: i.e., societies first generate supra-structural secretions—metaphorically resembling non-biological pearls (dreams and fantasies, ideas, myths, art, knowledge, and interpersonal relations)—and only afterwards do they generate new structures of material production and reproduction.

We thus arrive to a novel visualization of the human phenomenon at the moment of recognizing that history first traverses through a long *pre-economic* period in which people articulate merely through natural nexuses (the ecological interchange), or through *natural relations of production* (as a consequence of their solely ecological productive processes), and that only after the rise of economic exchange —i.e., when circulation of material commodities goes beyond the unit that produces them (P)—does human history fully enters its purely economic phase.

But economic exchange did not suddenly appear in history. Rather, it appeared after a lengthy process of gestation and maturation that can be traced back to the first known societies (Meillassoux 1972). As early as in bands and domestic communities, in strict sense not being closed or autarchic societies, some forms of material interchange take place, which do not reach the rank of economic interchanges despite they are occurring between different production units. The donation of goods for reasons of friendship or kinship, or the dowry given during a marriage transaction cannot be in strict sense considered as economic interchanges, because in neither of these "is it possible to confront what is produced (because of which) objects cannot be measured against one another. No exchange value can appear in such conditions (Meillassoux 1960, p. 64)." Thus, from a theoretical perspective it can be rightly assumed that economic interchange appears with the objective of coupling complementary economies, i.e., with the goal of satisfying needs that cannot be covered solely through ecological interchange.

As long as the ecosystems in the three types of landscapes (MEN, UEN, and CEN) provide P with all or nearly all the materials it requires for its reproduction, that appropriation unit will not be forced to have interchanges with other similar units. But whenever the intrinsic conditions of the ecosystems make it impossible to provide more than a portion of the means for subsistence, or when the cost of their appropriation becomes too high, the interchange between appropriation units will be favored and stimulated.

In its simplest primeval version, economic exchange makes it appearance in the form of trading of equivalent and complementary materials between two homologous production units (P1 and P2). From then on, as soon as the productive processes of each unit appear as mutually conditioning each other, the influence of a quantitatively new plethora of elements begin to recur in those processes. Production and consumption start responding to factors that no longer belong to the range of ecological interchanges. On one side, a part of the production must be excluded from self-consumption, and on the other side, a part of consumption begins to be dependent on what is externally traded.

The progressive development of this metabolism gradually brings a new character to the productive process, slowly immersing it inside a new logic. In Marx's terms: "The constant reiteration of trading turns it into a consistent social process. Through time it is obligate that at least a part of the products of labor is produced with the intention of being diverted to trade. From that moment are reaffirmed, on one side, the excision between the utility of things for the immediate needs, and their utility with trade in mind. Their use value becomes disjointed from their exchange value . And on the other side, the quantitative proportion in which they are traded becomes dependent upon their production itself (Marx 1975, pp. 107–108)."

The expansion and multiplication of trade promoted and generated labor division, private property, new institutions, and new relations (social, juridical, cultural) between human beings. With the appearance of money, commerce became consolidated and acquired full recognition. From the simple trade between neighboring productive units, trade between regional, national, and international markets was reached. All that resulted from innovations in transport that activated and speeded up the process of circulation. Finally, trading became universal and peaked to its full plentitude under capitalism and the modern world it generated.

In that way, the process of appropriation /production begins showing features that go beyond the merely ecological laws and gives rise to new interpretations and methods for their interpretation. Economic analysis makes its full appearance. Two highly relevant conclusions are reached to: (a) before the development of an economic phenomenon the process of appropriation was essentially ecological, i.e., the economic phenomenon does not appear from the vacuum, or is it born by *spontaneous generation*, it rather is the same metamorphosed productive process that previously obeyed to different logic and laws; and (b) the economic phenomenon adds, and is overlapped to the ecological phenomenon, which is not suppressed, so that any contemporary analysis of the productive process must, *a fortiori*, give recognition to both types of phenomena.

5.8 Use Value and Exchange Value

The distinction we have made in the previous Section was originally recognized by Marx (1975, p. 51) in his reflection about the dual or bimodal nature of the labor contained in merchandise, allowing for differentiating two attributes in the generated material flows: its *use value*, and its *exchange value*: "In the process of Exchange, the use value, which is a product of the direct exchange between man and nature, takes on an 'existence as an exchange-value or general equivalent, cut loose from any connection with its natural existence.' Then, through the mediation of this social metabolism, the exchange-value returns to its former immediacy, again becomes use-value. With the transition from circulation to consumption, the commodity's social determination becomes extinguished and is replaced with its natural determination, since its use-value is independent of the amount of time required for its manufacture (Schmidt 1971, p. 93)."

Or as stated by Marx: "…the use value of things is realized by people without exchange, that is, in the direct relation between the thing and people, while its (exchange) value, on the contrary, only in exchange, or within the social process…In the measure in which the process of trade transfers merchandises from hands in which they are not use value, to hands in which they are use value, we are in front of a social metabolism (Marx 1975, p. 102 and 127)."

Distinguishing use value from exchange value is crucial because it demarcates two ranges or dimensions within a same process, and because it reveals that the dynamics of the appropriation process are responding to two different, but intimately related domains that consequently require of different categories and treatments, although being in permanent coupling. In other words, all material flow of goods and services is a flow of energy, mater or water that once transformed or circulated becomes a flow of merchandises or commodities, and eventually of money, traversing through a circuit that can be slow or rapid, simple or complex, and that culminates in the consumption of what is appropriated from nature. This intermittent yet constant flow from the ecological to the social is determined by two different force fields, and consequently, any attempt of quantification is forced to arrive to a method that integrates these two fields in a coherent form.

5.9 Commodities

As a consolidated phenomenon, economic exchange is centered on *commodities*. "A *commodity* is something that is bought and sold, or exchanged in a market, any good or service produced by human labor and offered as a product for general sale. Some other priced goods are also treated as commodities, e.g. human labor-power, works of art, services offered by nature, even although they may not be produced specifically for the market, or be non-reproducible goods. A commodity has a use value an exchange value and a price. It has a use value because, by its intrinsic characteristics, it can satisfy some human need or want, physical or ideal. By nature this is a *social use value*, i.e. the object is useful not just to the producer but has a use for others generally. It has also an *exchange value*, meaning that a commodity can be traded for other commodities, and thus give its owner the benefit of others' labor (the labor done to produce the purchased commodity). Finally, *price* is then the *monetary expression* of exchange-value, although exchange value could also be expressed as a direct trading ratio between two commodities without using money, and goods could be priced using different valuations or criteria. According to the labor theory of value, product-values in an open market are regulated by the average socially necessary labor time required to produce them, and price relativities of products are ultimately governed by the law of value. In general terms, exchange values can also be measured as quantities of average labor-hours. Commodities which contain the same amount of socially necessary labor have the same exchange value. By contrast, prices are normally measured in money-units. For practical purposes, prices are, however, usually preferable to labor-hours, as units of account [Commodity [WWW Document], n.d. Wikipedia. URL http://en.wikipedia.org/wiki/Commodity]."

5.10 Exchange of Equivalents and Unequal Exchanges

The balance of material interchanges, which are ecological and economic, are quantified or measured by some method, and involve reciprocal actions or flows going to and from, can express either equivalences or inequalities that will have effects on the totality of the process. In this regard it is useful to examine the consequences of the balance in the interchanges between P and nature (TEN, UEN, and CEN), and between P and society (SEN).

Interchanges between P and the three realms of the natural space TEN, UEN, and CEN become unequal whenever P threatens the capacity for renovation of ecosystems under appropriation, i.e., when it endangers the material basis of the act of appropriation. Conversely, when P sustains constant return flow against constant effort (F_0), equality is manifested as a sign of health of the interchange system, indicating that P is realizing an adequate appropriation. As stated above, three assumptions derived from ecological theory set the patterns that must be followed for appropriation to be adequate, or equivalent.

First, the environmental or landscape units integrating the property, parcel, or productive space (terrestrial or aquatic) must be assumed. This first recognition allows for establishing the second assumption consistent in recognizing the productive *potential* of each of those previously characterized units. Afterwards it is possibly to recognized what geographers call the *suitability* of the natural units. The final assumption includes adopting an adequate appropriation strategy that allows for obtaining from the ecosystem/landscape the maximum return flow without compromising its capacity for renewal, i.e., in a sustainable way through time.

The unequal exchange between P and SEN, i.e., the economic exchange of non-equivalents, generally occurs as a mechanism of social exploitation, in which case one of the two actors of the interchange extracts a higher value (including the labor force) from the exchanged commodity. Such surplus value ripped off by multiple means, generally is obtained during the interchange of raw matters generated by P and the acquired commodities derived from manufacture or industry. Nevertheless, P can establish equivalence relations, for example through bartering or through traditional markets to which producers recur to make exchanges for complementing the supply of subsistence goods and services, for instance, in the regional markets from peasant or indigenous regions. Unequal exchanges reach their maximum expression during the economic transactions between P and SEN incarnated by monopolies or corporations that centralize merchandises—either in the form of commodities, services, money, or work—within a mechanism by which capital is concentrated and accumulated.

The unequal exchange in the economic sphere (flows F_4, F_5, and W_0)—which expresses the subordinate character of the rural relative to the urban-industrial sector, or of the periphery relative to the center—commonly transfers value from P to SEN by means of the sub-valuation of the goods and services derived from TEN, UEN, and CEN, from the labor force of the members of P (flow W_0), or from the over valuation of the goods and services that SEN sells to P; a phenomenon that has become especially common during the interchanges between rural producers in the South and consumers in the North. Several authors, among which Palerm (1980: Chap. 8) is noticeable, have added another component by disclosing a veiled form of exploitation: that in which P performs appropriation under traditional or peasant subsistence rationalities, but sell as commodities their products or labor force in capitalist markets. In the latter cases, the market makes no recognition neither pays what P invests in selfsupply (flows F_{1a}, F_{2a}, and F_{3a}), which is equivalent to not paying part of the salary of a worker, and which explains why some goods and services from P are so extraordinarily low priced or even free of cost—e.g., carbon sequestration, conservation of biodiversity, or maintenance of water flows—in the national and global markets.

We thus arrive to the recognition of two types of unequal interchanges articulated in the general process of appropriation: the ecological and the economic: what boils down to two different but joined together forms of exploitation. The latter distinction provides the base of a *theory of ecological-economic exploitation* providing insight of both the deterioration and collapse of the process of appropriation, and the different types of conflicts present in rural zones (Martínez-Alier 2002). This theoretical consideration implies understanding how exploitation between social sectors prompts the exploitation of nature, and vice versa, through synergies that have received little recognition and analysis from scholars, given that the studies made on this regards tend to embrace only one half of the story: economic analysts oversee the unequal ecological exchange, and ecologists forget about unequal economic exchanges.

5.11 Case Studies

5.11.1 Punta Laguna

The metabolism of a contemporary rural community—García-Frapolli et al. (2007, 2008) made a series of studies in a Mayan community from the Yucatan Peninsula, Mexico that provide an illustration of the application of the flow model of social metabolism at the community scale. The studied community was composed of three settlements with 44 families including 235 inhabitants, who appropriate from a surface area of nearly 5,400 ha by means of 13 productive activities listed in Table 5.1. Although flows can be assessed by means of several indicators (energy, labor, volumes, or monetary value), the authors preferred to use a monetary analysis.

The application of the above-described flow model (Fig. 5.1) at the scale of community allows for ordering in a coherent way the different activities carried out by families, measuring the flows of interchange, obtaining mean values, and revealing aspects of interest such as: (i) the annual distribution of effort (measured as workdays) invested by producers in each productive activity, (ii) the proportion of goods and services derived to both self-subsistence and the market, (iii) the monetary value of each productive practice, and (iv) the productive efficiency calculated as the ratio of invested work to the monetary value of the return flow. By that procedure, the model generates a metabolic profile that allows for making an integrated analysis of the different resources appropriated by the community, knowing which of these resources the community consume, transform and sell as commodities, the services they offer (ecotourism and field support for scientific research programs), and the labor force they temporarily sell outside the community.

The results of García-Frapolli et al. (2007, 2008) indicate that, on average, the community invests nearly half of its effort (46.5 % of the invested labor per year) to generating goods for self-subsistence, and the remaining effort (53.5 %) for producing goods and services for the market (Table 5.1).

Of the 13 activities performed by the community, five comprise 80 % of the invested labor. The two activities completely derived to the self-subsistence of the community together add up to almost half of the total effort, and nearly all the labor invested for self-subsistence: the *milpa*—parcels cultivated with maize, bean, squash, and other species—that receives 25 % of the total annual effort, and the home garden receiving 20 % of that same effort. As a counterpart, three of these main five activities are derived to the market and absorb nearly 40 % of the invested labor: production of crafts, production of charcoal, and sale of labor (Fig. 5.2).

When the return flows are calculated as economic value of produced goods and services, five activities (milpa, sale of labor, ecotourism, apiculture, and crafts) generate 70 % of the total produced value. Once again, the milpa generates 30 % of the return flow and 40 % is derived from apiculture, crafts, ecotourism, and sale of labor (Fig. 5.3); again underlining the relevance of the former activities.

The adoption of the flow model allows for the ordered analysis of metabolism at the scale of the community, while the transformation of material flows of goods and services to their monetary values facilitates the input/output, or supply/product analysis.

Table 5.1 Calculation of the effort invested (as workdays per year) and of the goods and services (as monetary value in Mexican pesos per year) in the 13 activities performed by the productive members in the community of Punta Laguna, Quintana Roo, Mexico

Activity	Workdays invested		Monetary value						Income/ Workdays invested
			Total		Self-subsistence		Market		
	Workdays	%	MX$	%	MX$	%	MX$	%	Ratio
Milpa	122.8	22.7	9,167	29.0	9,167	62.3	0	0.0	74.6
Home garden	98.8	18.3	1,737	5.5	1.737	11.8	0	0.0	17.6
Apiculture	17.3	3.2	2,750	8.7	0	0.0	2,750	16.2	159.0
Firewood extraction	22.3	4.1	2,284	7.2	2,284	15.5	0	0.0	102.4
Hunting	6.3	1.2	341	1.1	279	1.9	62	0.4	54.1
Goat raising	9.2	1.7	164	0.5	164	1.1	0	0.0	17.8
Production of charcoal	55.7	10.3	2,083	6.6	0	0.0	2,083	12.3	37.4
Building lumber extraction	5.3	1.0	1,058	3.3	1,058	7.2	0	0.0	199.6
Temporary labor	50.9	9.4	4,212	13.3	0	0.0	4,212	24.9	82.8
Crafts	99.5	18.4	2,364	7.5	0	0.0	2,364	14.0	23.8
Ecotourism	26.8	5.0	3,435	10.9	0	0.0	3,435	20.3	128.2
Field support for science	24.5	4.5	2,018	6.4	0	0.0	2,018	11.9	82.4
Fishing	0.6	0.1	28	0.1	28	0.2	0	0.0	46.7
Total	540	100	31,641	100.0	14,717	100	16,924	100	78.9
Relative percent			100 %		46.5 %		53.5 %		

See García-Frapolli et al. (2007) for details about the fol-lowed methodology

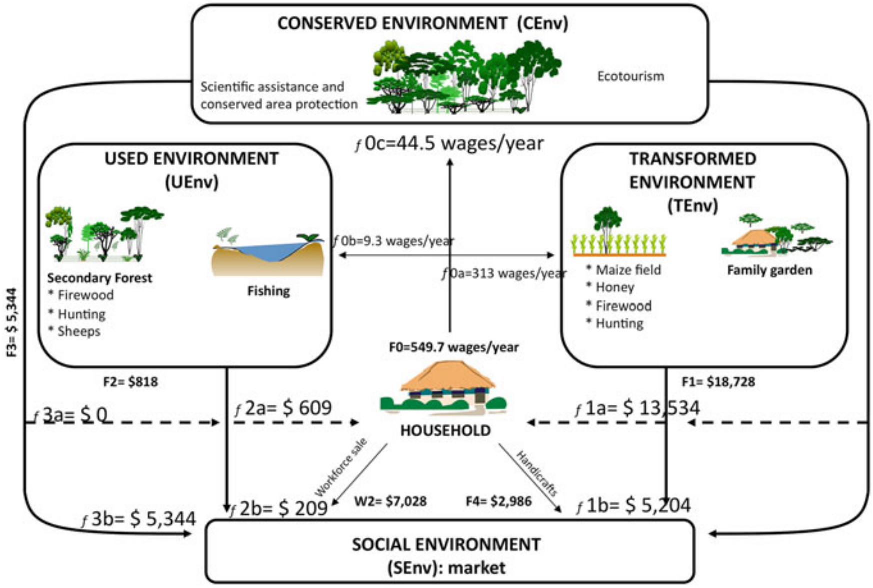

Fig. 5.3 Flow model for the community of Punta Laguna, Yucatán, México. The strategy of multiple uses followed by the community includes milpa agriculture, home garden, hunting, gathering, apiculture, production of charcoal, goat raising, services for ecotourism and field support for scientific research. The model quantifies the human effort as number of workdays per year (F_0) invested in the appropriation of resources from three landscapes (input), the obtained products converted to Mexican pesos (F_1, F_2, F_3 y F_4), and the work sold outside the community (W2). For details and methodology followed see García-Frapolli et al. (2008)

5.11.2 Santa Fe: The Metabolic Transformations of a Rural Community

Analyzing the traditional agrarian systems can provide us with useful lessons for the present, but when such systems have disappeared—as in the case of rural areas in the industrialized countries of Earth (European countries, U.S. and Canada)—historical analysis acquires a considerable value. That, however, depends on the availability and fidelity of extant statistical data. The study of the metabolic transformation occurring at the community scale (village level) provides understanding with a certain level of precision the social and ecological changes in a comprehensive way, a potential revealed by the scarce but valuable studies made (e.g., Krausmann 2004; Cussó et al. 2006). What follows is a summarized account of the case study of the community of Santa Fe near Granada in southern Spain. Anyone interested in a more detailed account is recommended to peruse the original papers (González de Molina and Guzmán-Casado 2006; Guzmán-Casado and González de Molina 2008, 2007a, b) from which this brief account was extracted.

The analysis of the information contained in several historical sources such as the Ensenada Cadaster, the Municipal Archive, and the statistics contained in the

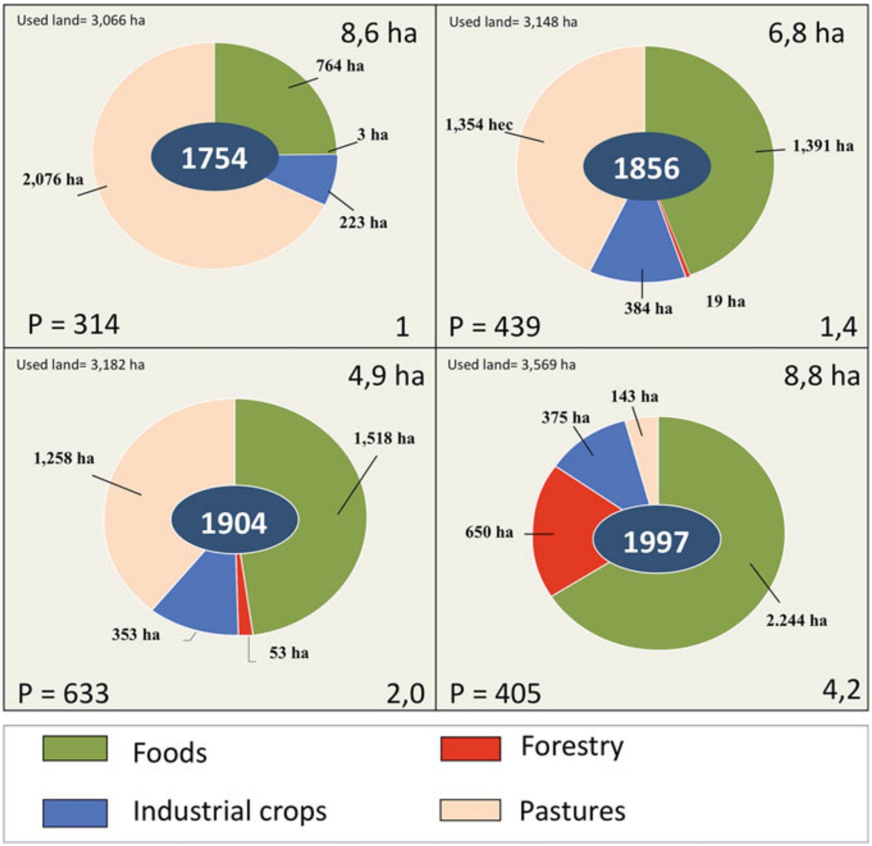

Fig. 5.4 Land use changes in the community of Santa Fe in 1754, 1856, 1904 and 1997, indicating the number of households (P), the total land used in hectares, the farm average size, and the invisible ecological footprint (the number of territories needed to maintain production without imported energy and materials). *Source* González de Molina and Guzmán-Casado (2006)

Agrarian Chamber of Santa Fe, allowed for reconstructing the social metabolism of Santa Fe and to have access to data about different economic aspects during four important time periods: 1752–1754, 1856, 1904, 1934, and 1997.

The data gathered for the above-mentioned time periods provided information about the number of appropriation units (P), the population, the productively active population, the land uses, the surface areas under different types of management, the volumes of production, the flows of energy, and the productivity in its different conceptions. In general, the historical analysis reveals the transformations underwent by the community and its territory while going from an organic to a fossil energetic base.

An arrangement of the data about Santa Fe in 1754 following the herein developed model (Fig. 5.4) reveals a community in productive, labor, and territorial equilibriums, as is shown by the surface areas devoted to the four basic productive activities: 2,500 ha for agriculture (rainfed, with eventual irrigation,

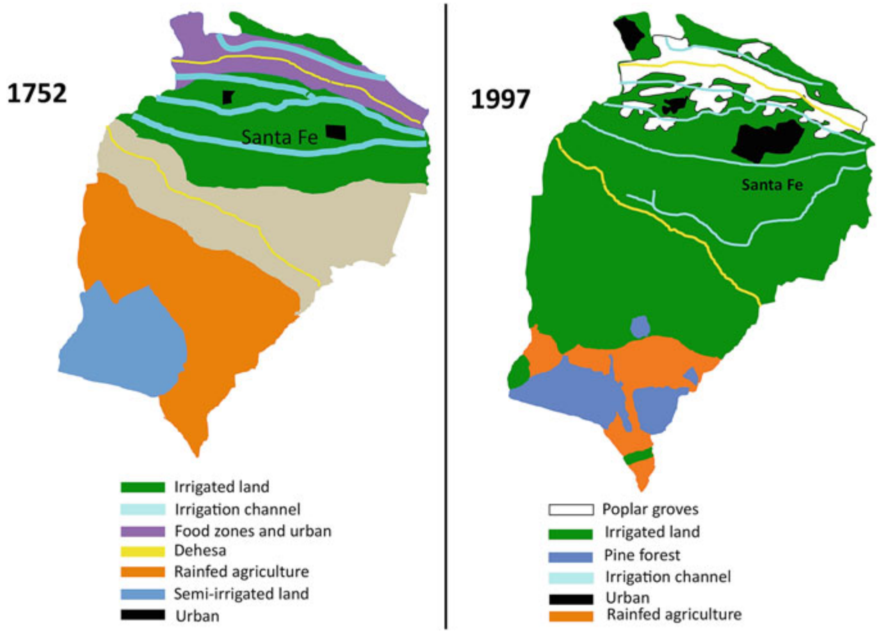

Fig. 5.5 Land uses changes in Santa Fe, Spain (1752–1997). *Source* González de Molina and Guzmán-Casado (2006)

and constantly irrigated); over 400 hectares for livestock raising (cropping of barley, grazing land with trees or *dehesas*, and pastures); and 703 hectares of forest for extracting firewood and lumber, for conservation of a gallery forest along a riverbank, and for flooding pastures. Such a territorial balance—in which livestock plays a key role as provider of manure for fertilization of agricultural soils, and extraction of firewood operates as the main energy source—is reinforced by an economic rationality combining production for self consumption and production for the external market (e.g., of hemp and linen).

As shown in Fig. 5.5, the main changes occurred in Santa Fe between 1752 and 1997 are related to the noticeable increases in land and labor productivity, which is clearly reflected in the increased volumes of agrarian products, and in the changes in land use, in particular, the surface area required for maintenance of soil fertility, a need that was originally satisfied by manure and agricultural byproducts, but that by the year 1997 became covered by chemical fertilizers. Such productive changes that were determined by changes in technology were oriented towards agricultural specialization, and consequently, determined by the dependency of the community from both external inputs, and availability of markets in which to sell its products.

These transformations took place with hardly any modification of key aspects, such as the expansion of the useful agrarian surface area in 20 %, a 30 % increase in the number of appropriation units, and a 3.3 % increment of the average size of the appropriated parcels (from 8.6 to 8.8 ha).

If all forms of social metabolism imprint a *visible trace or footprint* on the territory that is expressed as a configuration of concrete landscapes, and as a certain landscape equilibrium, the change of energy sources and productive rationality reveal a *hidden footprint* represented by what the community needs to import in terms of energy and materials for metabolism to remain valid, and which is equivalent to what the community has ceased to produce. This hidden footprint is, in a way, equivalent to the ecological footprint proposed by Wackernagel and Rees (1994), which became a widely applied indicator. In other terms, each metabolic configuration has a territorial cost that needs to be accounted for and evaluated. If energetic, alimentary or hydraulic self sufficiency is recognized as a positive factor of any socioecological system, then the metabolic transformation followed by Santa Fe along a time lapse of nearly 250 years turns out to have been inappropriate.

References

Carpintero O (2007) La apropiación humana de producción primaria neta (AHPPN) como aproximación al metabolismo económico. Ecosistemas 16(3):25–36

Cook S (1973) Production, ecology and economic anthropology: notes toward an integrated frame of reference. Soc Sci Inf 12:25–36

Cussó X, Garrabou R, Olarieta JR, Tello E (2006) Balances energéticos y usos del suelo en la agricultura catalana: una comparación entre mediados del siglo XIX y finales del siglo XX. Historia Agraria 40:471–500

García-Frapolli E, Ayala-Orozco BM, Bonilla-Moheno C, Espadas M, Ramos-Fernandez G (2007) Biodiversity conservation, traditional agriculture and ecotourism in the northeastern Yucatán Peninsula. Landscape Urban Plan 83:137–153

García-Frapolli E, Martínez-Alier J, Toledo VM (2008) Apropiación de la naturaleza por una comunidad maya yucateca. Revista Iberoamericana de Economía Ecológica 7:27–42

Giampietro M (2004) Multi-scale integrated analysis of agroecosystems. CRC Press, Boca Raton

Giampietro M et al (1992) Energy analysis of agricultural ecosystem management: human return and sustainability. Agric Ecosyst Environ 38:219–244

Giampietro M, Bukkens SGF, Pimentel D (1993) Labor productivity: a biophysical definition and assessment. Hum Ecol 21(3):1–32

Giampietro M, Pimentel D (1990) Assesment of the energetics of human labor. Agric Ecosyst Environ 32:257–272

Godelier M (1978) Infrastructures, societies and history. Curr Anthropol 19:763–788

González de Molina M, Guzmán-Casado G (2006) Tras los Pasos de la Insustentabilidad. Agricultura y medio ambiente en perspectiva histórica. Icaria, Barcelona

Grünbühel CM (2002) Applying local material flow analysis in three Amazonian communities. In: Amann C, Bruckner W, Fischer-Kowalski M, Grünbühel CM (eds) Material flow accounting in amazonia: a tool for sustainable development social ecology working paper 63, pp 17–25. IFF Social Ecology, Viena

Guzmán Casado G, González de Molina M (2007a) Transición socio-ecológica y su reflejo en un agroecosistema del sureste español (1752–1997). *REVIBEC* 7, pp 81–96

Guzmán Casado G, González de Molina M (2007b) Agricultura tradicional versus agricultura ecológica. El coste territorial de la sustentabilidad. Agroecología 2:7–19

Guzmán Casado G, González de Molina M (2008) Transformaciones agrarias y cambios en el paisaje. Un estudio de caso en el sur peninsular. In: Garrabouy R, Naredo JM (eds) El paisaje en perspectiva histórica. Formación y transformación del paisaje en el mundo mediterráneo. Zaragoza: Monografía de Historia Rural, pp 199–233 (Sociedad Española de Historia Agraria)
Ingold T (1987) The appropriation of nature. Manchester University Press, Manchester
Krausmann F (2004) Milk, manure and muscle power. Livestock and transformation of pre-industrial agriculture in Central Europe. Hum Ecol 32(6):735–772
Martinez-Alier J (2002) The environmentalism of the poor: a study of ecological conflicts and valuation. Edward Elgar, Cheltenham
Marx K (1913) A contribution to the critique of political economy. Chicago
Marx K (1965) Capital: a critical analysis of capitalist production, vol 1. Progress publishers, Moscow
Marx K (1975) El capital, vol 1. Tomo 1. Siglo XXI Editores, México
Meillassoux C (1960) Essai d'Interpretation du Phénoméne Économique dans les Sociétés Traditionnelles d'Autosubsistance. Cahiers d'Études Africaines, France
Meillassoux C (1972) Exchange, vol 1. Editions de l'Encyclopedia Universales, UK
Terray E (1972) Le Marxisme devant las Societes Primitives
Toledo VM, y Barrera-Bassols N (1984) Ecología y Desarrollo Rural en Pátzcuaro. UNAM, México
Vitousek P, Mooney HA, Lubchenko J, Melillo JM (1986) Human appropriation of products of photosybthesis. Science 277:494–499
Wackernagel M, Rees W (1994) Our ecological footprint. New Society Publishers, Gabriola Island

Chapter 6
Social Metabolism at the Regional Scale

6.1 Introduction

In order to satisfy its needs, P has two extreme and opposite options: obtaining all that is required from ecological interchange, i.e., from TEN, MEN, and CEN; or obtain what is needed only from economic exchange, i.e., from SEN. The former alternative demands adopting a strategy of diversified activities occurring throughout the year as the only possible way of obtaining from the landscape all the materials, energies, water, and services needed for its survival. The latter choice necessarily requires specializing in a single product from its metabolism with nature that is economically valued, thus monetizing P and allowing it to accumulate the necessary capital for the acquisition from the market of all its needs for subsistence (Fig. 6.1).

These two extreme options make P totally dependent on either nature or the market, with all the implications these dependences involve. In real life, although such a dilemma is possible but rather rare in the former case (autarky) and rather frequent in the latter, because the development of an economy based on accumulation of capital induces the specialization of P, and its dependency on commerce. However, an array of situations exists between autarky and dependence depending on a series of factors acting upon concrete cases, and causing continuous changes in the conditions through time.

The preference for a diversified, multiple, or specialized use of nature carries with it different kinds of risks for the P unit, and has different ecological and economic consequences. On one extreme, the diversified use of nature endows P with a higher capacity for resistance against natural uncertainties and surprises, and provides more flexibility and adaptability in front of economic risks. On the other extreme, the specialized use of nature results in higher ecological and economic risks, because it induces a lack of flexibility and diminishes the capacity of P for resilience (i.e., for adapting to unexpected perturbations).

The diversified use of nature is more adequate from the ecological and geographic perspectives, because it is based on, recognizes, and takes advantage of the natural variability of landscapes, vegetation covers, climates, soils, topography and

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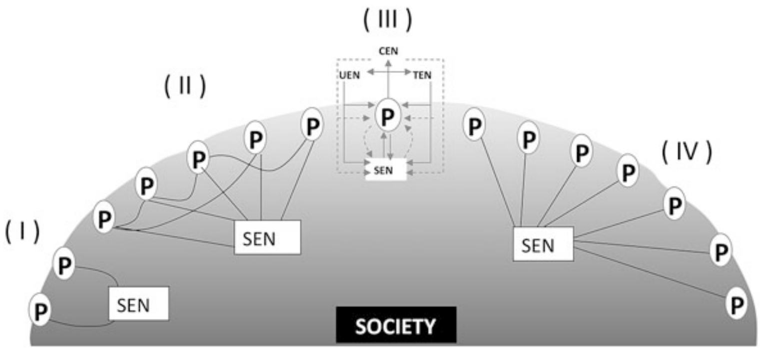

Fig. 6.1 The regional analysis goes beyond the scale of the single *P* unit (*III*) when including the economic interchanges between two units (*I*), between several units—either among them or in a common market (*II*), and between several units integrated in a common market (*IV*)

species that is intrinsic to the ecosystems being appropriated. On the contrary, a specialized strategy suppresses all natural variation of landscapes, vegetation covers, climates, soils, topography and species, transforming the natural space into a *factory floor*, unleashing processes which sooner or later will be reverted against the P unit, and which require of mechanisms of remediation that increase the costs of production. The most evident effect of specialization is what is known as *territorial efficiency*. Given that any landscape maintains a certain composition and structure giving it a territorial equilibrium, productive specialization immediately attempts against such quality (an example can be seen in Marull et al. 2006). In consequence, any strategy of diversified use of nature has a conservationist value, because a landscape mosaic maintains or even increases the number of species (biodiversity), as has repeatedly been demonstrated (e.g., Toledo 2005; Cordón and Toledo 2008).

However, a diversified strategy obstructs the efficiency of an economy dominated by capital, because it hampers massive production of commodities and the advantages of scale in relation to the inputs, instruments, and labor applied for production. There is then an intrinsic contradiction between specialization and flexibility, resilience, and ultimately, permanence.

The above made statements throw light upon the portentous resistance and adaptability of peasant economies—both past and present—that has kept the sector in constant growth. At the global scale, during the past three decades the small, household or communitarily structured producers duplicated their number (Toledo and Barrera-Bassols 2008). Any peasant P unit base their existence in a multiple appropriation strategy integrating and combining small scale agriculture, livestock, forestry, and fishing activities, and include in their strategy a fraction of generation of products or services for their exchange in the market (Toledo 1990). Thanks to that, the peasantry resists, subsists, and recreates itself still in the early twenty-first century and amidst bursting urban and industrial burgeoning (Pérez-Vitoria 2005, 2008).

6.2 Beyond P

Appropriation occurs in a territorial or space matrix having several scales, which makes processes of interest to be articulated in a hierarchical way. Thus, the analysis of the process of appropriation can be made at different scales, each one of these scales being determined and determining the other scales. The scales at which the process of appropriation can be analyzed range from examining a single P unit—delimited by the size of the property of P—to examining all the P units of Earth; i.e., from the *local* to the *global*.

In practice and according to Zonneveld (1995), three main levels can be discerned in the range of spatial scales, each one responding to different spatial heterogeneities. The first one is the *topological* heterogeneity identifiable from a few square meters to several square kilometers (maps at scales up to 1:25,000), essentially revealing vertical heterogeneity including vegetation strata, soils, etc. This is the scale that has been preferred by scholars studying ecosystems. A second level named *chorological* reveals the horizontal heterogeneity resulting from analyzing a series of patches or mosaics of topological units, involving maps at scales from 1:100,000 to 1,000,000, and being equivalent to the regional or hydrological catchment levels. Finally, the *geospheric* scale refers to global processes and is expressed in maps at scales of several tens of millions.

6.3 The Regional Scale

The flow model we have defined and described allows for analyzing the process of appropriation at the first and second scale levels, a range determined by the size of the property including the ecosystems/landscapes under appropriation, and that can be gradually expanded as new P units are added to the analysis. The articulation of several P units from a given territory, for instance a number of households from a rural community, allows for arriving to the next level, and to the connection through economic interchanges of several rural communities within a municipality or region will enable the regional analysis (Fig. 6.2).

In practice, as the analysts moves along the different scales—or the different levels of aggregation of P units—distinct configurations of the metabolism between P and SEN make their appearance in the concrete territories, and a variety of ecological and economic interactions with their consequent synergies are revealed. Also revealed are the causes and effects motivated by processes at the different scales in a double direction: towards larger scales, and towards smaller scales.

Each one of the scales offers the possibility of cartographic representation of the process of appropriation, which can also be made incorporating a historical perspective by the diachronic expression of space (see examples in González de Molina and Guzmán 2006; Olarieta et al. 2006; Marull et al. 2006). Overall, the

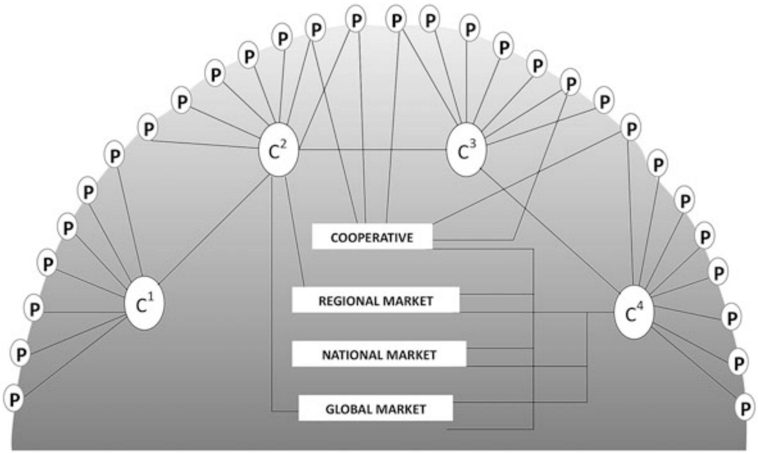

Fig. 6.2 Hypothetical example of a multi-scalar analysis in which the economic interchanges made by several *P* units (households) within the communities they belong to (C1–C4), a cooperative, or the regional, national, and global markets

flow model that is proposed at a given scale becomes amplified and enriched as the researcher opens his scope across the contexts of territory and their dynamics through time. The above involves the expansion of the spatial—geographic—and social ranges of the analysis of social metabolism, its connections and its synergies. In this regard, the studies of Eric Tello and his interdisciplinary group is of special interest, their perspective combines the analysis of energy and material flows (social metabolism) with the study of land cover and land use changes environmentally evaluated using the metrics and indices of landscape ecology. For landscape ecology, landscapes are a territorial expression of a determined social metabolism and, in consequence, the territorial efficiency results from the synergy established between the energy and mater flows, and the ecological dynamics of the landscape (Tello 2013).

6.4 The Regions: The Study of the Metabolic Interlock

Expanding the scale—say to a region encompassing rural communities, urban nuclei, and industrial centers—not only allows for spatially widening the analysis of appropriation, but also reveals the *metabolic network*, which means making a comprehensive study of all the metabolic chain within a delimited territory (such as a basin or an economic region). It is studying rural, urban, and industrial metabolism in an integrated way and in a regional space that is determined by one or several criteria (Baccini and Brunner 2012).

The study of social metabolism at the regional scale allows for understanding the synergies and dynamics established between particular processes of appropriation, circulation, transformation, consume, and excretion. The analysis implies identifying not only the P units, but also the units in charge of circulation and transformation of what is appropriated or produced by P, and of the nuclei of rural, urban, and industrial consumers of what is produced, circulated, and transformed. Finally, the analysis can also detect the flows that end up being excreted towards nature by the above-mentioned processes in the form of residues, wastes, compounds, and emissions.

The study of the metabolic network then assumes the identification of material flows throughout the complete metabolic chain, and exploring the dynamics generated between the units holding such flows. As can be expected, at the regional scale the level of complexity of processes reaches a complexity such as to become a challenge for investigators, which forces either increasing the number, disciplinary variety, and quality of research teams, or focusing the analysis in one or a few products of the total flow—for instance, water, compounds, fuels, foodstuffs, raw materials, etc.

The study of the metabolic network at the regional scale is to become an enormously valuable unit of analysis, whose aggregation provides understanding territorial metabolic dynamics occurring at different scales, and to deconstruct macro or multiregional synergies that due to their complexity are difficult to understand or are beyond research efforts. Concatenation of regional metabolism will in turn reveal new phenomena whose next limit is delimited by national borders.

6.5 Bosawás: Metabolic Analysis of an Indigenous Region

Lets turn to a study case in the Biosphere Reserve of Bosawás (BRB) in Nicaragua that covers nearly 8,000 km^2 and is populated and surrounded by nearly 30,000 inhabitants belonging to indigenous nuclei—from the *Miskita* and *Magyanga* nations extending through a large part of the Atlantic coast of Nicaragua and Honduras—and to households of mestizo colonizers (Stocks et al. 2007). Six indigenous territories surround the BRB (Fig. 6.4), and in one of them called *Kipla Sait Tasbaika* (KST)—meaning "territory of the rapids," a study was made of the metabolic flows (Cordón and Toledo 2008; Cordón 2011). The territory of the KST includes fourteen indigenous communities, of which twelve are Miskita and two Magyanga (Fig. 6.3).

The research was based on data from enquires made to household members in the KST territory. Two enquires were made, one in April of 2003, and another one in August of 2004, and in both data about the use of natural resources were gathered from visited households. A total of 606 households with a total population of 3,928 people was visited in 2003, and 390 households with 2,733 inhabitants were visited in 2004, corresponding to 83.6 % and 58.2 % of the total

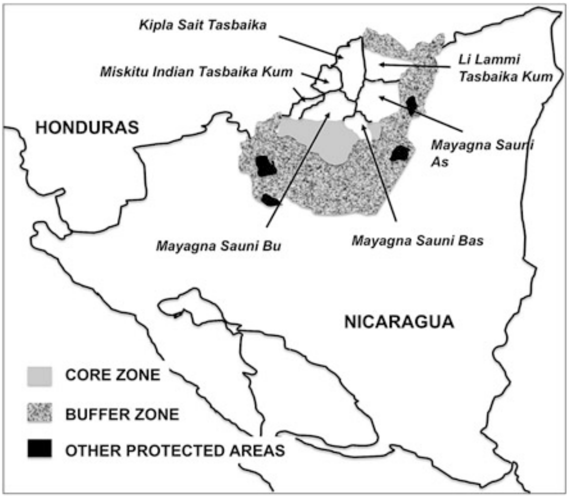

Fig. 6.3 Distribution of indigenous settlements in the Biosphere Reserve of Bosawás in the border between Nicaragua and Honduras

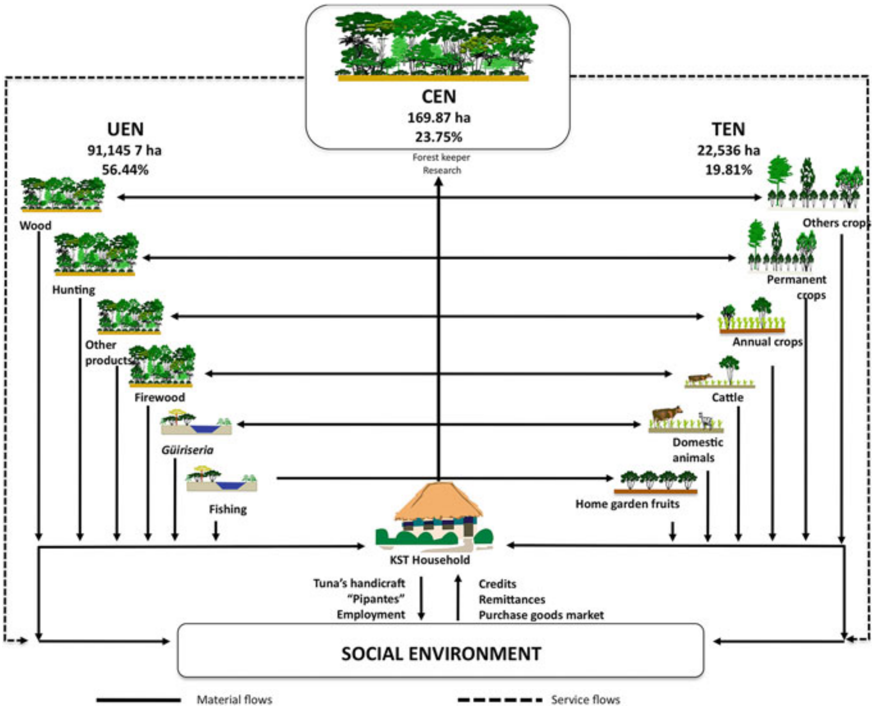

Fig. 6.4 Flows of goods and services in the communities of the Kipla Sait Tasbaika (KST) region in Bosawás, Nicaragua

population of the KST, respectively. In order to obtain profiles of the metabolic flows of the micro-region, average values were recorded for all the communities in the studied territory (for details see Cordón and Toledo 2008).

The data gathered from enquires were arranged following the flow model herein developed (Fig. 6.4). The model allowed for identification of six activities related to the MEN (hunting, fishing, gathering of firewood, lumber and other products, and gold extraction), six activities related to the TEN (three types of agriculture, grasslands, livestock raising, and fruit gathering in door gardens), and two activities related to the CEN (assistance to researchers, and vigilance in the reserve), and flows of economic exchange with the SEN (Fig. 6.4).

The analysis of value of each activity measured as the percentage of households that practice them revealed the total strategy adopted. Although the data gathered about the material and energy flows were qualitative, patterns of combined activities were detected. Four activities make up the basis of most households and communities:

94 % of households practice agriculture, extract firewood, and gather fruit in the home garden, and 86 % also raise livestock. To these food and energy platform are added hunting and fishing (nearly 71 %) or only fishing (64 %). All other activities have a minor relevance because they are focused more to commercial trade, so that some households extract gold, and others hunting or gathering. The emerging pattern of natural resource management is that of a typical *subsistence economy*.

The evaluation of this strategy in relation to spatial patterns of resource use reveals correlations of great interest. Of the six indigenous territories surrounding the reserve, the communities in the KST had the lowest deforestation impact (Stock et al. 2007), with a *per capita* deforestation of 0.09 ha a figure contrasting with that of the remaining indigenous communities, and in particular with mestizo settlements, having much higher deforestation rates.

References

Baccini P, Brunner PH (2012) Metabolism of the Anthroposphere. The MIT Press, Massachusetts

Cordón MR, y Toledo VM (2008) La importancia conservacionista de las comunidades indígenas de la reserva de Bosawás, Nicaragua: un modelo de flujos. Revista Iberoamericana de Economía Ecológica 7:43–60

Cordón MR, (2011). *Estrategias indígenas, conservación y desarrollo rural sostenible en la reserva de la biosfera de Bosawas, Nicaragua*. PhD. dissertation. Universidad Internacional de Andalucía, Spain

González de Molina M, Guzmán-Casado G (2006) Tras los Pasos de la Insustentabilidad. Agricultura y medio ambiente en perspectiva histórica. Barcelona, Icaria

Marull J, Pino J, Tello E, Mallarach JM (2006) Análisis estructural y funcional de la transformación del paisaje agrario en el Vallés durante los últimos 150 años. *Áreas (Revista Internacional de*. Ciencias Sociales 2:105–126

Olarieta JR, Rodríguez-Valle, FL. Tello E (2006). Conservando y destruyendo suelos, transformando paisajes (el Vallés, Cataluña, 1853–2004). *“Áreas (Revista Internacional de Ciencias Sociales)”* 25, 39–66
Pérez-Vitoria S (2005). *Les Paysans son de Retour*. Actes Sud Papier, Paris
Pérez-Vitoria S (2008). *La Riposte des Paysans*. Actes Sud Papier, Paris
Stock A, McMahan B, Taber P (2007) Indigenous, colonist, and government impacts on Nicaraguás Bosawas Reserve. Conserv Biol 21(6):1495–1505
Tello E (2013) La transformació històrica del paisatge entre l’economia, l’ecologia i la història: podem posar a prova la hipòtesi de Margalef? Treballs de la Societat Catalana de Geografia 75:195–221
Toledo VM, y Barrera-Bassols N (2008) La Memoria Biocultural. La importancia agroecológica de las sabidurías tradicionales, Barcelona, Icaria
Toledo VM (1990). The ecological rationality of peasant production. In: Altieri M, Hecht S (eds) Proceedings agroecology and small farm production CRC Press, USA
Toledo VM (2005) La ecología rural. Ciencia y Desarrollo 174:36–43
Zonneveld IS (1995) Land Ecology. SPB, Academic Publishing, Amsterdam

Chapter 7
Social Metabolism at the National Scale

7.1 Introduction

Regarding material exchanges and flows, every Nation State (N) ultimately functions in the same way as a unit of appropriation/production (P), which means N reproduces the same operational processes of P, but at an exponentially higher scale. At the national scale, within the territory of each unit of N, material (produce, forest products, crops) and energetic (foodstuffs, organic fertilizers) inputs are obtained from domestic extraction of resources, whose flow can be divided in proceeding from each of the following three classes of environment: Utilized Environment (UET), Transformed Environment (TET), and Conserved Environment (CET). The input flow of N is the result of the sum of all the input, circulation, transformation, and excretion flows from every P within its national territory.

The study of social metabolism at the national scale magnifies a new flow. Given that inside the *entrails* of a country commodity and service flows—derived from the appropriation of an ensemble of P units settled within the national territory—circulate, become transformed in multiple ways, and are consumed away from their original location by a huge number of individuals or by sectors, gives place to a process that at the metabolic level of P remained unidentifiable or reduced to its minimum expression: excretion.

The fact is that the metabolic network generating at each segment a flow of wastes that end up circulating in the natural universe, is finally enclosed by the general metabolic circuit between society and nature through the excretion of water, materials, and energies, which must be assimilated, i.e. recycled, by the ecosystems. The three types of environments (UET, TET, and CET) receive the totality of the excretion flows occurring within N, thus conforming its output. In theory, it should be possible to define excretion units (E), a task that seems impossible given the enormous variety of waste emitting sources.

Since no country exists that continues to reproduce its metabolism without some sort of exchange occurring beyond its borders, to the P and N flows must be added those between other Nation States. Because of that, every nation (N)

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receives commodities and services through commercial exchanges with other countries of the world, which in turn exchange commodities and services generated within their own territories (import and export; Fig. 7.1).

7.2 Metabolic Profiles at the National Scale

There are over 50 indicators of the material and energy exchanges between countries that are easily accessed from recognized sources of data and statistics (Table 7.1), such that it is possible to acquire figures for the four main exchange flows between natural areas (ecosystems) occurring within the territories of any nation (input and output), and between any of the remaining countries in the world (imports and exports). To these data, information can be added about surface areas and characteristics of the UEN, TEN, and CEN, in both terrestrial and marine national territories, together with essential demographic data: national, rural, urban, agroindustrial, and traditional population numbers, among other.

With the above data it is possible to draft basic metabolic profiles for a given country (see the example of China in Fig. 7.2), from which a pattern analysis can be made both of factors as between countries. These four exchange flows (input, output, imports, exports) provide an initial overview of the situation of each country regarding both its natural base (the ecosystems providing materials, energies, and services, and assimilating wastes), and their commercial exchange with the rest of the world. The accelerated growth of world commerce during the last decades (even above the levels of production growth), especially between countries in Europe, North America, China, South America, and southern Asia—leaded by Japan—is a highly relevant phenomenon (see Schandl et al. 2009).

A study of *global metabolism*—i.e., of the international concert—must then begin with an analysis of the main four exchange flows, locating each country within the World-system (Fig. 7.3), or in other terms, within the geo-eco-political space of the central, semi-peripheral, and peripheral geometry that is now acquiring a new dimension when being articulated with ecological or natural phenomena (Jorgenson and Pick 2003; Frank 2007). This means not only identifying the parameters, patterns, and processes of exchanges, but also identifying the realms of both the metabolic processes, and of the dimension determining them, such as demography and its dynamics, the relations between rural and urban populations, self sufficiency and alimentary dependence, flows of commercial exchange, flows of water, CO_2 and other gases, energy, and wastes, *per capita* and national values, materials, etc.

Four indicators of value at the national level are: the gross domestic product (GDP), its disaggregation by economic items or sectors, the energies used, and the volumes of emitted gases. The metabolic profile allows for ordering and interpreting from a different perspective all of the numerous national statistics that are currently available. Arriving to national indexes reflecting precise procedures regarding exchanges both between domestic nature and resources, and between other countries, is a pending task. These national analyses should in turn be

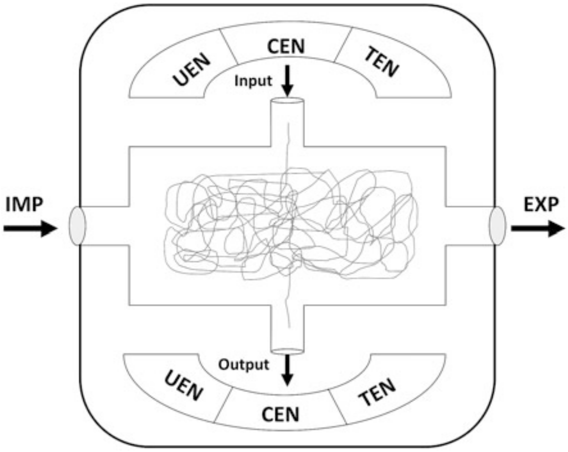

Fig. 7.1 Diagram representing the metabolism of a Nation State, which depends on exchanges of resources within its own territories (inputs and outputs), and exchanges made with other Nation States (imports and exports). Abbreviations *UEN* utilized environment, *CEN* conserved environment, *TE* transformed environment, *IMP* imports, *EXP* exports

interpreted and compared with other indexes such as the Ecological Footprint Index, the Human Wellbeing Index of United Nations Educational, Scientific and Cultural Organization (UNESCO), the Human Appropriation of Net Primary Production (HANPP) (or of the products of photosynthesis), among other indicators.

7.3 A Study Case: The Spanish Agriculture

Despite its distinctive characteristics, the Spanish agriculture shares similar issues with other agricultures of developed countries (Moore 2010). Spanish agriculture is immersed in a profound structural crisis caused by the model of agricultural expansion itself, which has linked the income of farmers to an increasing productive effort. The origins of the crisis can be found in the continued decay of the exchange relation with the sector of urban industry, and hence, of the agricultural input in comparison with the remaining economic activities. This deterioration has forced the State to subsidize agriculture through the European Common Agricultural Policy. Dependency has been dramatically enhanced, today representing nearly one third of the agricultural income. The lack of profitability of agricultural and animal husbandry activities has favored farmland abandonment by many farmers, an appreciable decrease in employment, and a forced increase of part time activity. From the nearly three million farms existing in 1962 (INE 1962), by the year 2009 this number had decreased to little over one million (INE 2009), and the agricultural assets have diminished in a proportional ratio, from 3.7 millions in 1970 to somewhat over one million at the present, of which only two thirds are occupied.

At the same time, the cultivated surface has decreased in over three million hectares (−17%), while the abandonment and depopulation of rural areas is becoming a concerning phenomenon. Of the 326 regions in which the Spanish territory is divided (*comarcas*), 138 concentrate 90 % of the population.

Table 7.1 Indicators of the material and energy exchanges between countries

Indicators	Unit	Sources	Table and column
Social (economic)			
1. Gross domestic product (GDP)	MUSD	WRI	5-1
2. Per capita GDP	MUSD	WRI	5-3
3. Agricultural GDP	MUSD	WRI	5-4
4. Industrial GDP	MUSD	WRI	5-5
5. Services GDP	MUSD	WRI	5-6
9. Agricultural economically active population	Numbers	FAO	Variable
10. Agricultural GDP (men)	Numbers	FAO	Variable
11. Agricultural GDP (women)	Numbers	FAO	Variable
12. Total GDP	Numbers	FAO	Variable
Social (demographic)			
13. Total population	Numbers	SYB	Table A-1
14. Percentage of urban population	%	FAO	Variable
15. Urban population	Numbers	FAO	Variable
16. Rural population	Numbers	FAO	Variable
17. Rural population in organic production	Pop	IFOAM	Variable
18. Rural agro-industrial population	Pop	SYB	Holdings <10 has
19. Rural traditional population	Pop	SYB	Holdings >10 has
20. Number of fishers	Pop	WRI	9-14
Input (appropriation)			
21. Total agricultural production	TMT	FAO	A-3
22. Total meat production	TMT	FAO	B-2
23. Cereal production	TMT	FAO	B-1
24. Fruit and vegetable production	TMT	FAO	B-3
25. Total energy production	MTOE	IEA	1-1
26. Per capita consumption of water	m^3/ha/year	WRI	9-2
27. Food energy consumption	TMT	FAO	D-1
28. Total annual extraction of water	km^3	WRI	9-3
29. Per capita annual extraction of water	m^3	WRI	9-4
30. Annual extraction of water for agriculture	m^3/ha/year	WRI	9-5
31. Annual extraction of water for industry	%	WRI	9-6
32. Annual extraction of water for homes	%	WRI	9-7
33. Total fished volume	TMT	WRI	9-9
34.Total fished product from aquaculture	TMT	WRI	9-11
35. Total primary energy supply (TPES)	MTOE	IEA	1-11
Output (excretion)			
36. Total production of gases	MMT	WRI	8-13
37. Production of CO_2	MMT	WRI	8-1
38. Production of methane	MMT	WRI	8-10
39. Production of nitrous oxide	MMT	WRI	8-11

(continued)

Table 7.1 (continued)

Indicators	Unit	Sources	Table and column
40. Production of fluorinated gases	MMT	WRI	8-12
41. Per capita production of CO_2	MMT	WRI	8-3
Imports			
42. Fishery products	MUSD	WRI	9-12
43. Energy	MTOE	IEA	1-11
44. Food	%	SYB	C-6, Vol. 1
45. Value of agricultural imports	MUSD	SYB	Vol. 1
46. Fuels and derivatives	MUSD	WTO	Several
47. Manufacturing industry	MUSD	WTO	Several
Exports			
48. Fishery products	MUSD	WRI	9-13
49. Energy (Thousands of metric tons)	MTOE	IEA	1-11
50. Food	%	SYB	Vol. 1/Col. 6
51. Value of agricultural exports	MUSD	SYB	Vol. 1
52. Fuels and derivatives	MUSD	WTO	Several
53. Manufacturing industry	MUSD	WTO	Several
Ecological			
54. Total surface	Km^2	CIAWF	Per country
55. Total surface of natural protected areas	Km^2	WRI/WDPA	10-1
56. Total surface of natural protected areas	%	WRI/WDPA	10-2
57. Arable land surface under permanent cultivation	%	WRI/WDPA	11-6
58. Grassland surface	%	WRI/WDPA	11-8

MUSD millions of dollars, *Pop* population, % percentage, *TMT* Thousand of metric tons, *MTO* Millions of metric tons oil equivalent, Km^2 square kilometer, Km^3 cubic kilometer, Km^2 square meter, *MMT* millions of metric tons. *Sources FAO* Food and Agriculture Organization: www.fao.org, *WRI* World Resources Institute: multimedia.wri.org, *WDPA* World Database on Protected Areas: www.unep-wcmc.org/wdpa/, *SYB* Statistical Yearbook, World Census of Agriculture. FAO. Statistical Development Series No. 9. Par II. (www.fao.org); *IEA* International Energy Agency: www.iea.org, *IFOAM* International Federation of Organic Agriculture Movements www.ifoam.org, *CIAWF* The CIA World Factbook: www.cia.gov, *WTO* World Trade Organization http://stat.wto.org

The remaining regions have population densities lower than ten inhabitants per square kilometer, a figure indicating a critical demographic situation (INE 2009). Agricultural activities have an increasingly lower weight among rural population (a process known in Spanish as *desagrarización*). The outcome of this process is that the generational replacement is being compromised, because the average age of farmers exceeds 55 years.

In parallel, Spain consumes a net daily average of 3,405 kcl, with a 27.4 % increase since the 1960s (Schmidhuber 2006), a diet involving the abandonment of the Mediterranean good habits and the acquisition of dietary habits that have been responsible for 41 % of the population being overweighed. The feeding habits of the Spaniards—and also of third party countries—is today one of the main causes

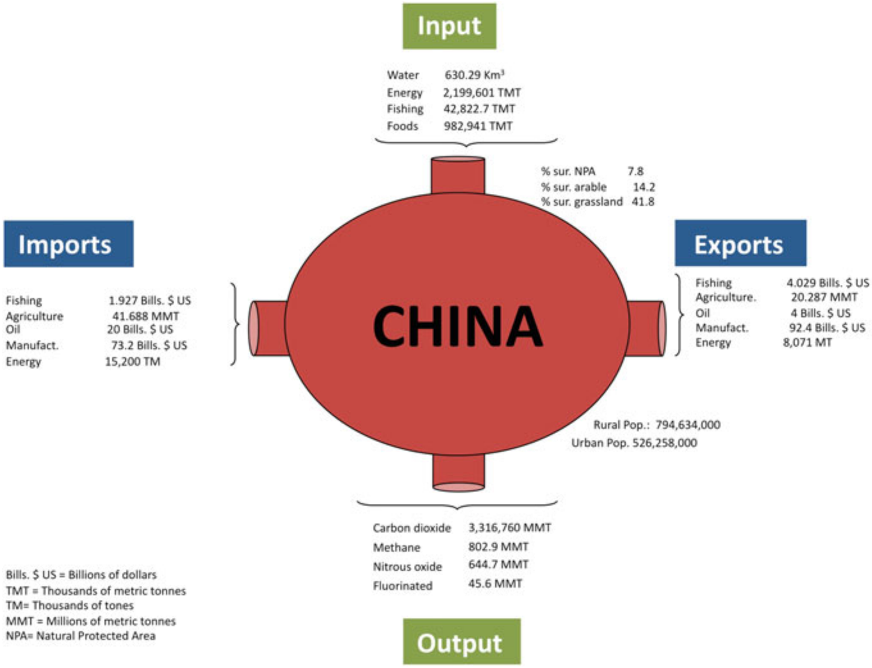

Fig. 7.2 Using the statistics of sources included in Table 7.1, a schematic metabolic profile of China is presented (see text)

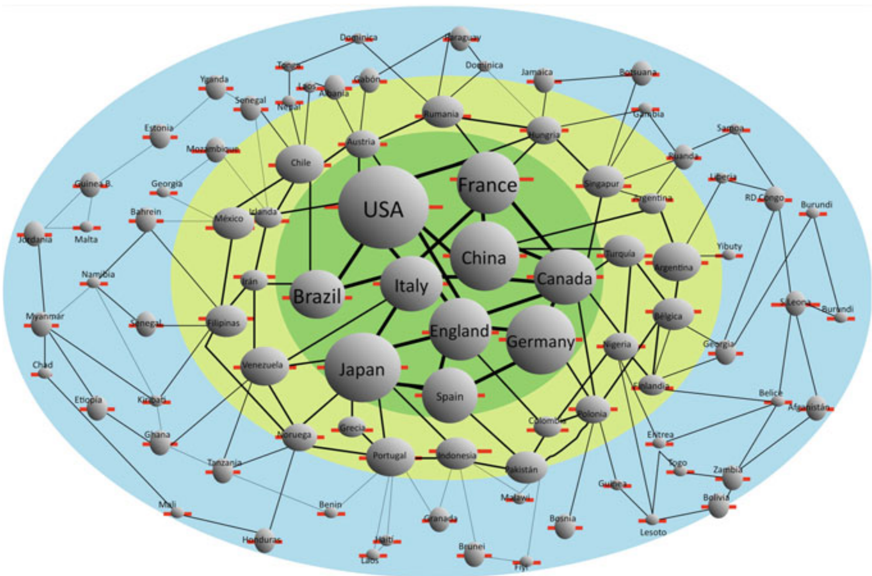

Fig. 7.3 Visualized each country as a unit interchanging with nature and among them, the planet resemble a swarm resulting from a global network

of unsustainability in terms of human and ecosystem health. The above-mentioned consumption volume requires 109 million metric tons of animal and plant biomass, equivalent to 2.43 metric tons per person per year, or 6.65 kg/person/day (Infante and González de Molina 2013). The primary energy consumption of the agrifood system that makes this consumption rates possible was of 1,408 PJ in the year 2000, representing 26.87 % of the total consumption of 5,240 PJ. One third of this energy budget corresponds to the agricultural sector itself. For each energetic unit consumed as food, over six energy units are used for its production, distribution, transportation, and preparation. The inefficiency of the food production process mirrors its unsustainability. Each food item consumed hides behind it a history of multiple energy and material consumptions, gas emissions, or unequal forms of economic exchange turning feeding into a process loaded with social and environmental impacts. Spanish agroecosystems suffer from severe problems, among which are: overexploitation of water resources, pollution of water with nitrates and pesticides (European Commission 2013), high rates of erosion (Gómez and Giráldez 2008), a worrying loss of biodiversity, and others (Garrido 2012).

7.4 Some Indicators of Spanish Agricultural Growth

But, how was this point reached? The present situation has been the consequence of the process of industrialization of Spanish agriculture. We analyze the evolution of agrarian metabolism during the twentieth century and identify different stages in the industrialization of Spanish agriculture from the physical point of view. Our analysis attempts to exemplify the usefulness of the metabolic approach at the national scale. With this analysis, we intend to understand the most relevant driving forces and learn from the past for designing the future transition to a more sustainable food system. To do that, we have used the Material Flow Analysis (MFA) (Schandl et al. 2002; Giljum 2006; Risku-Norja and Mäenpää 2007), but adapted to the agricultural sector together with some suggestions made by Giampietro (2003) and by Ramos-Martín et al. (2009). All the collected data have been processed according to the most recent developments in the use of this methodology made by Krausmann et al. (2008a, b), Muñoz et al. (2009), Krausmann et al. (2009), and specially by Fischer-Kowalski et al. (2011).

The usefulness of the biophysical analysis for knowing the function and evolution of the Spanish agricultural activity—having such a high social and environmental relevance—can be appreciated in contrast with the traditional monetary approach. Figure 7.4 shows the evolution of the Spanish agricultural sector expressed as monetary income. The value of the final agricultural production (FAP) at constant 1995 prices was multiplied by nearly 5.3 between 1953 and 2009, peaking in the year 2003 when the value of FAP was nearly six times that of 1953. In 1953, Spain was still suffering the atrocious agricultural policies of the Franco dictatorship; hence the volume of agricultural production was lower than it was 20 years earlier during the second Spanish Republic. Despite that, the figures

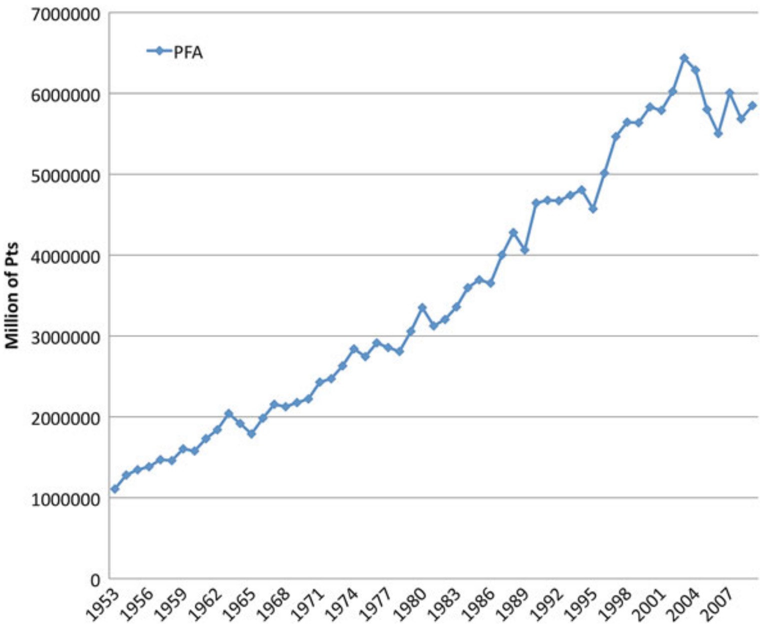

Fig. 7.4 Evolution of final agricultural production in Spain (in 1995 pesetas). *Source* Spanish Ministry of Agriculture. Agricultural Statistics

show a spectacular growth attributable to the application of the Green Revolution technology, i.e., to the economic effects of the industrialization of agriculture.

As mentioned above, at the national scale it is required to process a large amounts of statistical data published by the Nation States, which in a few countries began to be compiled during the late nineteenth century, but that became widespread after Second World War. In the present case, the analysis required to gather and analyze Spanish agricultural statistics that are neither homogeneous nor complete for the whole period. Annual production series are available of the production of plant biomass—cereals, legumes, grape, and olive—beginning in the late nineteenth century and until the 1930s, but data about total agricultural production is only available from 1922, and disaggregated per year from 1929. Previously, the missing information was reconstructed from complementary sources, namely the annual memoirs published about assorted topics by the *Junta Consultiva Agronómica*. Thus, the Spanish agricultural production has been estimated for three moments: 1900, 1910, and 1922. From 1929, annual series of agricultural production have been published—since 1929 in the *Anuarios Estadísticos de las Producciones Agrícolas* and since 1972 in the *Anuarios de Estadística Agraria* (available online from the virtual library of the Ministry of Agriculture at http://www.magrama.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/). Also considered were 5 year averages with centers in the years 1933, 1940, 1950, 1960, 1970, 1980, 1990, 2000, and 2008. Also using 5 year averages, the exports and imports of biomass were calculated from foreign trade sources. From such sources, the quantity and evolution of biomass of the Spanish economy were calculated. In addition, based on the same sources cited above, the level of appropriation of grasslands (based on the feeding needs of herds and current data of their use) and forests (Infante et al. 2013) was also calculated. Details of the analysis can be found in González de Molina et al. (2014).

7.5 The Utility of Metabolic Analysis

A monetary analysis shows only part of what has happened while hiding the socio-ecological costs, i.e., it is necessary but insufficient. The biophysical analysis is of particular usefulness for explaining how the current unsustainability situation was reached to. Figure 7.5 shows the evolution of biomass production by the Spanish agriculture sector between 1900 and 2008 expressed in megatons of dry matter. The data show in physical terms that the domestic extraction of biomass grew at a moderate rate throughout the twentieth century, contrasting with the monetary growth.

While in monetary terms the agricultural production nearly sextuplicated, in monetary terms it grew only 44 %; a figure similar to that experienced in the former Czechoslovakia (Kuskova et al. 2008). Although the total domestic extraction increased by 74 %, a considerable percentage of this extraction has been progressively stopped being used and abandoned or destroyed. By prioritizing that portion of the agricultural activity that is directly related to markets, a considerable amount of useful agricultural residues remain unaccounted for or are given a very low value, thus the monetary account overestimates growth.

In fact, the evolution of the Spanish agriculture during the last century can be considered as a process of growing commoditization of production and of the factors that make it possible. The technological and productive efforts were oriented towards maximizing the portion of biomass having higher market value and mobility, reducing the multifunctionality of crops. As shown in Table 7.2, the domestic extraction of crops grew considerably between 1900 and 2008 (by 353 %), while agricultural residues lost weight relative to the bulk yield of crops, particularly in the biomass of grasses that are currently abandoned. In other words, the growth of agricultural production did not correspond to an equal increase of total biomass extracted from Spanish agroecosystems, but only of the portion having high market values.

At the same time, since the 1960s the livestock production had a considerable growth while it changed its composition to meet the increasing demand of meat and dairy products of the Spanish population (Fig. 7.6). However, such expansion was not sustained by Spanish agroecosystems, instead, since 1970 the abandonment of croplands and grasslands has acquired worrisome proportions. This abandonment process was related to the low profitability of extensive livestock production and the fall of fodder prices. Thus the growth of Spanish livestock production—mostly intensive and practiced on small land surfaces—depended on

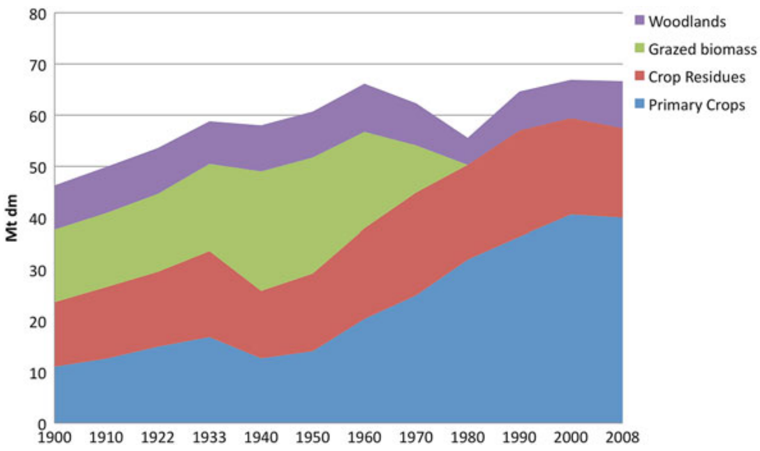

Fig. 7.5 Evolution of domestic extraction of biomass (Mt)

Table 7.2 Basic data of biomass production in Spanish agriculture between 1900 and 2008 (megatons of dry matter)

	1900	1933	1950	1970	1990	2008
Vegetal biomass						
NPP actual	127	132	132	161	175	193
Unused biomass	1	3	2	1	11	16
D E* (used)	46	59	61	62	65	67
D E* (total)	48	62	62	63	76	83
Primary crops	11	17	14	25	36	40
Crop residues	13	17	15	20	21	17
Grazed biomass	14	17	23	9	0	0
Woodlands	9	8	9	8	8	9
Imports	0,8	1,0	0.5	5.3	14.6	34.7
Exports	0,4	0.4	0.3	1.6	6.0	13.0
Domestic consumption	46,7	59.4	60.9	66.1	73.2	88.3
Feed	27	36	38	36	36	35
Seeds	0.6	0.9	0.7	1.0	1.1	1.3
Food	6	9	7	11	14	16
Industry and others	12	12	14	13	13	45
Animal biomass						
Food	0.34	0.54	0.55	1.42	2.81	4.04
Industry and others	0.02	0.03	0.02	0.02	0.02	0.02
Manure	10	17	19	19	24	27

Source González de Molina et al. (2013)
* Domestic extraction

massive imports of cereals and legumes (or even processed animal foodstuff) for feeding livestock. This fact explains why the domestic extraction and biomass consumption (domestic extraction minus imports) have displayed a divergent

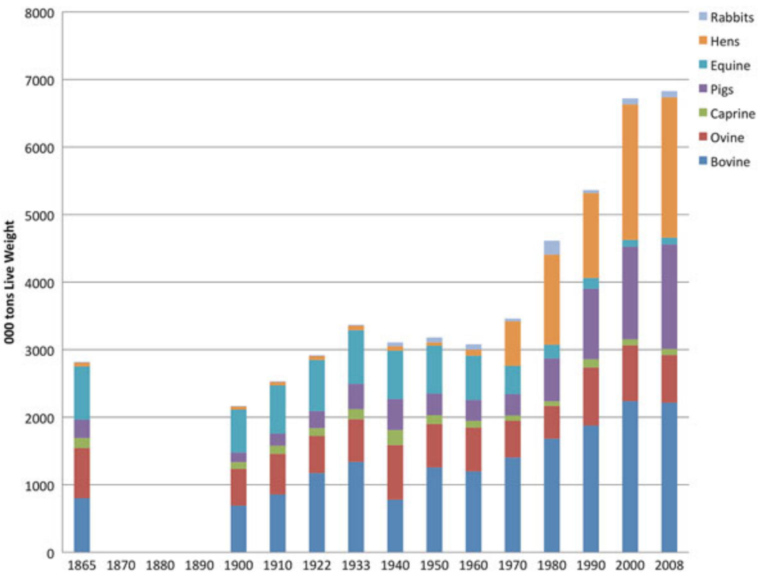

Fig. 7.6 Evolution of livestock production in Spain between 1865 and 2008 (metric tons of live weight)

evolution and a decoupling trend. As seen in Table 7.2, until 1970 the domestic extraction and consumption remained closely linked, but since that year the role of imports became increasingly important, such that by 2008 the net balance of foreign trade of biomass amounted to 23 % of the domestic consumption (imports reaching up to 37 %; Fig. 7.7).

Contrary to what is told by the economic history—based on monetary data—Spain was never a net exporter of biomass. In fact, foreign trade played a rather modest role in the evolution of the Spanish agricultural sector until the late 1970s. As a consequence of the globalization process, foreign trade became a key factor of the Spanish food and agriculture sector: on one side it enabled the specialization of Spanish agricultural products (oil and horticultural and fruit products) to enter the international markets, particularly European; and on the other side, it allowed for sustaining the growing consumption of meats and dairy products of Spaniards, supplying an important percentage of animal foodstuffs (Fig. 7.7). In fact, the current availability in Spain of animal foodstuffs exceeds the demand, given that an appreciably amount of biomass from grasslands and crop residues that is potentially useful for feeding animals remain unused, abandoned or destroyed. This is revealing a loss of efficiency and a waste of animal foodstuffs similar to that described for human food products (Stuart 2011).

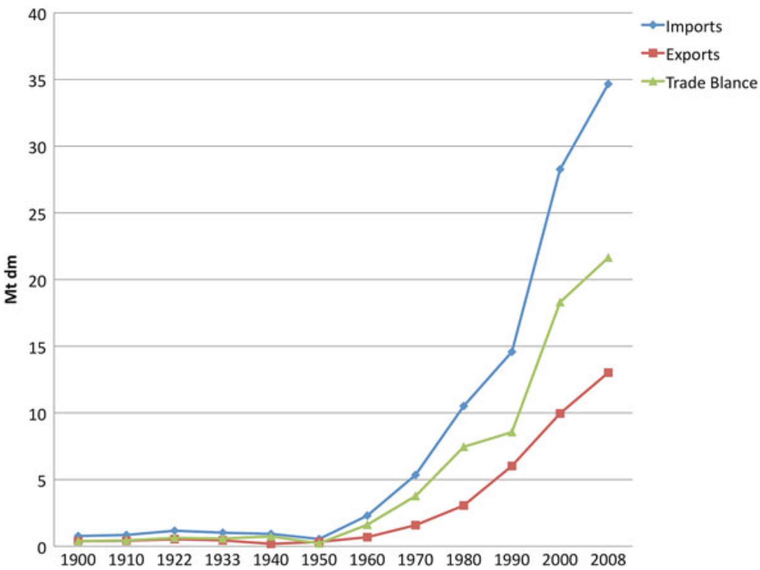

Fig. 7.7 Trade in Spain of plant biomass between 1900 and 2008 (Mt of dry matter)

7.6 Four Phases of the Industrialization Process

The behavior of the metabolism of biomass in twentieth century Spain allows for distinguishing four main phases in the process of industrialization, one of them being specific for Spain (the dictatorship of Franco), but many European countries probably sharing others. The first phase took place between 1900 and the Spanish Civil War (1936–1939) and was characterized by a parallel growth of domestic extraction of crops, pastures, and forest products. During this phase, the traditional competition between land usages that had been characteristic of the agrarian sector during the nineteenth century was disrupted when the expansion of crops took place at the expense of pastures and forests (Garrabou and González de Molina 2010). This enabled the expansion both of croplands and livestock herds without appreciably decreasing the net primary productivity of forests or grasslands. The expansion of irrigated croplands and the introduction of chemical fertilization, particularly of phosphates (Fig. 7.8), explain this phenomenon. Along the first third of the twentieth century the availability of phosphorous was increased, but despite the growth of livestock herds, phosphorous from chemical fertilization exceeded that from organic sources (i.e., organic fertilizers and manures), which with a relatively small supply of chemical inputs allowed for a considerable increase of the domestic extraction of plant biomass.

A second phase is unique to the Spanish case and reflects the damage brought about during the first decades of the Franco dictatorship (the *Autarkic* period). During this period the situation reversed to that during the late nineteenth century, but without any possibility of integrating the different land usages. The fall in

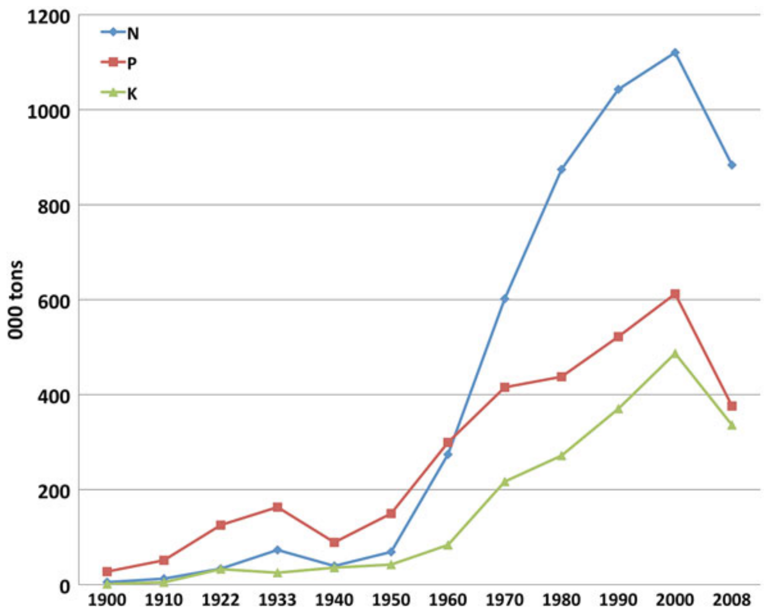

Fig. 7.8 Evolution of the consumption of chemical fertilizers in Spain between 1900 and 2008 (metric tons)

consumption of chemical fertilizers lowered agricultural production (domestic extraction of croplands). Famine was physically manifest and there was a drastic drop in agricultural income. The livestock production further required natural pastures, human appropriation of pasturelands reaching the maximum values of the century. The resulting impact on food consumption was demolishing, creating an unprecedented food crisis (González de Molina et al. 2013).

The third phase was coincident with the process of industrialization linked to the adoption of the innovations proposed by the Green Revolution and the massive application of industrial inputs.

This period that has been thoroughly described by historiography was a period of quantitative and qualitative changes. From the standpoint of restoration of the soil fertility, chemical nitrogen fertilizers that before the Civil War were much less relevant than phosphate fertilizers, acquired a foremost importance and generated issues of over fertilization and nitrate pollution. A substantial portion of the agricultural growth was based on commercial biomass. Part of such expansion is explained by genetic transformations introduced by the Green Revolution, but is also accounted for by the decrease in use of crop residues. For example, the industrialization of agriculture was accompanied by replacement of traditional cereal and legume varieties—of which fodder was an essential component of animal foodstuffs—by long-stemmed, high grain yield varieties in which grain yield offsets fodder production. Simultaneously, in parallel with the lowering of fodder prices, the more important contribution of monogastric livestock, and the virtual disappearance of animal traction, an increasingly higher proportion of hay ended up being burnt or left to lie on the land.

The last phase could perhaps be considered as a new stage of agricultural development, or post-industrialized agriculture, and reflects the globalization of the food system. This phase has lasted since the early 1980s and until nowadays. The most striking feature of this phase is the decoupling of biomass consumption from the agroecosystems, i.e. the domestic consumption of domestic extraction. It is also characterized by a new phase of growth of food production due to an unequal ecological exchange; that is, thanks to the massive importation of food and feed. The same situation occurred in the Swedish agriculture (Saifia and Drakeb 2008) and appears to be also happening in most European agricultural systems (Weisz et al. 2006; Witzke and Noleppa 2010; see Fig. 7.9). The consequences have been a release from the pressures exerted over the territory by the spectacular growth experienced since the 1970s in the total input of biomass of the Spanish economy, which at present has nearly been doubled. Such pressures have been transferred to third party countries, mostly from Latin America. Especially important in this period is the rapid fall of the human appropriation of pasture and an increase in the previously unknown general inefficiency of agricultural metabolism (abandonment of farmland and pasture, exponentially increasing losses in the human and animal food chain, among other issues).

7.7 The Driving Forces

Many diverse forces acted upon the technological change that radically transformed the relations of Spanish farmers with agroecosystems (Fernández Prieto 2001). But, in our opinion, the institutional factors and the policies of distribution of agricultural income explain, first, the adoption of innovations to increase the farmland productivity, and afterwards and acting in a complementary way, labor productivity. The generalized trend towards productive intensification remained to be the main impellor of the technological innovation, until the marginal increments of farmland productivity began to diminish. From then on, cost savings gained preference impelled by mechanical and chemical technologies.

The process of industrialization of the Spanish agriculture was imprinted by the market pressures to lower the price of agricultural products, stimulating responses that, first trended to specialize the production, and later, to increase the yields per unit of surface thus saving land, and finally, to replace human labor for machinery and agrochemicals. In this process, the degree of market dependency of farmers gradually increased by the commodification of, first, the agricultural process, afterwards, of the factors of production, and finally, of the complete reproduction of the productive cycle. From a situation in which the reproduction of the domestic economy depended on the suitable management of the ecosystem, to a situation in

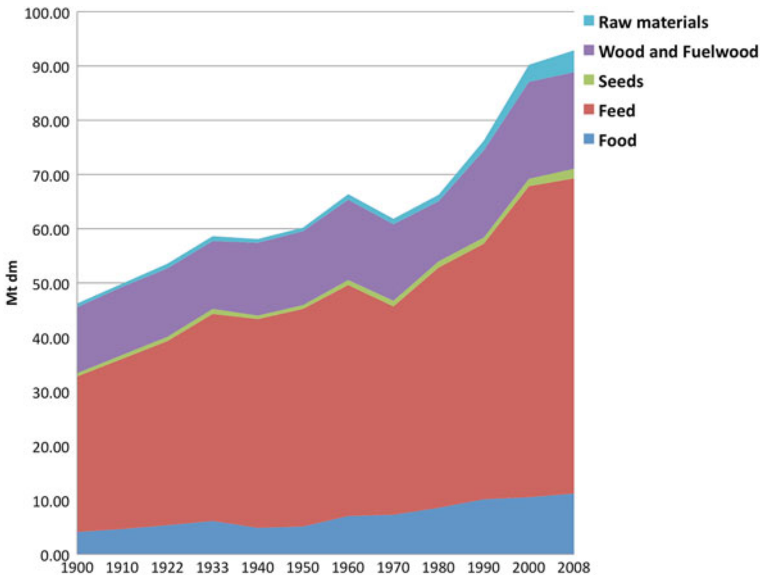

Fig. 7.9 Evolution of domestic consumption of plant biomass in Spain between 1900 and 2008 (Mt of dry matter)

which the use of external inputs became a warrantor of a minimum yield; i.e., a transition from an autonomous to a market dependent reproduction (Van der Ploëg 1990, 1993).

Indeed, the deterioration of the agricultural income (see example in Fig. 7.10) created a favorable context for a rapid diffusion of technological innovation that was reinforced by the parallel increase in social inequality. The growing shortage of income became a potent motor for agricultural intensification and the involvement in the market of small farmers through buying and selling of inputs. The inequity inside the agricultural system, and between this and the urban-industrial sector encouraged the productive efforts. For example, two of the most important moments of the technological transformation—the adoption of chemical fertilizers and mechanization—were preceded by deteriorated social situations in terms of distribution of farm income and access to means for livelihood. The industrialization of agriculture met its perfect ally in social inequity, its ideal nourishing broth, allowing it for seizure of more and more agricultural parcels to be delivered into the financial industrial complex (Guzmán Casado and González de Molina 2006).

Until the structural incorporation of chemical fertilizers, and of inputs from external flows of energy and material, social inequality had been based on an unequal assignment of land and livestock tenure and the combination of such inequality with peoples' reproductive strategy. In that context domestic inequity was the determinant element of the intensification of agricultural production.

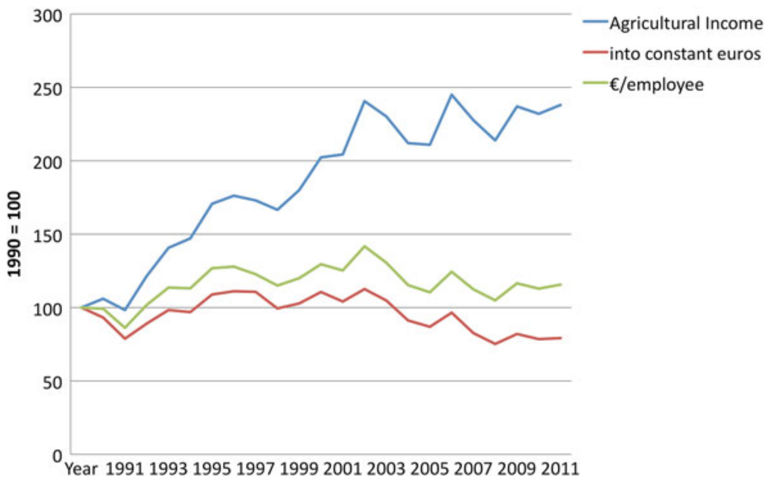

Fig. 7.10 Evolution of Spanish agricultural income between 1990 and 2011. *Source* COAG (2010)

But as it became necessary to import essential factors for production such as fertilizers, fodders, and fuels, the market started to become the fundamental mechanism of exploitation of farm labor and of the distribution of part of the added value of agriculture to other economic sectors: agricultural input industry, broad-scale distribution of products, or the food industry. Internal inequity has gradually led way to external inequity as a motor for industrialization of agriculture. As the flow of external material and energy—frequently from fossil sources—was increased, the rise in yields and productivity bettered the income of farmers and its relative distribution among the agricultural sector, but also there was a rise in external costs and a decrease in global profitability of the system.

In other terms, maintenance of certain level of order—i.e., of living standards and welfare—in developed societies, in which Spain is included, has required the sustained flow of materials and energy from their environment to compensate for their increasing entropic disorder brought about by increasingly inegalitarian social structures. Since the early twentieth century, ensuring a continual and low cost supply of biomass (foodstuffs and raw materials) from farmlands to urban areas became a necessity, while the exchange relation between agriculture and urban industry turned evermore unequal. To the interior of the agricultural sector, such loss of equity and profitability, i.e., the increase of social entropy has been counteracted by means of a considerable increment in dissipation of energy and materials, with the concomitant generation of severe environmental deterioration. During recent decades, this process of entropic acceleration of biomass metabolism has been enabled thanks to the transfer to third party countries of a significant amount of the metabolic entropy derived from the maintenance of an environmentally detrimental and socially unfair model of production and consumption. In summary, the Spanish agricultural sector has acted as a receptor of transferred disorder for, in turn, generating order for landowning classes, and concomitantly for the urban industrial conglomerate. Finally, the entropy in the agricultural sector has been curtailed by transferring part of it to agroecosystems and to farmers from Latin American countries.

References

Coordinadora de Organizaciones de Agricultores y Ganaderos (2010) De la reestructuración al desmantelamiento. Diez años del siglo XXI en el campo. Análisis de la evolución de los sectores agrario en el contexto estatal, europeo y mundial. COAG, Madrid

European Commission (2013) Report from the commission to the council and the European parliament on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2008–2011. UE, Brussels

Fernández Prieto L (2001) Caminos del cambio tecnológico en las agriculturas españolas contemporáneas. In: Pujo P, González de Molina M, Fernández Prieto L, Gallego D, Garrabou R, El pozo de todos los males. Sobre el atraso de la agricultura española contemporánea. Editorial Crítica, Barcelona, pp 95–143

Fischer-Kowalski M, Krausmann F, Giljum S, Lutter S, Mayer A, Bringezu S, Moriguchi Y, Schütz H, Schandl H, Weisz H (2011) Methodology and indicators of economy-wide material flow accounting. state of the art and reliability across sources. J Ind Ecol 15(6):855–875

Frank AG (2007) Entropy generation and displacement: the nineteenth-century multilateral network of world trade. In: Hornborg A, Crumley YC (eds) The world system and the earth system. Global socioenvironmental change and sustainability since the Neolithic. Left Coast Press, Walnut Creek, pp 303–316

Garrabou R, González de Molina M (eds) (2010) La reposición de la fertilidad en los sistemas agrarios tradicionales. Editorial Icaria, Barcelona

Garrido A (coord.) (2012) Indicadores de sostenibilidad de la agricultura y ganadería españolas. Fundación Cajamar, Almería

Giampietro M (2003) Multi-scale integrated analysis of agro-ecosystems. CRC Press, Boca Raton

Giljum S (2006) Material flow-based indicators for evaluation of eco-efficiency and dematerialisation policies. In: Lawn P (ed) Sustainability indicators in ecological economics. Edward Elgar, Cheltenham, pp 376–398

Gómez JA, Giráldez JV (2008) Erosión y degradación de suelosAndalucía: Consejería de Agricultura y Pesca Junta de Andalucía

González de Molina M, Guzmán Casado G (2006) Tras los pasos de la insustentabilidad. Agricultura y media ambiente en perspectiva histórica, siglo XVIII-XX. Editorial Icaria, Barcelona

González de Molina M, Soto D, Guzmán G, Infante J, Herrera A, Aguilera E, Cid A, García R (2014) The Metabolism of Spanish Agricultura, 1900–2008. Working paper. Sociedad Española de Historia Agraria, Spain (www.seha.info)

González de Molina M, Soto D, Infante J, Aguilera E (2013) ¿Una o varias transiciones? Nuevos datos sobre el consumo alimentario en España (1900–2008). XIV Congreso de Historia Agraria (Badajoz, noviembre 2013). Sesión B.1: La transición nutricional en perspectiva comparada: mitos y realidades. Badajoz, 7 y 8 de Noviembre de 2013 (www.seha.info)

Infante Amate J, Soto Fernández D, Cid Escudero A, Guzmán Casado G, Aguilera Fernández E, García Ruiz R, González de Molina M (2013) Producción y consumo de madera y leña en España. Una serie provincial de los aprovechamientos forestales y cultivados (1900–2000). Working Paper. Sociedad Española de Historia Agraria, Spain. (www.seha.info)

Infante J, González de Molina M (2013) Sustainable degrowth' in agriculture and food: an agro-ecological perspective on Spain's agri-food system (year 2000). J Clean Prod 38:27–35
Instituto Nacional de Estadística (1962) Censo agrario de. www.ines.es
Instituto Nacional de Estadística (2009a) Censo agrario de. www.ines.es
Instituto Nacional de Estadística (2009b) Censo de Población y Vivienda del año. www.ines.es
Jorgenson AK, Kick E (2003) Globalization and the environment. J World-Syst Res 9:195–203
Krausmann F, Erb K, Gingrich S, Lauk C, Haberl H (2008a) Global patterns of socioeconomic biomass flows in the year 2000: a comprehensive assessment of supply, consumption and constraints. Ecol Econ 65:471–487
Krausmann F, Schandl HY, Sieferle RP (2008b) Socioecological regime transition in Austria and United Kingdom. Ecol Econ 65:187–201
Krausmann F, Gingrich S, Eisenmenger N, Erb K, Habewrl H, Fischer-Kowalski M (2009) Growth in global material use, GDP and population during the 20th century. Ecol Econ 68(19):2696–2705
Kuskova P, Gingrich S, Krausmann F (2008) Long term changes in social metabolism and land use in Czechoslovakia, 1830–2000: an energy transition under changing political regimes. Ecol Econ 68:394–407
Moore JW (2010) The end of the road? agricultural revolutions in the capitalist world-ecology, 1450–2010. J Agrarian Change 10(3):389–413
Muñoz P, Giljum S, Roca J (2009) The raw material equivalents of international trade. J Ind Ecol 13(6):881–898
Ramos-Martín J, Cañellas-Boltá S, Giampietro M, Gamboa G (2009) Catalonia's energy metabolism: using the MuSIASEM approach at different scales. Energy Policy 37:4658–4671
Risku-Norjaa H, Mäenpää H (2007) MFA model to assess economic and environmental consequences of food production and consumption. Ecol Econ 60:700–711
Saifia B, Drakeb L (2008) Swedish agriculture during the twentieth century in relation to sustainability. Ecol Econ 68:370–380
Schandl H, Fisher-Kowalski M, Grunbuhel C, Krausmann F (2009) Socio-metabolic transitions in developing Asia. Technol Forecast Soc Chang 76:267–281
Schandl H, Grünbühel C, Haberl H, Weisz H (2002) Handbook of physical accounting. Measuring bio-physical dimensions of socio-economic activities, MFA-EFA-HANPP, Social Ecology Working Paper 73
Schmidhuber J (2006) The EU diet—evolution, evaluation and impacts of the CAP. FAO, http://www.fao.org/fileadmin/templates/esa/Global_persepctives/Presentations/Montreal-JS.pdf. Accesed 3 Nov 2013
Stuart T (2011) Despilfarro. El escándalo global de la comida. Alianza, Madrid
Van der Ploeg JD (1990) Labour, market, and agricultural production. Westview Press, Boulder
Van der Ploeg JD (1993) El proceso de trabajo agrícola y la mercantilización. In: Sevilla Guzmán E, González de Molina M (eds) Ecología, campesinado e historia. Ediciones La Piqueta, Madrid
Weisz H, Krausmann F, Amann C, Eisenmenger N, Erb K-H, Hubacek K, Fischer-Kowalski M (2006) The physical economy of the European Union: cross-country comparison and determinants of material consumption. Ecol Econ 58:676–698
Witzke H, Noleppa S (2010) EU agricultural production and trade: can more efficiency prevent increasing "land grabbing" outside of Europe? OPERA Research Center. http://www.appgagscience.org.uk/linkedfiles/Final_Report_Opera.pdf. Accesed 20 June 2013

Chapter 8
Global Metabolism

8.1 Introduction

The exchange of flows of materials and energy between countries (units of N) gives place to an intricate mesh of relations, the sum of which constitutes the scale of global metabolism (Fig. 8.1). The particularities of countries, each one having different degrees of social, cultural, technological, and informational complexities, sizes of national territory, quantity and quality of domestic resources, variety of ecosystems and landscapes, etc., causes interactions to vary as well, such that novel properties emerge that are not observed at other scales. For example, unequal exchanges and the consequent imports and exports of order (exergy) and disorder (entropy) between groups of countries within the World-system (see Hornborg 2007; Frank 2007; Wallerstein 1974), the global flows of matter and energy (Naredo 2006), or the produced impacts expressed by the concept of ecological footprints (Wackernagel and Rees 1996). The global scale metabolism is starting to be analyzed beyond the comparison of metabolic patterns by country, by, for example, studying the transformations of flows of matter and energy by region, i.e., groups of nations within a given territory (e.g., Schandl et al. 2008).

8.2 Economic Growth and Inequity Between Countries

Since World War II, the planet experienced great transformations including a fast technological and industrial development (Allen 2010), high economic growth rates (Maddison 2009), and an unprecedented expansion of international trade (O'Rourke and Williamson 1999), changes which are causing fundamental transformations in the modes, scale, and intensity of human nature relations (Steffen et al. 2007). Translated to material terms, such transformations are generating a massive increase in consumption rates of materials and energy. The global use of resources multiplied by eight during the twentieth century and its growth has been accelerated during the past few decades (Krausmann et al. 2009).

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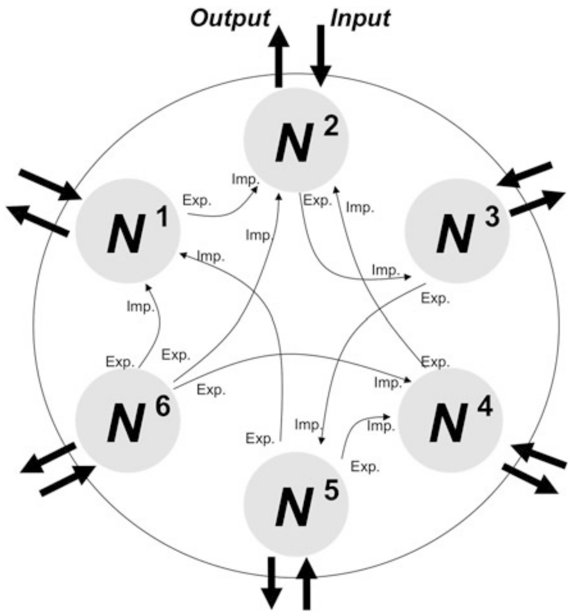

Fig. 8.1 Diagram showing metabolic connections between countries (N) and between each one of these with their domestic natural resources, which defines the object of study of global (international) metabolism

By the end of the 1950s the consumption of inorganic resources for the first time exceeded that of organic resources (Fig. 8.2).

Consumption of inorganic resources amounts to over 70 % of the total used resources. The total extraction of materials passed from 35 to 63 Gt between 1980 and 2008, with an important increase in extraction and use of construction materials and minerals, which parallels the impacts of fast demographic expansion and rates of urbanization, such that an inhabitant of the planet currently needs around 9 Mt per year of resources, while one hundred years early that same figure was only above 4.5 Mt. That explains that the yearly per capita consumption has only duplicated, from slightly over 4.5 t one hundred years ago, to 9 t nowadays (Krausmann et al. 2009). Global emissions of CO_2 continue to rise due to the growing use of fossil fuels, 80 % of the total global emissions being produced by only 19 countries. Nearly all mountain glaciers in the world are losing volume, causing severe impacts on human beings. The level of the ocean has been raising an average of 2.5 mm per year since 1992 (Table 8.1).

The per capita consumption of energy grew at an annual rate of 5 % from 1992 and 2008. In 2009, the world's energy consumption rate lowered for the first time in thirty years to 2.2 % due to an economic and financial crisis (Enerdata 2011). Half of such a decrease took place in the OECD (IEA 2011). A rise in consumption of primary energy of 4.7 % took place in 2010. It is expected that energy consumption rates continue to grow, thus realizing the prediction of a rise in temperature of 3.5 to 6 °C by the end of the present century (IEA 2011).

The data in Table 8.1 show that the monetary value of economic activity increased faster than its physical equivalent, i.e., the consumption of materials,

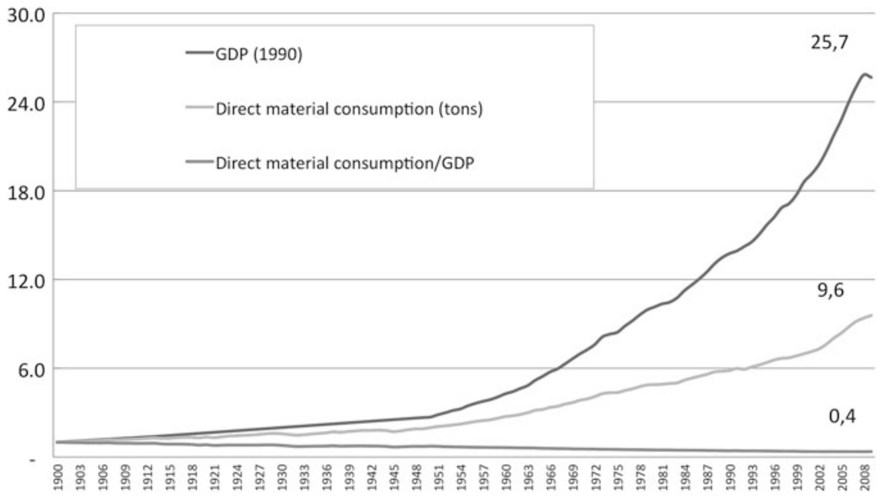

Fig. 8.2 Consumption of biomass and inorganic materials in metric tons per inhabitant per year. *Source* Krausmann et al. (2009)

Table 8.1 Total global and regional gross domestic product (GDP) and material consumption from 1980 to 2005

	PIB (USD)			DMC (million tons)		
	1980	2008	[1980 = 100]	1980	2008	[1980 = 100]
Africa	633	1,594	251	1,766	3,950	224
Asia	6,187	23,091	373	10,958	33,238	303
Europe	6,105	10,756	176	8,940	8,936	100
Latin America	1,904	3,930	206	3,672	6,994	190
North America	4,628	10,324	223	7,299	9,207	126
Oceania	250	609	243	694	1,008	145
World	20,030	50,974	254	33,745	63,598	188

Source Maddison (2013) and SERI (2008) (www.materialflows.net.2013)

which gives place to interpretations postulating the decoupling between economic growth and its physical basis, or the *dematerialization* of the world economy. The trends in production and consumption of materials appears to have been stabilized in developed countries, while in countries with emerging economies such as Brazil, China, India, or Mexico the use of materials per capita continues to grow as less developed countries embrace high consumption models. Overall, resource consumption continues to rise at a global scale—by 88 % since 1980—independently of its monetary value, thus denying the notion of the dematerialization of global economy.

Nevertheless, 20 % of the more affluent world population was accountable of 86 % of the global consumption in 1998, while the poorest 20 % only consumed 1.3 % of that total. The per capita metabolic rates vary considerably between countries. For example, India has a yearly consumption rate of materials of 4 t per inhabitant, while in Canada it is of 25 t. In average, the metabolic rate of industrialized countries—one fifth of the world's population—is two an a half times higher than the global average, and 4 to 5 times higher than that of poor countries (UNEP 2011).

8.3 The Key Role of International Trade

But why is there such an asymmetry between developed and developing countries? Both the consideration of underdevelopment and development as sides of a same coin and the Marxist assumption that economic development is intrinsically unequal, have a yet more obvious biophysical basis. In fact, asymmetry between countries—as famine and poverty—are not circumstantial but structural phenomena fluctuating in time but persistent, given they are derived from economic growth and the model of international trade supporting it. Development cannot exist without underdevelopment, affluent countries require of poor countries to exist. Economic growth and inequality are inseparable from the industrial metabolic regime; in fact, despite the promises and expectations of international organisms, economic growth has not abolished but exacerbated inequalities. According to a recent report of the Credit Suisse Bank (Reuters, Zurich 10/10/2013), global wealth peaked to a historical maximum record of 241 trillion dollars, increasing by 68 % during the past ten years. However, the richest 10 % owns 86 % of the total world's financial assets, while 1 % owns 46 % of that total. Currently there are 98,700 individuals with fortunes of over 50 million dollars, more than half of them in US.

Many structural factors can be invoked to explain the notorious differences between countries, spanning from population density to institutional frameworks of States. But international trade is singled among such factors by playing a key role in the functioning of the metabolism of industrialized countries and acting as the main axis of globalization and its legitimizing ideology: Globalism. International trade has the unique goal of ensuring economic growth of some at the expense of others, and even that of the apparent dematerialization of developed economies. In fact, during recent decades highly industrialized countries have experienced a relative decrease in their per capita materials and energy consumption rates per GDP unit; a condition that as already mentioned has not been accompanied by a global decrease in consumption of materials and energy, but all to the contrary.

This relative dematerialization was the consequence of the translation of certain metabolic processes from industrial to developing—peripheral—countries. Nuclear countries with industrial metabolisms have for some time shown a trend to externalize those processes that consume higher levels of materials and energy, produce more wastes, or require more inputs of labor (Caldeira and Davis 2011). Many such processes are associated to the metabolic processes of appropriation, transformation (specially those more intensive in terms of energy use and waste generation), and excretion. Thus, peripheral countries become waste receptors—i.e., exporters of low cost environmental services—and adopt the position of exploited entities in the international concert. Development of industrial metabolism went from supporting itself on domestic extraction of materials, to adopting the domestic consumption—in a sense, parasitic—of energy and materials mostly coming from foreign countries, and obtained through unequal exchange relations. In Chap. 9 we were able to demonstrate this in the analysis of Spanish foodstuffs production.

In consequence it can be said that, from the physical perspective, the considerable economic development of industrialized countries is due in large part to the appropriation of natural resources and environmental functions of peripheral countries. In this context, inequality has played and continues to play a relevant role in the operation of industrial metabolism, its stability, and its magnitude. Without inequality it is difficult to understand why some countries sustain consumption rates of materials and energy at levels exceeding the capacity of sustenance of their territories. Often, such exploitation has taken place by political and military means, through colonial subjugation of territories. But, despite having the latter methods been frequently used, the usual mode of operation has been unequal economic exchange in that some receive resources and services from others in trade of a partial compensation of their real value.

International trade—acting as an instrument for transferring large amounts of energy and materials throughout the world—experienced an unprecedented growth during the past few years. Between 1970 and 2006, the value of industrial trade grew each year at an average of 7.2 %. In that same period of time, the value of manufactures multiplied by ten, that of fuels and mining products by a little over two, and the value of traded agricultural products triplicated. This increase in the value of international trade was not only monetary but also in terms of physical volume: from 5,400 millions of metric tons (5.4 Gt) it jumped to 19 Gt by 2005. In the latter year, manufactures were only 24 % of the market in physical terms, but 74 % in monetary terms. Despite that, fossil fuels were 49 %, biomass 20 %, minerals 18 %, and other products 3 % of the global exports. In the year 2000, international trade flows represented 20 % of the global volume of extracted materials (Giljum et al. 2008).

This increment in commercial exchange has had global consequences on the environment. The impacts generated by merchandise in their places of origin have become more severe due to the ecological impact of their transportation. According to the fourth report of IPCC, the transportation sector contributed 13.1 % of total CO_2 equivalent emissions. Logically, also the emissions embedded in merchandises increment as trade volumes increase. Some estimates place the CO_2 emissions involved in exchanged products at 27 % of total emissions for the year 2005 (Peters et al. 2011). Something similar is occurring in the impact of international trade on drinking water. Between 1997 and 2001, the water footprint of international trade—measuring the direct and indirect consumption of water in merchandises—represented 16 % of the total water footprint.

Through international trade, industrialized countries attain relatively high per capita incomes with relatively low levels of consumption of natural resources. Industrialized countries mostly export manufactures having high added value, involving more and better jobs, and generating a positive effect. On the contrary, many peripheral countries have specialized in exporting raw materials (mostly in Africa), or manufactures (Many Asian countries), thus sustaining high rates of domestic extraction of resources and considerable environmental damages, without obtaining a correlative rise in their per capita income. Such is the general pattern, which is only disturbed by a handful of industrialized countries that due to their low population density also export raw products, such as Australia or Canada. Latin America obtains 70 % of its income from exporting agricultural products and raw materials; over three quarters of the exports from the Near East are fossil fuels, and 80 % of African exports are agricultural and mining products, or fossil fuels.

In monetary terms, trading balances tend to be equilibrated, but the same is not true in physical terms. The trading balances of materials between countries reveal the bare reality of an unfair relation of socio-ecological exchange: industrialized countries tend to be net importers, while peripheral countries have until nowadays been net exporters of materials (Table 8.2; Fig. 8.3). In the year 2005, the industrialized countries imported nearly two billions of metric tons (2 Gt), two thirds of which came from the peripheral countries, and one third from countries in the former Council for Mutual Economic Assistance (Comecon). In 2006, over one half of all minerals were extracted beyond the borders of industrialized countries.

In some countries specialized in exportation of natural resources, such as Peru or Chile, the domestic extraction of materials grew faster than the GDP, rising the intensity in the use of materials in their economies, in a process opposite to that of dematerialization. Furthermore, some studies made of the foreign trade of European countries show that the hidden flows of materials are of the same or a higher order of magnitude than the direct flows, and that the hidden flows of imports are not totally compensated by those produced by exports. In this way an unequal allocation is generated, not only of monetary value, but also of the impact from the life cycle of merchandises on natural resources and environmental services. The most material intensive and environmentally dirty—but, paradoxically, also the less expensive—processes take place in peripheral countries (Caldeira and Davis 2011). In other terms, industrialized countries externalize their metabolic processes having high energetic and material intensities in detriment of the peripheral countries. In appearance, such a mode of distribution of metabolic processes makes the affluent countries responsible for the treatment or relocation of wastes; but with increasing frequency wastes are reexported to peripheral countries.

The case of Chile is paradigmatic: in 2003, this Latin American country was a net exporter estimated in one million metric tons (1 Mt) when only taking into account the direct flows, but when indirect flows are also considered the estimation is of 634 Mt. This hidden face of international trade—promoted by the dogma of free trade and, above all, pretending to provide industrialized countries with all the materials and energy they need for their unsustainable metabolism to continue to

Table 8.2 Trade balance of raw materials in 1995 and 2005

	1995		2005	
Concepts†	OECD countries	Rest of the world	OECD countries	Rest of the world
DE	21,300	25,130	23,790	33,650
MEI	7,890	2,160	11,440	3,450
MEE	3,580	6,460	4,290	10,600
RMC	25,610	20,810	30,950	26,498
RTB	4,310	−4,310	7,160	−7,160

† Abbreviations: DM, domestic extraction; MEI, materials embodied in imports; MEE, materials embodied in exports; RMC, raw material consumption; RTB, raw material trade balance. Source: Bruckner et al. (2012, 572)

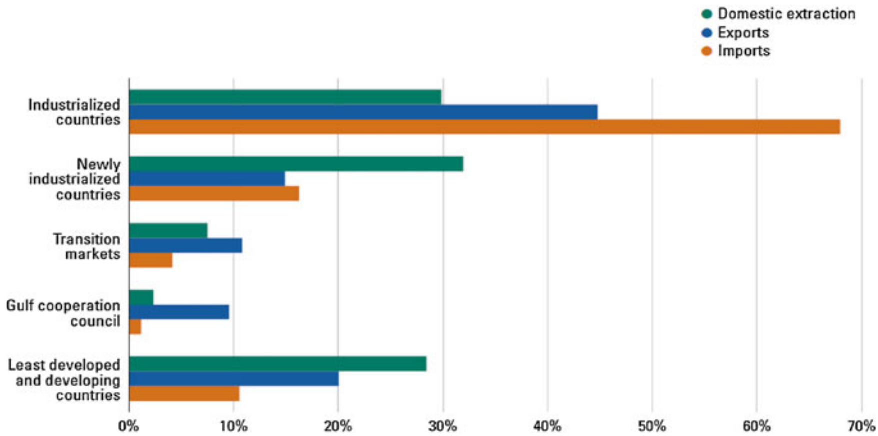

Fig. 8.3 Raw material extraction and trade by country type. *Source* SEC database, http://www.uni-klu.ac.at/socec/inhalt/3812.htm, see Steinberger et al. (2010)

grow—must be accounted for when designing sustainable alternatives to the present statu quo. The inclusion of hidden or indirect flows in the physical accountancy of national economy and trade flows, together with their adequate fiscal treatment, must be the foundation of any egalitarian relation between countries.

8.4 Unequal Exchange and Environmental Deterioration

Because unequal exchange does not require of an extensive use of violence, nor the complete control of either the territory where resources are located or of the labor force (as in the cases of slavery or serfdom), it became the most sophisticated exploitation technique of history. Societies based on the industrial metabolism—being more or less dependent on both internal and external production of biomass—have been able to sustain a relation with peripheral territories that is more based on commercial trade than in the use of political and military means.

In short, the exchange becomes unequal by three closely related ways, which as summarized by Martínez-Alier (2007, 233), warrant the sustainment of metabolic processes of industrialized countries. The first one transits through low remuneration in the form of prices given to natural resources and environmental functions (contrasting with the high price given to transformed goods) that deteriorates the trading relation by forcing peripheral countries to export larger volumes of natural resources in order to obtain a given volume of imported goods. The prices of raw materials have been dropping for decades, which compel underdeveloped countries to export higher amounts of natural resources to sustain their income level. This was the thesis of developed dependency sustained by Prebisch in the 1950s and 1960s.

To this first way to unequal exchange, Marxists economist added a second one claiming that exports of poor countries were more intensive in terms of underpaid human work, such that there was an unequal exchange in terms of embedded labor. The third way to trade inequity is the ecological, which was introduced during the 1980s emphasizing the fact of economic growth depending not only on own resources, exploitation of labor, and technological innovation, but on the growing use of materials and energy from exporting countries (Bunker 1985; Hornborg 1998; Muradian and Martínez-Alier 2001; Singh 2003; Giljum and Eisenmenger 2003). By these means, the affluent countries not only undermine their own production conditions, but also the conditions of existence of the peripheral peoples. Poor countries exploit their natural resources with little or no transformation, thus with minimal added value and economic domestic impact. Often, the extraction of natural resources for exportation acts as enclave economies having limited effects on the local economy. Many of these extractive activities are considerably capital intensive, thus generating a low number of jobs for the local population.

The socio-ecological consequences are even more dramatic. According to what was shown by Bunker (2007, 249), unequal exchange in extractive economies causes the loss of natural assets, which hampers future productivity of human work (Bunker 2007, 249). As was stated by Eisenmenger and Giljum (2007, 299), extractive economies specialize in the extraction of resources for exportation rather than for domestic consumption. Many rich countries reduce their environmental impact by importing resources and exporting wastes, a process commonly known as the Dutch fallacy (Ehrlich and Ehrlich 1990; Frey 2003; Jorgenson 2003). By doing this, developed countries not only deplete natural resources but also cause the deterioration of environmental services, which further plunges future development expectations. Peripheral regions are exploited as sources of negentropy and sinks of entropy (Hornborg 2003, 7). André Gunder Frank (2007, 304) resumed this in graphical terms: “physical/ecological entropy is generated by economic growth and shifted from the center to the periphery.” In other words, unequal exchange produces a net loss of resources that will never be possibly invested for developing peripheral countries (Leff 1986; Martínez-Alier 1993).

8.5 The Unviability of the Industrial Metabolism Regime

There are some who think that market economy aided by minimal state intervention will ensure both the subsistence of the over nine billion human beings living by the middle century on our planet, and the possibility of enough economic progress for any country reaching the same level of wellbeing enjoyed by industrialized countries. Simply, economic growth must be sustained. This belief is supported by the idea that without economic growth no jobs or distribution of wealth could be possible.

Even within environmental thought, some claim that we are in the middle of a transition that started 300 years ago between agrarian—which is still dominant in territorial terms—and industrial metabolism (Fischer-Kowalski et al. 2007, 223), a process that will end when poor countries reach the level of development of the rich countries. Such an accomplishment is the most craved goal of not few politicians and intellectuals in developing countries claiming their right for enjoying the life standards of industrialized economies: after all, they contend, it is a matter of equity.

While global access to the same levels of prosperity characteristic of Western countries is a reasonable objective that is socially fair, it is ecologically unviable. Nor is it possible to generalize the levels of endosomatic and exosomatic consumption of the West, nor could that be attained by economic growth. If as we stated above economic growth is the essence of the industrial metabolism, then it seems unlikely that sustaining a social relation system based on inequity would lead us to reach equal development. As we see, the growth of the metabolic profile of industrialized countries is dependent upon the underdevelopment of peripheral countries. The culmination of the transition between the agrarian and the industrial metabolism is physically and socially impossible: capitalism and nature forbid it.

If the present average metabolic rate of Europe—16 tons per capita per year projected to the year 2050 with a global population of nine billion—was generalized to the whole planet, the global consumption of materials would nearly triplicate rising to 140 Gt per year. That would imply a five-fold increase of the current metabolic rates of many countries. The annual use of biomass would be more than doubled, that of fuels would be quadrupled, and the yearly consumption of minerals and construction materials would triplicate. The carbon emissions per capita may be tripled and global emissions could be quadrupled, reaching 28.8 Gt C/year, thus exceeding the most pessimistic scenario modeled by the Intergovernmental Panel on Climatic Change (IPCC) (PNUMA 2011). So we are not undergoing a process of transition towards the domination of the industrial metabolic regime, but experiencing its habitual operation mode. The only feasible transition is towards a different metabolic regime based on a significant reduction in the consumption rates of materials and energy, which to be sustainable must be distributed among countries as equally as it is possible. Such egalitarian allocation of consumption requires the shrinking of developed countries' metabolism, and simultaneously, a rise in metabolic profiles of the poorest countries. That is covered in the final chapters of this book.

References

Allen RC (2010) The British industrial revolution in global perspective. Proc Br Acad 167:199–224

Bruckner M, Giljum S, Lutzb C, Wiebeb KS (2012) Materials embodied in international trade: global material extraction and consumption between 1995 and 2005. Glob Environ Change 22(3):568–576

Bunker SG (2007) Natural values and the physical inevitability of uneven development under capitalism. In Hornborg A, McNeill JR, Martínez-Alier j (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 239–258

Bunker SG (1985) Underdeveloping the Amazon: extraction, unequal exchange and the failure of the modern state. University Chicago Press, Chicago

Caldeira K, Davis SJ (2011) Accounting for carbon dioxide emissions: a matter of time. Proc Natl Acad Sci USA 108(21):8903–8908

Ehrlich PR, Ehrlich AH (1990) The Population Explosion. Simon and Schuster, New York

Eisenmenger, N. and Giljum, S. (2007). Evidence from Societal Metabolism Sutdies for Ecological Unequal Trade. In *The WorldSystem and the Earth Systeam. Global Socioenvironmental Change and Sustenainability Since the Neolithic*, eds. A. Hornborg and C. Crumley, 288-302. Walnut Creek: Left Coast Press

Enerdata (2011) Global energy statistical yearbook. Enerdata, Grenoble

Fischer-Kowalski M et al (2007) Conclusions: likely and unlikely pasts, possible and impossible futures. In Fisher-Kowalski M, Haberl H (eds) Socioecological transitions and global change. Trajectories of social metabolism and land use. Edward Elgar, Cheltenham, pp 223–255

Frank AG (2007) Entropy generation and displacement: the nineteenth-century multilateral network of World Trade. In Hornborg A, Crumley C (eds) The world system and the earth system. Global socioenvironmental change and sustenainability since the neolithic. Left Coast Press, Walnut Creek, pp 303–316

Frey RS (2003) The transfer of core-based hazardous production processes to the export processing zones of the periphery: the Maquiladora centers of northern Mexico. J World-Syst Res 9:317–356

Giljum S, Eisenmenger N (2003) North-South trade and the distribution of environmental goods and burdens. SERI Studies 2

Giljum S, Behrens A, Hinterberger F, Lutz C, Meyer B (2008) Modelling scenarios towards a sustainable use of natural resources in Europe. Environ Sci Policy 11(3):204–216

Hornborg A (1998) Towards an ecological theory of unequal exchange. Ecol Econ 25:127–136

Hornborg A (2003) The Unequal exchange of time and space: toward a non-normative ecological theory of exploitation. J Ecol Anthropol 7:4–9

Hornborg A (2007) Footprints in the Cotton fields: The industrial revolutionas time-space appropiation and environmental load displacement. In Hornborg A, McNeill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 259–272

IEA (2011) World energy outlook 2011. International Energy Agency/OECD, Paris

Jorgenson AK (2003) Consumption and environmental degradation: a cross-national analysis of the ecological footprint. Soc Probl 50(3):374–394

Krausmann F, Gingrich S, Eisenmenger N, Erb K-H, Haberl H, Fischer-Kowalski M (2009) Growth in global materials use, GDP and population during the 20th century. Ecol Econ 68(10):2696–2705

Leff E (1986) Ecología y Capital. Siglo XXI Editores, México

Maddison A (2009) Historical Statistics for the World Economy: 1–2001 AD. http://www.ggdc.net/maddison/ Accessed 4 may 2013

Maddison A (2013). Historical Statistics for the World Economy: 1-2006 AD. Online data base. 2008. http://www.ggdc.net/maddison/. Accessed 26–11–2013

Martínez-Alier J (1993) Temas de historia económico-ecológica. In: Revista Ayer 11:19–48
Martínez-Alier J (2007) Marxism, social metabolism, and international trade. In Hornborg A, McNeill JR, Martínez-Alier J (eds) Rethinking environmental history. world-system history and global environmental change. Altamira Press, Lanhan, pp 221–237
Muradian R, Martínez-Alier J (2001) Trade and environment: from Sourthen perspective. Ecol Econ 36:286–297
Naredo JM (2006) Las raíces económicas del deterioro ecológico. Siglo XXI Editories, Madrid
O'Rourke KH, Williamson JG (1999) Globalization and history: the evolution of a nineteenth-century Atlantic economy. The MIT Press, Cambridge
Peter GP, Minx JC, Weber CL, Edenhofer O (2011) Growth in emission transfer via international trade from 1990 to 2008. Proceedings of the National Academy Sciences (PNAS) 108(21):8903–8908
PNUMA (2011) Anuario PNUMA: temas emergentes en Nuestro Medio Ambiente Global. PNUMA
Schandl H, Fisher-Kowalski M, Grunbuhel C, Krausmann F (2008) Socio-metabolic transitions in developing Asia. Technol Forecast Soc Chang 76(2):267–281
SERI (2008) Global resource extraction 1980 to 2005. Sustainable Europe Research Institute, Vienna
Singh SJ (2003) In the sea of influence: a world system perspective of the Nicobar Islands. Lund University Press, Lund
Steffen W, Crutzen PJ, McNeill JR (2007) The Anthropocene: are humans now overwhelming the great forces of nature? Ambio 36(8):614–621
Steinberg J, Krausmann F, Eisenmenger N (2010) Global patterns of material use: A socioeconomic and geophysical analysis. Ecol Econ 69:1150–1157
UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth. United Nations Environment Programme. United Nations Environment Programme, Nairobi
Wackernagel M, Rees J (1996) Our ecological footprint. New Society Publishers, Philadelphia
Wallerstein I (1974) The modern world system. Capitalist agriculture and the origins of the european world-economy in the sixteenth century. Academic Press, London

Chapter 9
The Cinegetic or Extractive Mode of Social Metabolism

9.1 Introduction

The human species as such (*Homo sapiens*) is at least 200,000 years old, but if humanness was inclusively considered, its antiquity must be extended to about two million years. During that period, evidence from paleoanthropological research indicates the existence of a minimum of eight species of the genus *Homo* related to *H. sapiens*. For nearly all of its history, the human species lived grouped in *cinegetic* or *extractive* societies (Meillassoux 1967). The qualifying terms cinegetic and extractive, describe societies in which human actions over the terrestrial and aquatic landscapes—including, continental and oceanic waters—are limited to: *hunting*, including several forms of trapping; *gathering*, both of plants and animals such as insects, mollusks, and crustaceans, or of their products (honey); and *fishing*.

In these three modes, the acts of appropriation of nature occur as a removal from the ecosystem of handpicked *parts*—plants, animals, and minerals—because of which only exceptionally is the structure or dynamics of the ecosystem intentionally modified. Organisms being appropriated are affected only at the level of their populations, and rarely at the level of the landscape, as in the intentional use of fire for modifying certain habitats and favor gathered species of plants or of animal preys. This means that the consequences of the irresponsible use of resources are essentially restricted to the overexploitation of the appropriated plant and animal species, thus disturbing their population and reproductive processes.

9.2 The Simplest Social Organization

The first mode of social metabolism—the only existing way of appropriation of nature until about twelve or ten thousand years ago—was that of extractive societies occurring in the simplest social organizations of hunters, gatherers, and fishers. While apparently obvious, the study of this appropriation modality had to

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overcome endless bias and prejudice. During decades, the dominant perspective of the primeval cinegetic societies was focused on their individual members being prehistoric or pre-human entities located in a *twilight zone* between the realms of natural (natural history) and human (history) evolution, and totally or mostly obeying to natural laws. As Childe wrote, the advent of agriculture put an end to human beings making a living: "like any other beast of prey, a parasite on other creatures by catching and collecting what food nature happened to provide [Childe 1942, 55]." Thus, hunter-gatherer societies were approached from the perspectives of Biology, Ethology or Sociobiology, applying the same concepts used for studying societies of primates and other vertebrates as if humans were exclusively an animal species *inserted* in nature.

Although in this stage of metabolic development, humans seem to behave as *one more species in an ecosystem* thus appearing as simple biological elements, in practice and from the social perspective, humans perform qualitatively distinct processes. In fact, otherwise than all other animal species, humans extract resources from nature by means of a metabiological act: appropriation/production. Because of that, as stated by Ingold (1987), the concepts of predation, foraging, cooperation, and territoriality used for analyzing animal species are not equivalent to those of hunting, gathering, distribution and tenure: the former belonging to the domain of ecological interactions of animal species mostly of vertebrates, and in particular of primates; the latter, to the human social domain.

The substantial difference between, say a troop of baboons predating, foraging, cooperating, and defending a territory, and a band of humans performing apparently similar actions, is that humans obtain materials from nature through an act conceived from the social collective, and in which humans act as *intentional agents* for which nature belongs to a separate reality (emergence of self consciousness). Humans approach the natural world as subjects *in confrontation with* an object, not as an animal species under the control of nature: they now are performing the social human act of *appropriation*.

Under this initial stage of cinegetic-extractive social metabolism, humanity disseminated to occupy virtually all the habitats in the planet by means of a colonization process that spanned over one hundred thousand years. Modern *Homo sapiens* originated from a small population in eastern Africa that spread over the whole continent beginning 100,000 years ago. About 40,000 to 60,000 years later, a small subset of that same population entered Asia triggering the second, and longer, expansion through two probable directions: one, along the southern and eastern coasts of Asia and western Oceania; the second, towards central Asia, and from there, to the west into Europe, and to western Asia and northern Siberia, eventually arriving to America. The chronology of these itineraries has been confirmed by genetic (Stix 2013) and linguistic evidence, such that a correspondence has been established between genetic and linguistic genealogies (Cavalli-Sforza 2001).

Regarding social metabolism, the human species was exclusively cinegetic-extractive until the advent of agriculture, so that by 12,000 or 10,000 years ago it occupied most of the planet from Australia, a large part of western and northern

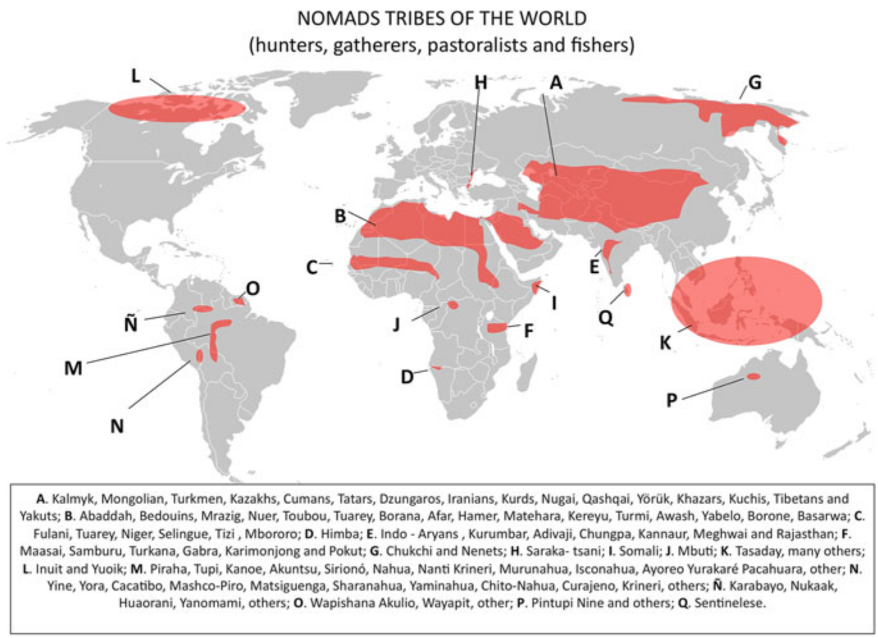

Fig. 9.1 Distribution in the world of hunter, gatherer, pastoralists and fishers societies

North America, including northern Mexico, and large parts of South America, Asia, and Africa, with a population estimated in nearly one million inhabitants (Lee and De Vore 1968). Towards the year 1500, the expansion of the emerging agricultural societies—the second mode of appropriation—had displaced societies of hunters, fishers and gatherers to marginal, peripheral, and isolated areas in the southern extreme of South America, the North American pacific coastline, the driest portions of Australia, the Arctic polar circle, Siberia, and parts of Africa and Asia (Fig. 9.1).

Even with populations severely decimated by extinction, integration, or by cultural dissolution, the cinegetic metabolism exists, resists, and subsists in several parts of the world, encompassing a population estimated to be of 300,000 to 500,000 (Burger 1987; Lee and Hitchcock 2001), which, based on language, include nearly one thousand peoples or cultural units. Such a linguistic heterogeneity represents one sixth of the total global cultural diversity, with its best representation in Australia (about 400 languages) and Africa (Birdsell 1973; Lee and Hitchcock 2001).

Given that most, or nearly all, of what is known about extractive or cinegetic societies derives from ethnographic research of extant peoples, the characterization of the metabolic processes in this initial stage of appropriation requires to acknowledge that the analysis of contemporaneous groups only allows for a certain level of detail when making sketches of past reality. The above-mentioned fact is relevant because most present extractive societies have been *polluted*, and hence modified, by their contacts with agricultural, urban and industrial societies through exchanges of technology, information, knowledge, and economic goods. The idea of isolation of contemporaneous extractive societies has been denied by the evidence of commercial relations between them since hundreds, or maybe thousands, of years (Headland and Reid 1989). This concern has even led to questioning the existence of cinegetic societies in the humid tropics of the world, a matter that has been amply discussed and controverted (Bailey et al. 1989; Colinvaux and Bush 1991).

In essence, a clear distinction needs to be made between the modality of cinegetic-extractive social metabolism that originated during the Pleistocene, and that arising after the advent of agricultural societies, i.e., between the Paleolithic-Neolithic, and the Holocene extractive societies (Marlowe 2005). Despite these distinctions, once the differences—mostly technological—between both modalities are pondered, and after confrontation with fossil and archaeological remains available from the Pleistocene, the extant cinegetic societies provide with a highly valuable source for understanding the initial form of social metabolism.

9.3 The Productive Versatility of Cinegetic Societies

Because of the very low technological level of these first human societies—limited to the use of rudimentary instruments, fire, dogs, and human energy—the three fundamental activities (hunting, gathering, and fishing) of this mode of appropriation gain relative importance according to the productive potential of each ecosystem or landscape occupied. For example, according to the Ethnographic Atlas (Murdock 1967), Lee and De Vore (1968) analysis of 58 extant extractive societies led him to find a correlation between geographic location—and hence climate—and the relative importance of hunting, fishing and gathering. While, due to the abundance and diversity of plant species, gathering predominates in groups inhabiting warm and temperate regions, in extreme cold climates hunting predominates, while fishing becomes the main source of resources between 40 and 60° of latitude (Lee and De Vore 1968, 42).

This productive versatility allowed for colonization of an ample variety of landscapes. Where resources in oceans, rivers, lakes, and lagoons were abundant, fishing became the main activity, supplemented with hunting and gathering; contrariwise, in cold habitats where large mammals were abundant, hunting of big game was privileged, while in deserts hunting focused on small preys. Porter and Marlowe (2007) analyzed 146 pre-agricultural and agricultural societies with different regimes—hunters, fishers, and gatherers; and horticulturists, shepherds, and irrigation farmers, respectively—finding that cinegetic or extractive societies occupy habitats that are as productive as those inhabited by agricultural societies in terms of net and gross primary productivities.

The social and demographic versatility of the cinegetic-extractive metabolism is revealed in the continual adaptation of human groups to the existing ecological conditions, expressed as the abundance or scarcity of essential resources, mainly of food and water. Thus, the amount and availability of resources (both in space and time) determines the duration and extension of annual migration cycles (nomadism) throughout their base territories, even allowing for sedentarism, as in the coastal regions in Australia or eastern North America in which the abundance of fish not only makes displacement unnecessary, but even promotes unusual levels of human population (Sutles 1968; Birdsell 1973). In other cases, adaptation is achieved by means of the forced reduction in the number of unproductive—albeit consumer—members of the group through diverse practices such as infanticide (predominantly of female children) and abortion.

The available ethnological evidence of correlations between the spatial and temporal abundance of resources with ecological zones or regions, climates, and variations in extractive activities, allows for understanding large-scale changes that took place accompanying past climatic variations. For example, the first and medium coldest periods of the Pleistocene, as well as the rise of temperatures towards the end of this period and the beginning of the Holocene, had immediate repercussions on the extractive activities—including in the associated knowledge and technologies—and hence on human diet, eventually affecting the size of human populations, and their social and productive organization. Added to the above are intrinsic factors of human societies, such as the domestication of fire or dogs, the beginning of language, the cooking of foodstuffs—which apparently stimulated the increase of the size of the brain (Wrangham 2009), and the increase of life expectancies that established communication between grandchildren and grandfathers (Caspari 2013). Altogether, despite these being the simplest of human societies, they imply an intricate interplay of causes, dynamics and synergies.

9.4 The Metabolism of Cinegetic Societies

Following the basic model developed in Chap. 4, the first step for analyzing the metabolic process in the first cinegetic societies is to determine the basic unit of appropriation (P). Research made of hunting, fishing, and gathering societies identify three social units, each corresponding to a different scale of social organization: *family*, *band*, and *tribe* (Fig. 9.2). While the family is the bottom social and demographic cell, it is generally imbricated in and forming part of a band, together with other families. Likewise, the assembly of bands benefiting from a given territory, speaking the same language, and sharing a common history, form a tribe. Although exceptional or unusual cases may occur, there is an agreement in that while the family operates as the social and demographic nucleus, and the tribe essentially responds to a cultural identity, it is the band which functions as the unit in charge of appropriation, and in consequence, it is the band which should be adopted as the basic unit in metabolic modeling.

The band is an independent and autonomous social unit—characterized by being patrilineal, patrilocal and exogamous, egalitarian, and non-hierarchical—that

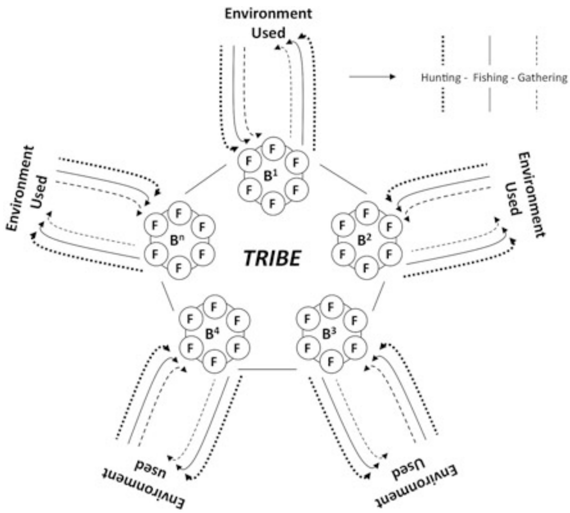

Fig. 9.2 Diagram showing the main productive units in a cinegetic-extractive society (family, band, and tribe), and the exchanges occurring between these and nature. Abbreviations: F, family; B, band

recognizes and uses the resources of a given territory, and that is regulated by means of councils. That is, the band is a human nucleus formed by a number of males and their corresponding wife or wives, and by their respective offspring, which reproduces by means of exchanging women with other bands (exogamy), and which are communitarily regulated. At this organization level the only division of labor is based on gender: women are almost always devoted to gathering, while men predominantly hunt and fish.

That the band, and not the family, is the appropriation unit of extractive societies is demonstrated by the fact that the products obtained during the appropriation process are commonly egalitarian shared between all of its members, independently of the contributions and participation in the appropriation process, and of their sex or age, although in close relation with kinship. This fact sets the limits of the basic productive or appropriation unit.

The correct delimitation of P is crucial for identifying the metabolic processes and for establishing the limits between ecological and economic exchanges. Practically all of the analyses made of the economy of extractive societies—led by the pioneer work of Sahlins (1972)—confounded or were in disagreement about the frontiers of the ecological and the economic realms, an indefinition that derives from the dual (natural-social) nature of the human phenomenon, which was previously highlighted by Ingold (1987), and that conforms the fundamental axiom of ecological and social analyses resulting from the concept of social metabolism. Sahlins (1968, 1972), who made one of the finest analyses about the material exchanges, unfortunately examines extractive societies pooled together with the simplest of agricultural societies under the common term *tribal societies*, thus making it difficult to distinguish the particularities and differences of what are two different metabolic regimes, as will be seen below.

Thus, it seems as if the three units representing the three hierarchical levels or scales of social organization of extractive societies correspond to three separate but articulated dimensions: that of biological or demographic reproduction (family); that of material reproduction (band); and that of cultural reproduction (tribe). In this stage of human development, the individual forming part of extractive societies performs three activities: as a biological actor, or reproductive individual; as an agent of appropriation/production; and as a member of a given culture or cultural group. These three dimensions are as three clocks with interlinked gears.

In the extractive mode of appropriation, based on the only three functions allowing for extracting goods from nature (hunting, fishing, and gathering), the material and tangible portion of the metabolic process is reduced to appropriation, transformation (minimal), and consumption, given that at this stage of social development there is no circulation of products, and hence all that is produced has a *use value* (see Chap. 5) for the producing community. Boldly stated, these are societies that merely sustain ecological exchanges, because the material exchanges between sectors of the society occur only as social exchanges, not yet reaching the category of economic exchanges (Toledo 1981).

During this initial metabolic stage, and more specifically, in its Paleolithic version, the exchanges of produced materials within the society express social relations given that the economy is still not embedded inside the society or culture. This reciprocal exchange of *things* takes place between next of kin, friends, or neighbors in the forms of dowry or aids in matrimonial transactions, friendly agreements, alliances, and peace treaties ensuring coexistence. This condition can be generalized for all extractive societies prior to agriculture, but became modified with the appearance of agricultural societies that stimulated commercial exchange (mostly of foodstuffs and other basic products). That is the reason for distinguishing between the Paleolithic and Neolithic modalities of this extractive mode of appropriation.

Another characteristic feature of cinegetic societies is that, in their metabolism, the circulation and consumption of the appropriated/produced goods is not deferred but (nearly) instantaneous, given the lack of knowledge or technology for preserving or storing the obtained products. There is no holding, accumulation, or centralization of production, but the nearly immediate consumption of products: a fact that is determinant in social, organizative, and, particularly, in demographic terms.

The abundant studies made of the demography of extractive societies have arrived to rather accurate calculations of the number of individuals that could be attained under this socio-ecological modality. These estimates are reached by modeling ideal situations through the weighting of several factors, such as abundance and variability of available resources, and the frequency, intensity, duration, and easiness for communication. There is an agreement in that bands do not exceed 100 individuals, with a *magic number* of 25, while the populations of tribes range between 200 and 900 members, with a *magic number* of 500 (Birdsell 1968, 1973).

The above-mentioned demographic thresholds provide with a vision of past and present situations. If the human population during the early Holocene (12,000–10,000 years ago) is assumed to be of one million, it may be speculated that in that period there were nearly 2,000 different cultures (tribes), all under the cinegetic-extractive modality of social metabolism, and that the nearly 500,000 individuals currently remaining in that stage of human development represent about 1,000 different cultures; i.e., there has been a 50 % reduction in their cultural variation.

The limited technological capability of this first metabolic regime—that hampers storage of goods, almost inevitably forces the displacement due to abundance or scarcity of resources, and reduces metabolism to almost immediate consumption of what is appropriated or produced (because the little volume of circulating goods has social rather than economic intentions)—has consequences, not only upon demography, but also upon the intangible spheres (the *software*), such as social and productive organization, institutions, and cultural identity.

9.5 The Intangible Dimensions of Cinegetic Metabolism

The intangible dimensions of this metabolism are characterized by the impossibility of building a central and lasting political power—given the sole existence of a decentralized organization lacking authority, which responds to the weakness of matrimonial and filial relations, and to the fragility and instability of the institutions (bands and tribe), which weakens social cohesion. The continuous mobility of bands reduces and debilitates the cultural cohesion of the tribe to which they belong in terms of a common language and an epithet distinguishing them form the *outsiders*. Forced to *face-to-face* communication, the members of a tribe grouped in bands require a minimum of personal contact for maintaining their own language alive. Because of that, the permanence of a culture under this mode of appropriation requires of a communicative geography allowing for a minimum interaction between bands (migrating) throughout the year, in order to ensure the permanence of their language or dialect. As a counterpart, their cosmovisions inducing the practice of a *sacred ecology* allows them for maintaining an equilibrated relation with natural processes, mainly with the populations of plants and animals operating as their sources of supplies.

This first socio-ecological modality spanning throughout nearly 200,000 years, and that allowed for the colonization by the human species of a large part of the planet, has well-established limits both in terms of its capacity for incrementing the return flow of matter and energy resulting from its actions, as in building societary structures beyond a certain limit. Such limitations are the result of the complex interaction between the abundance of appropriated resources in space and time, and the limitations of sources of energy, technological level, demographic constraints, potential social cohesion, and requirements for communication (language) making possible the identity of the group. That explains why in its initial phase, human societies are represented by a set of hundreds of thousands of minute units (bands with an average of 25 members), nomadic, with a weak communication between them, and dispersed here and there throughout the vast surface of the earth.

Despite such limitations, the cinegetic-extractive metabolism reached its maximum achievement—an almost unequalled feat—of sustaining the human species for nearly two hundred thousand years under adverse environmental conditions, such as climatic instability, and with minimal inputs. It is impossible to forget that it is thanks to our first conspecific populations that humanity remains to exist.

References

Bailey RC et al (1989) Hunting and gathering in tropical rain forest: is it possible? Am Anthropol 91:59–82

Birdsell JB (1973) A basic demographic unit. Curr Anthropol 14:337–350

Birdsell JB (1968) Some predictions for the Pleistocene based on the equilibrium systems among recent hunter-gatherers. In Lee RB, DeVore I (eds) Man the Hunte. Aldine Publishing Company, USA, pp 229–240

Burger J (1987) Report of the frontier: the state of the world's of indigenous peoples. Zed Books, London

Caspari R (2013) The evolution of grandparents. Sci Am 22:38–43

Cavalli-Sforza LL (2001) Genes, peoples, and languages. North Point Press, San Francisco

Childe G (1942) Los orígenes de la civilización. Fondo de Cultura Económica, México

Colinvaux PA, Bush MB (1991) The rain forest ecosystem as a resource for hunting and gathering. Am Anthropol 93:153–160

Headland TN, Reid LA (1989) Hunter-gatherers and their neighbors from pre-history to present. Curr Anthropol 30:43–66

Ingold T (1987) The appropriation of nature. University of Iowa Press, USA

Lee RB, DeVore I (eds) (1968) Man the Hunter. Aldine Publishing Company, Chicago

Lee RB, Hitchcock RK (2001) African hunter-gatherers: survival, history and the politics of identity. African Study Monographs Suppl 26:257–280

Marlowe FW (2005) Hunter-gatherers and human evolution. Evol Anthropol 14:54–67

Marlowe FW (2007) Hunting and gathering: the human sexual division of foraging labor. Cross Cult Res 41:170–195

Meillassoux C (1967) Essai d'Interpretation du Phénoméne Économique dans les Sociétés Traditionnelles d'Autosubsistance. Cahiers d'Études Africaines, France

Murdock GP (1967) Atlas Etnográfico del mundo. Instituto Lingüístico de Verano, Perú

Sahlins MD (1968) Tribesmen. Englewood Cliffs. Prentice Hall, UK

Sahlins MD (1972) Stone age economics. Tavistock, London

Stix G (2013) Traces of a distant past. Sci Am 22:60–67

Sutles W (1968) Coping with abundance: subsistence on the Northwest coast. In: Lee RB, DeVore I (eds) Man the Hunter. Aldine Publishing Company, Chicago

Toledo VM (1981) Intercambio ecológico e intercambio económico. In: Leff E (ed) Biosociología y articulación de las ciencias. UNAM, México

Wrangham R (2009) Catching fire: how cooking made Us human. Basic Books, New York

Chapter 10
The Organic Metabolism

10.1 Introduction

All evidence points to that about between 10,000 and 5,000 years ago a complex combination of factors—including a leap in mental capacity of humans, a generalized increase in temperatures (end of the Glacial age), and particularly, the management of landscapes and plant and animal species—gave place to a qualitatively different relation between human societies and their environments. This *leap* is known as the *Agricultural* or *Neolithic Revolution* and it originated a second metabolic regime, which released a series of potentialities of human groups that had remained unexpressed under the limited relations with nature of extractive or cinegetic societies. This second metabolic regime surfacing in several parts of the world nearly 10,000 years ago became the socioecological support of human societies for several millennia, until only 300 years ago when a new form of articulation with nature was enabled by the *Industrial Revolution*.

The key factor triggering a qualitatively different process and generating new and unexpected modalities of social complexity was, undoubtedly, the human capacity for manipulating its environment that was started several thousand years ago. Although this new period is commonly timed at nearly 10,000 years ago, it was rather the result of a lengthy and gradual process of *domestication of Nature*. There is evidence of the use of fire for modifying landscapes with some intention to favor the abundance of gathered or hunted foodstuffs occurring in Africa (50,000 years ago), Australia (40,000), and New Guinea (30,000). Also, archaeological records exist of the management of water (its deviation or retention) in order to favor populations of useful plants.

As noted before, these practices needed to have been executed by individuals endowed with a mental capacity allowing them for going beyond problem solving based on the sole application of procedures and routines that were derived from acquired experience, required a long-term visualization of problems, planning, selection of strategies, and solving of new or unexpected problems; all of which implies the acquisition of a certain level of memory, language, imagination, and intelligence (Wynn and Collidge 2008).

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While archaeology could hardly prove when or where these transformations of the human mind took place, it does provide indirect evidences of such event. The first confirmation of an *immaterial* or *symbolic culture* is a putative necklace made of marine shell beads found in the Blombos cave near Cape Town, South Africa with an antiquity of 75,000 years (Henshilwood and Marean 2003). Otherwise, the records of the first tombs from about 40,000 years ago provide evidences of self-consciousness and the conceptions of time and death. The earliest ideographic or pictographic representations, having a similar antiquity, reinforce this consciousness.

10.2 The Onsets of Agriculture and Animal Husbandry

These evidences suggest that at some point during the development of hunting, fishing and gathering societies—in which there was resource abundance allowing not only for a demographic increase, but more importantly, for a sedentary life—conditions occurred for beginning the modification of landscapes and of plant and animal species. The study of domestication processes talking place in contemporary human communities allows for a better understanding of events happened in antiquity. In the case of plants, according to Casas et al. (1997, 2007), humans perform three actions for manipulating the vegetation and plant species beyond simple gathering: *tolerance, foment* or *induction*, and *protection*; all of which are intermediate between simple gathering and cropping, and which correspond to three mechanisms of the domestication process.

Tolerance includes practices by which the producer permits the existence of useful wild plants inside cropping fields. By means of foment or induction the producer promotes the increment in density of useful plant populations within plant associations through different mechanisms (using fire, intentionally broadcasting seed, etc.). Finally, protection implies the intentional tending of useful wild plant species populations in their own habitat, such as by soil fertilization, pruning, protection against pests, frosts or draughts, elimination of competitors or predators, etc. (Casas et al. 1997, 2007). Similar domestication processes took place for animals, in which selective capture of young specimens and their sustenance allowed for favoring individuals depending on their contributions as foodstuffs or pelts, degree of tameness, advantages for transportation, relevance for agricultural practices, and capacity for interaction. In both cases, evidences corroborate the existence of a necessarily gradual process, despite that along the dilated time period it appears as sudden changes or *unexpected leaps*.

From the basically passive act of species extraction (Paleolithic), humans proceeded to managing or manipulating populations of useful species by means of a process of artificial or human selection which favored those morphological, physiological, and genetic characters, or their combinations resulting in more advantages for humans, thus creating new subspecies, races or varieties of plants and animals.

Fig. 10.1 Major centers of agricultural diversity in the world. *Source* Harlan (1992)

It is very likely that all these practices preexisted in a confined way since several tens of thousands of years, and that the climatic change that took place during the late Pleistocene favored their diffusion, multiplication, and optimization. Plant and animal husbandry was thus born in several regions of the world at about 10,000 or 12,000 years ago. During this Neolithic or Agricultural Revolution not only were there an enormous variety of new plant and animal domesticates originated (assessed to be between 1,200 and 1,400), but also new varieties and races appeared which overall a remarkable increase in the planet's biodiversity: of potato alone, there are about 12,000 locally recognized varieties; and of rice, nearly 10,000 (Toledo and Barrera-Bassols 2008).

According to studies made by the Russian geneticist N. I. Vavilov, it is possible to identify eight centers of domestication around the world, which were modified by Harlan (1992) based on archaeological evidences from the territories where crops originated. Harlan (1992) defined five geographic regions, which he called centers, and another three regions known as non-centers. These centers are located in Middle East—Fertile Crescent—region (Jordan, Syria, Turkey, Iraq and Iran), Mesoamerica (México and Central America), and northern China, and the non-centers are located in Africa, Southeast Asia, and South America. Smith (1998) later added a new center of origin of crops in North America, and more recently Neumann (2003) proposed New Guinea as another center of origin for banana, sugar cane, and several tubers (Fig. 10.1).

Most cases of animal domestication also occurred in the above-mentioned regions, sometimes synchronically, and other times somewhat later (Cox and Atkins 1979). After the dog, The first animal species to be domesticated, mostly in the Middle East, and others in other Asian zones, Europe and Africa, were the sheep (11,000 years ago) and the goat (10,500–10,000), and somewhat later, the bovines and the pig (9,000). In America, animal domestication was less prolific due to the extinction of the large sized fauna in North and South America because of overhunting and probably because of the most recent arrival of humans. Species of camelids (llama and alpaca) were domesticated in the Andes region, while the dog and the turkey were domesticated in Mesoamerica. Manipulation of plant and animal species (and in strict sense, of their evolutionary mechanisms) resulted in a domestication process driven by protection, selection, and hybridization. On the other side, dominium over metals—first iron, bronze later—allowed for elaborating tools associated to this biological domestication: plows and other agricultural tools, yokes, harnesses, and horseshoes.

10.3 Domestication of the Landscapes

The transformation driven by human societies in order to obtain food did not limit itself to plant communities, but it reached soils, topography, microclimates, and other physical factors, and included the manipulation of ecological and microbiological processes such as forest regeneration and fermentation. To species domestication followed landscapes domestication when the first Neolithic societies modified the natural landscapes to create anthropized zones, i.e., zones for the production of goods.

These novel Neolithic landscapes were designed for adding, and *not for substituting*, new products to those provided by hunting, fishing, and gathering, and were achieved by means of adequate management of ecological, geomorphological, and hydrological processes, and usually without largely disturbing the natural cycles and processes. These large-scale changes include all the range of modifications of structure, function, and evolution of landscapes. Three of such designed systems are noteworthy at a planetary scale: hydraulic agriculture, terraces, and intertropical agroforestry management of forests.

Several vestiges of intensive hydraulic agriculture are found throughout the world, noticeably in each of the regions in which remarkable civilizatory processes took place such as Mesopotamia, Egypt, India, México, and The Andes. These systems were designed to modify topography and natural water flow in a way that appropriate conditions were created for irrigation or hydraulic agriculture (Fig. 10.2).

For example, there is evidence of terraces established in the humid lowlands of the Gulf of México and the Yucatán Peninsula (Siemens 1989, 1998). Also, similar systems were found in Guatemala, Belize, Venezuela, Colombia, Ecuador, Bolivia, and Peru (Donkin 1979; Denevan 1982). These terrace systems in general known as *elevated fields* are made of a network of channels and platforms built along the shores of lakes, rivers, or flood plains, and include the regulation of drinking water to maintain the water levels allowing for developing intensive agriculture (Siemens 1998).

Fig. 10.2 Inundated rice pads epitomize intensive agricultural systems and express a sophisticated adaptation of the landscape to human needs, including domestication of species specifically suited for such modified conditions, such as rice and the water buffalo

In the Andean highland of Lake Titicaca in Peru and Bolivia, a hydraulic agriculture system known as *waru-waru*—currently reactivated in part—occupied a surface of over 200,000 ha in antiquity. Likewise, the Aztecs used *chinampas*, a system that is probably the most sophisticated, low technology hydraulic agriculture system (Fig. 10.3). Chinampas, spreading over 12,000 ha, among other functions, provided the foodstuff needed (maize, beans, amaranth) by a population estimated in over 228,000 people (Denevan 1982).

The conversion of natural forests to anthropized forests has also been an ancient practice along the world's tropics. Such process implies the transformation of the original forest composition to create *forest gardens* through management of tree species and the introduction of useful herbs and shrubs, such as the commercially important crops coffee, cocoa, cinnamon, black pepper and other spices, rubber, and vanilla. These forest gardens are a way to reconstruct natural forests in which wild and cultivated plants coexisted with the objective of maintaining the structural characteristics and ecological processes of natural forests to benefit local human communities, and to preserve certain level of biological diversity.

Studies made of traditional agroforestry systems have shown their biological, ecological, and productive relevance in countries such as India, Papua, New Guinea, Sri Lanka, Indonesia, Tanzania, Uganda, Nigeria, and México, where they

Fig. 10.3 A remarkable traditional design from Mesoamérica is the hydraulic agriculture system known as created in the shores of lakes in the Valley of México, which functioned as the breadbasket of Tenochtitlán, the capital city of the Aztec empire

are generated by local cultures using ancient local knowledge. Examples of these systems are the *Shambas* from Uganda, the *Kebun-Talun* from western Java, the *Pekarangan, Ladang*, and *Pelak* from Sumatra-Indonesia, the *Kandy* from Sri Lanka, and the *T'elom* and *Kuajtikiloyan* of the Huastec (Tenek) and Nahua peoples from México, respectively.

Agricultural terraces are among the oldest systems for managing geomorphological, soil, and water processes in landscapes having abrupt reliefs and steep slopes. Archaeological records suggest that the antiquity of terraces from several world regions is of 3,000–4,000 years. Terraced landscapes have allowed for, or stimulated the development of numerous civilizations in each continent, as for example in China, India, Japan, Korea, and Ethiopia—where agriculture achieved high levels of development, and in three other key agricultural regions: the Mediterranean, the Andes, and Mesoamerica (Sandor 2006).

10.4 The Multiple Significances of the Neolithic Revolution

Beyond productive aspects, this second modality of articulation with nature unleashed a series of new processes, whose synchrony is difficult to understand, among which are: sedentarism, growth of population in human nuclear settlements (represented in first instance by the village), social hierarchy, the use of a novel work force represented by animal traction, the extension of the time period between appropriation and consumption of resources (including food storage), and very significantly, the appearance of economic exchange, i.e., the circulation of produced goods beyond the appropriation/production unit.

These and many other processes interact in complex synergies giving place to new social configurations, in which the complexity of social relations and human life were completely determined by phenomena such as social hierarchy and specialization, multiplication of human settlements, generation of surpluses towards non producer sectors, and of course, an explosive expansion of the intangible or non material dimensions: techniques, knowledge, ideologies, beliefs, and institutions. The appearance of cities about 5,000 years ago was the spatial expression of a society that became stratified as the result of a social power organized by the State, and capable of absorbing the generated surplus—through several coercive mechanisms—of a majoritarian agricultural sector in charge of the appropriation of nature: the peasantry. By the year 3000 BC the human species had reached a global population estimated in 14 millions (Modelski 2003), which indicates the significance of shifting from the extractive to the agrarian mode of appropriation.

The impacts on the ecosystems and landscapes of the planet that were triggered by this new modality of articulation with nature need to be mentioned. Domestication of species of plants and animals not only modified the original composition of plant communities, but also generated new spatial patterns: agricultural fields for generating human food and fodder for the new domestic animals, or timber and non-timber forest products. The intensity of these transformations was probably gradually increased, and was dependent on the particular conditions at each site. Landscape transformation was facilitated by the use of fire and by management of water, as well as by the continual improvement of tools, and of varieties of useful plants and animals.

In this context, a particular paradoxical situation is outstanding: the appearance of pastoralist modalities leading to a Neolithic nomadism. Indeed, animal domestication gave place to a particular differentiation by which certain human groups with high skills for managing herds expanded to regions that were little or not at all suitable for cropping, and in which even hunter-gatherers would have had difficulties to succeed. By this procedure, either sedentary or nomadic pastoral societies appeared in landscapes rich in grasslands, which colonized vast arid and semiarid or cold regions in east Africa, the Sahel and the Sudan sub-Sharan Belt, the Mediterranean, southeast and central Asia, Tibet, Mongolia, and southern Siberia, together with the steppes in the southern Arctic Ocean, parts of Greenland, northern Eurasia, and North America (Vasey 1992).

Pastoralist societies, whose antiquity is estimated in 6,000 years, played a central role in the history of Eurasia and in the expansion and diversification of language in Europe (Cavalli-Sforza 1996). In demographic terms, contemporary pastoralist groups have a total population of no less than 20 millions, distributed in northern Africa (14 millions), the Arabic countries (5 million), Mongolia (half a million), the ex-Soviet Union, and China (Burger 1987).

In terms of social metabolism the appearance of this new metabolic regime gave origin to a second mega-landscape, the transformed environment (TEN) that added to, but did not replace, the utilized environment (UEN). This transformed environment added to the rise of economic trade, which circulated part of the production to other sectors, i.e., the social environment (SEN), thus incrementing the complexity of exchanges at the local or domestic scale.

10.5 The Distinctive Features of the Organic Metabolic Regime

A distinctive feature of the organic metabolism was, and continues to be, the use of solar energy as the fundamental source of energy resources in the appropriation process, which is achieved both by the improvement and higher efficiency of utilization of living organisms (biological converters), and by the invention of artifacts indirectly using the solar energy, such as watermills, windmills, and wind-propelled sailboats. Amazingly, this particularity limited the scale of ecosystemic transformations for over 10,000 years: from the early societies of plant and animal domesticators, to the beginning of the industrial and scientific revolution of the eighteenth century.

Except from some products elaborated from mineral sources, most artifacts and raw materials used by humans originated in the land and were the product of photosynthesis. Biomass provided both foodstuffs and raw materials, as the fuels needed for social functions (Wrigley 1988, 1989; Sieferle 2001). Agrarian activities were at the core of social metabolism, going well beyond the satisfaction of the endosomatic requirements of the human population. Agrarian activities were the center of economic activity because they supplied the bulk of the energy used for production, transportation, metallurgy and crafts, and also the bulk of raw materials, such that all other economic activities were strictly dependent on them. Croplands provided food, medicine, fodder, and fuels (crop waste and byproducts); pastures supplied food and, particularly, the means for transportation and warfare; and forests supplied fuel and materials for buildings and transport vehicles (carts and boats).

Because of this dependency on agrarian production, crops needed to provide more energy than that invested in their production (Tello et al. 2013). For example, in the pre-industrial agriculture of the humid portions of Europe, it has been estimated that the amount of food needed for sustaining agrarian activities was between 14 and 20 % of the total produced food; in different terms, the energy input-output ratio was of 5–1 (Fischer-Kowalski et al. 2007, pp. 224–226). In this regard, the use of coefficients for measuring the efficiency of the global investment of resources for production has become more frequent in scientific literature, such as the *Energy Return on Investment* (EROI) (see Giampietro et al. 2010)

Table 10.1 Density of human population

	Population density Inhabitants/km^2	Live weight (kg/ha)
Foraging	0.01 to 1	0.005–0.5
Pastoralism	1–2	0.5–1
Shifting cultivation	20–30	9–14
Traditional farming		
Pre-dynastic Egypt	100–110	45–50
Medieval England	150	75
Global mean in 1900	200	100
Chinese mean in 1900	400	180
Modern agriculture		
Global mean in 2000	400	200
Chinese mean in 2000	900	410
Jiangsu province in 2000	1,400	630

Source Smil (2013, p. 105)

measuring biomass investment efficiency, which begins to be applied for agrarian societies in the past (Fischer-Kowalski and Haberl 2007, Smil 2010, Tello et al. 2013). While in more suitable croplands cultivation soon became permanent, the more widespread system was slash-and-burn agriculture. The latter system allowed for achieving populations ten times higher than those of hunter-gatherer societies, ranging between 20 inhab/km^2 in eastern North America to 60 inhab/km^2 in southeastern Asia (Smil 2001, pp. 212–214; Table 10.1).

Thus, societies under the organic metabolic regime organized themselves in a closed circuit having its origin in the appropriation process, while at the same time the excretion processes were incorporated and, given the organic nature of wastes, turned into inputs. The processes of transformation were nearly inexistent or were restricted to domestic products or crafts (preserves, sausages, salted meats, etc.). The distribution process was mainly at a local scale. Agro-food chains were short, and their energetic and raw material costs had a low significance.

10.6 The Metabolic Appropriation Process

The appropriation and production of biomass was thus the decisive metabolic process around which all the other processes gravitated, and was made possible by means of implementation of cultural management of ecosystems. Because external inputs of energy were either minimal or inexistent, management of ecosystems was forced to reproduce the natural ecosystems as closely as it was possible (Gliessman 1998, p. 271). The impossibility of storing or transporting significant amounts of energy obliged to restart the process every year. To that means, management needed to interfere with the nutrient (carbon, nitrogen, and phosphorous) and water cycles, and in the mechanisms of biotic regulation.

Management of carbon was achieved through application of organic matter, which also contains appreciable amounts of nitrogen, phosphorous and potassium. In such way, in the absence of synthetic fertilizer production and of phosphate rock reserves, agricultural practices attempted to mobilize nutrients between different parts of the agro-ecosystems and the surrounding atmosphere. By such practices, producers struggled to compensate for the losses caused both by cropping and by natural processes such as lixiviation or volatilization. The restoration of fertility became the crucial factor from which the yield and stability of the agricultural production was dependent on.

Most nutrients were replenished by returning to the land the animal and plant wastes, i.e., by recycling organic waste products (manures, forest litter, crushed bones, sewage, cesspit residues, ashes, sediments, etc.) (Wilken 1991). Perhaps the most extended practice was the application of manure from cattle, which became improved along time, particularly in Europe and eastern Asia, but manures were scarce and required of large amounts of labor for their application. Gathering, fermenting, and applying manure signified important losses of nutrient contents, and farmers needed to apply enormous amounts of manure in order to replenish soil fertility. Thus the availability of manures was always limited.

The Chinese case is often quoted as an extreme case of the use of organic wastes that could not be expanded to other territories. During the late nineteenth and the early twentieth centuries rice producing regions received 10 t per hectare of organic fertilizer, which gave place to an important economic activity for managing and transporting large amounts of organic wastes from cities and towns. Nearly 10 % of the total work invested in Chinese agriculture was dedicated to fertilization (Smil 1994, p. 62; Ellis and Wang 1997).

But not all societies could achieve the same level of acquisition of organic mater. In some territories, scarcity of organic fertilizers was somewhat structural, as in climates of low precipitation and biomass production in which herds were not large enough to provide manure for covering the needs of fertilizer (González de Molina 2001; Garrabou and González de Molina 2010). The scarcity of herds in many latitudes forced the use of fallow, green manures and planting of legumes in rotation with other crops, thus maximizing nitrogen supply. The latter formula was extensively used in Europe since antiquity and also in eastern Asia. The combination of legumes and green manures, fallow periods, and cereals, originated crop rotation, practices that became the energetically more efficient way to optimize the possibilities of traditional agriculture (Van Zanden 1991). By crop rotation, not only was soil fertility restored, but also crop weeds, plant diseases and plagues were controlled.

The availability of water determined which crops could be cultivated. Some crops (citric and other fruit trees, vegetables, fodders, cotton, sugar cane, etc.) could only be planted if abundant and constant supplies of water were accessible for irrigation. In such areas, the diversification and specialization of crops, and of course the rise of net primary productivity and hence of useful products from crops, depended on the technological possibilities for irrigation. Irrigation water was transported using gravity thus taking advantage of the kinetic energy provided by water runoff along slopes. Thus, orography and runoff coefficients conditioned the extension of irrigated agriculture, while river and stream hydraulic regimes conditioned water availability throughout the year (Garrabou and Naredo 1999; González de Molina and Ávila Cano 1999). Such irrigation systems were based on small derivation reservoirs with hardly any capacity for storage, and a network of channels for conduction of water to the crop fields.

Animal traction was indispensable for performing the toughest tasks such as plowing, threshing and transporting grains, extracting oils, and extracting irrigation water. This animal traction input allowed for cultivating a more extensive surface than it was possible with human labor alone. Oxen, cows, and water buffaloes equipped with appropriate harnessing performed the hardest tasks, to which horses and other equines were later added. Working beasts also provided important products such as manure, milk, meat, and hides. In agrarian societies that were basically vegetarian, milk and fresh meat provided valuable supplements of protein. Hide became the raw material for numerous tools indispensable for cultivation and for traditional manufactures. Animals propagated by themselves, but the use of domesticated animals requires large investments of plant biomass for the metabolic processes needed for their maintenance and reproduction (Fischer-Kowalski and Haberl 1997, p. 64). Complementarity of human and animal labor was ideal as long as working animals could be maintained either by grazing pastures existing on land not considered suitable for cropping, or by biomass not directly consumed by humans (Gliessman 2002, pp. 273–274). Proliferation of burden beasts, even with more sophisticated harnesses and machines, which could have allowed for a higher proportion of human labor substitution and a higher productivity, could not progress beyond a given threshold value in which feeding animals competed for land with humans. During the early nineteenth century in Europe a horse team consumed a minimum of 2 t of grain per year, or about nine times the grain consumed by a person during the same period of time (Smil 1994, p. 76). Limitations also existed in terms of the maximum traction potency deployed: oxen can only tow between 14 and 24 % of the weight pulled by a horse, and their speed is generally about two thirds that of horses at a walking pace. Thus, an ox can only deploy a towing force of between 300 and 400 W in a sustained way, while a relatively weak horse reaches a potency of 400 or 600 W (Wrigley 1992; Smil 2001, p. 222).

Farmers pretended to grow a larger variety of plants, and to make them more productive and resistant, or in other terms, to obtain the maximum possible amount of useful biomass. To that means, farmers developed through time processes of domestication, selection and improvement of cultivable plants in order to improve the ratio between harvestable biomass and total biomass. The process of selection was oriented towards species and varieties of useful plants that allocated higher amount of photosynthates to harvestable parts in detriment of other plant parts. This does not imply that, as in the present, the process of selection and breeding had the only goal of increasing the commercial yields of plants. During the last few decades the process of seed selection has been looking for certain parameters of high yields, flavor, appearance, genetic uniformity, fast response to fertilizers and irrigation, ease of harvest and processing, resistance to transportation damage, and a reduced caducity. In agrarian societies farmers pursued other objectives beyond commercial benefits when practicing selection, for example in the case of cereals, obtaining suitable animal feed and use of hay for construction or fuel. That explains the significant differences observed in the harvest coefficients of modern and traditional varieties.

Current plant breeding aimed at the accumulation of biomass in harvestable parts has reduced the amount of energy allocated to characteristics conferring higher environmental resistance. Because of that, present cultivars need optimal conditions of soil humidity, nutrient availability, absence of pests and diseases, temperature, and sunlight than those possibly met in the past. It is thus not strange that traditional cultivars had less commercial yields, but were instead best adapted to their environments (Odum 1992, p. 204), and resistant to eventual drought, structural scarcity of nutrients, or the attack of pest insects.

Any attempt to maximize crop yields necessarily implied a reduction of biological diversity through higher density of crops, elimination of competitors, and the control, or elimination, of *harmful* fauna. However, farmers needed to maintain maximum biodiversity if they were to gain in stability and reliability of crops. Due to that, peasant agroecosystems had in general a higher biological diversity of populations, more diversity of crops and not cultivated plants including wild plants in and around cultivated fields. In such conditions, susceptibility to pests and diseases was lessened.

One of the main features of species domestication was high genetic variation, with hundreds or even thousands of varieties or races being distinguishable within cultivated species. Each race or variety had by common rule a genetic buildup responding to specific ecological conditions: ranges of humidity, temperature, natural cycles or rhythms, climatic or edaphic thresholds, and responded to particular needs for human consumption (size, color, flavor, scent, manageability, spatial and temporal availability, nutritional value, suitability for crafts, etc.).

Definitely, all societies under the organic metabolic regime developed practices of agroecosystem management that produced lower average yields than those of modern agriculture. Except in tropical climates, they all shared common features such as cultivation of cereals as their base for sustentation, crop rotation of cereals and legumes, and the use of animals predominantly as working force and to a lesser degree as sources of food. However, crop combinations and their rotation, the types of domesticated animals, and of course, diets were specific to regions. Despite the apparently low intensity of cultivation, the organic agriculture was able to sustain population densities above 100 inhabitants per square kilometer. More intensive farming systems in Asia and Europe were able to feed over 500 inhabitants per square kilometer, i.e., over five people per hectare (Smil 2008, 2013).

If an average harvest of 300 kg of grain per hectare is assumed for the year 1000 AD, and of 400 kg/ha by the year 1700, the total world harvest can be estimated to have been of about 50 and 120 million tons for each date, respectively. Assuming that edible plants provided 90 % of the needed calories in the diet, or an average of about 3.5 GJ per capita per year, such harvest volumes could have fed 200 and 500 million people in the above-mentioned years, respectively. Taking into consideration that estimates of the world population place it at 300 million inhabitants by the year 1000, and 600 million in 1700, about one third and 15 % of the population for both years must have been fed by gathering, slash-and-burn agriculture, and pastoralism. During the eighteenth century modest but significant increases in land productivity were achieved, which allowed for proportional increases in population. Between 1700 and 1800, the extension of cultivated land went from 300 to 420 million hectares, i.e., a 40 % increment, while the human population increased 65 % going from 600 millions to nearly one billion inhabitants. The availability of cultivated land per capita decreased by 20 %, and it must be assumed that average yields per unit of cropland were incremented at the same rate (Smil 2013, 119–120).

10.7 Extraction, Transformation and Distribution

If the capacity of human intervention in ecosystems was limited, also limited were the capacity for extraction and transformation. The scarce ability for concentrating and storing energy imposed a limited use of metals. For example, the European production of iron during the seventeenth century was of only 2 kg per capita per year (Schandl and Krausmann 2007, p. 104). The production of metals using the highest technology was of 2,000 t per year. Metallurgy and the use of its products were strictly limited until the development of steam machines and the introduction of the use of coal instead of charcoal.

Besides animal traction and the kinetic energy of wind and water, the main force driving the crafts and manufactures sectors, and providing heat for cooking and warming homes was the combustion of biomass, including firewood, charcoal, crop wastes, and where forests were insufficient or absent, dry manure, plant or animal oils and waxes. The potency that could be reached was much lower than that which would be later achieved from the use of fossil fuels. The energetic density of biomass is below 15 MJ/kg of fresh weight, while that of coal is of between 25 and 30 MJ/kg, and that of oil of between 40 and 45 MJ/kg (Fischer-Kowalski et al. 2007, p. 227). The efficiency of biomass conversion was also low. For example, energy conversion in charcoal involved a 60 % loss respect to the energy contained in firewood (Malanima 1996, 2001). The availability of charcoal and firewood could even set a limit to the growth of cities. The per capita requirements of firewood, including the needs of industrial activities, has been estimated to have been between of 1 t for cities within the tropics, and of twice that amount in colder climates. It has been calculated that in the middle nineteenth century, just before the use of coal was adopted, between 3 and 6 t per capita of charcoal and firewood were consumed each year in the US and northern central Europe (Smil 1994, p. 119).

Animal and human traction were also limited due to structural reasons: fatigue from effort, and land allocation for food production. The efficiency of human and animal traction when these are converted to movement depended on improved designs of wheels, slopes, inclines, pulleys, and cranes, which allowed for an increased potency. The limited potency—of about 100 W for human work and of 300 W for oxen traction—restricted the capacity for transformation of human activities, and as will be seen below, the radius of their displacements.

The size of the metabolic process of distribution was considerably restricted given its dependency on the appropriation process, and consequently, the limited possibilities for transportation. The low speed of burden beasts, their limited capacity for transportation of merchandises (326 kg for carts pulled by horses in Rome of the fourth century, and of 490 kg of oxen driven carts), added to the poor condition of roads, and created unfavorable conditions for transportation. The capability for medium and long distance transportation of people, animals, and merchandises was severely restricted. The passengers on a cart could travel 50–70 km per day (Smil 1994, p. 131).

There were also other structural factors that hindered the mitigation of such power limitation by increasing the number of tracking animals. All of the materials involved in transportation—including harnessing and its metal components, which needed of previously extracting the minerals and to be afterward casted—were largely dependent on the amount of available biomass for feeding the animals and for fuel needed in metallurgic shops. Wood, fodder or basic foodstuffs, and other products in bulk could not be transported by land to long distances, the average being estimated to have in general been of 10–50 km (Fischer-Kowalski et al. 2007, p. 227). There was a sort of *iron law of transport* (Sieferle 2001) that dissuade from moving bulk merchandises to distances in which animals consumed more energy than that contained in what was transported.

In consequence, transport between the Orient and Western territories, for example between the Indies and Europe, was for many centuries constrained to high value merchandises transported in small volume—precious metals, spices, or textiles among others—that Wallerstein (1974) called *preciosities* and which given their high symbolic or economic value were worth of transportation despite their energetic contents. Exceptions for this transportation restriction were certain materials including precious woods, metal for warfare and some building materials that were more important to the dominant social groups than for the metabolism of the importing country as a whole (Martínez-Alier 2007, p. 232; Hornborg 2007a, p. 6). These transport constraints had also consequences upon the size of factories because importation of fuels or raw materials could not overcome the limitations in location and installed potency that derived from the use of energy from combusted biomass, or from eolic or hydraulic power. An example is the production of iron, for which in the eighteenth century about 50 square meters of firewood were required involving a yearly exploitation of between 10 and 20 ha of forest in order for the forest not to be overexploited. Consequently, a typical iron furnace with an annual capacity of 500–1000 t needed to exploit an equivalent surface of forest of between 50 and 200 km^2, with an average transport distance of firewood of between 4 and 8 km, a distance that was the limit for balancing the energetic costs of transport, thus restricting the establishment of factories or shops to certain places and energetic intensities (Fischer-Kowalski et al. 2007, p. 227).

Fluvial and maritime transport first powered by rowing and later by sails, was energetically much less expensive than terrestrial transportation thus being the sole feasible way for long-distance transportation. However, also by boat, the transported volume of economic and ecologic exchanges between territories was limited. British ships of the Colonial India fleet had in 1800 a capacity of around 1,200 mt. Nineteenth century clippers barely exceeded a speed of 9 m per second (Smil 1994, p. 139). These figures give an idea of the physical restrictions prevailing until the late nineteenth century restricting international trade, and hence the exchange of materials and energy between societies.

10.8 Markets, Consume and Excretion

From a physical standpoint, the market represents a social relation of exchange of energy, materials, and information mediated by power relations materialized as currency or other attributes. Because the population of agrarian societies tended to achieve self-sufficiency and circulation, and exchanges were physically limited, the market played a secondary role, in part due to transport limitations, and in part to market being a relation of power mediated either by privileges, status, money, lineage, or by relations of patronage, kinship, friendship, or vicinity. Market was also a social mechanism strongly influenced by ethical considerations from a moral economy regulating and prioritizing equilibrium and stability rather than growth or excessive enrichment.

If, as it seems, the market has a trend towards the growth of the productive effort—selling more to gain more—its limitation in a stationary society becomes logic when considering that the profiting of some ends harming others. Environmental damages or resource scarcity were more rapidly reflected in prices than in present day markets in which the use of fossil fuels and mineral reserves allows for sustaining productivity, even when the resource base becomes degraded.

Maybe because of all the above, the prices or exchange value of basic products was closely associated with the value of use. For example, the market assigned a value to foodstuffs according to their endosomatic usefulness, i.e., based on the amount of kilocalories they supplied to whom ingested them, so that products providing more energy had higher prices. Nowadays, however, price determination follows different principles, the utilitarian association being practically lost. For instance, vegetables have today a relatively larger cost than cereals, despite that the latter supply many more kilocalories than the former (González de Molina and Guzmán-Casado 2006), in general, the price and nutritional value of foodstuffs being uncorrelated.

All these restrictions had a fundamental incidence over the metabolic process of consumption, which was constricted within relatively narrow and sometimes random margins. The ratio of endosomatic to exosomatic consumption that in some current societies can reach 80–1 did not surpass a value of 8–1, although it usually was of 2–3 to 1 (Malanima 2005, p. 16).

The low capacity of mobilization and transformation of materials of these societies also explains why the excretion process was relatively small and, in the case of agrarian activities, closely linked to the appropriation process and playing a chief role in restoration of soil fertility. The organic nature of nearly all materials used and its eminently local circumscription facilitated recycling. The relocation of wastes that, despite what has been said could be generated for example from combustion of biomass, or from the transformation of minerals and other substances, could not represent a thereat to the global environment, but could have impact at more reduced scales. Maybe deforestation—that was practiced to a larger or lesser extent by most agrarian societies—was the local practice that had most global effects on the environment.

With certainty, the fundamental source of energy was in the *domestic extraction* of biomass that agrarian societies were able to harvest in their own territories, and to a much lesser extent, in the importation of external energy or materials. Enough research has been made about societies with organic metabolism, which on one side allows for corroborating what has been until now said, and on the other, for delimit the typical metabolic profile of these societies (Table 10.2).

Fischer-Kowalski et al. (2007, pp. 225–227) compiled several works about the size of social metabolism, observing certain regular patterns and limits as shown in Table 10.2. These authors' studies about Austria and the United Kingdom, two of the wealthiest countries of the second half of the eighteenth century, have shown that the primary energy input received by these nations was of between 50 and 80 GJ/year, and confirm that most of the primary energy was derived from biomass, while wind and hydraulic energy amounted to only 1 % of the total energy input. Between 3 and 10 GJ/year of the harvested biomass was destined for human food, but despite food production was the main goal of agrarian production, the use of domestic animals—also for feeding humans, but above all for obtaining traction power and manure—forced to dedicate between 30 and 40 GJ/inhabitant/year to feeding animals. The remaining portion of the energy input, oscillating between 15 and 35 GJ/inhabitant/year, was devoted to heating homes, provide power for manufacturing shops and small factories, which was dependent on climatic conditions, the importance of industrial or manufacturing industries, and the availability of firewood, and hence, of forests.

Agrarian societies were able to sustain largest real estate assets than hunter-gatherer societies. But despite all, in consequence to the low capacity of intervention in nature of agrarian societies, the stock of buildings and infrastructure did not reach very high levels. Although based on recent studies made in local communities of peripheral countries, it is estimated that between 1 and 2 t of stock corresponded to each inhabitant (Mayrhofer-Grünbühel 2004; Ringhofer 2010).

Fridolin Krausmann (2008) reached to similar conclusions in his study of preindustrial agriculture in four study cases (Theyern, Nussdorf, Voitsau and Großarl) representing the diversity of agroclimatic regions in Austria. A study we made of the agrarian metabolism (thus excluding energy sources not derived from biomass, and only considering agrarian activities) of the peasant community of Santa Fe, Granada in southern Spain during the middle eighteenth century, resulted

Table 10.2 Per capita annual metabolism for different modes of subsistence (metabolic profile)

Hunter-gatherers	Agrarian societies	Industrial societies
Energy input (GJ per capita per year)		
10–20	ca. 65	223
Biomass	Biomass	Energy carriers
(Foodstuffs, wood…)	Vegetables, 3;	Fossil energy, 125;
	Fodder, 50;	Hydraulic energy, 23;
	Wood, 12	Wood, 33;
		Agricultural biomass 42
Materials input (t per capita per year)		
ca. 1	ca. 4	21,5
Biomass	Biomass	Diverse materials
(Foodstuffs, wood…)	Plant foodstuffs, 0.5;	Agricultural biomass, 3.1;
	Fodder, 2.7;	
	Wood, 0.8	Wood, 3.3;
		Fossil fuels, 3.0;
		Gravel, sand, etc., 9.0;
		Others, 3.2

Source (Fischer-Kowalski and Haberl 1997, p. 70)

in figures within the same order of magnitude, although at lower values given the soil and climate conditions of a semiarid climate with limited access to irrigation. The domestic energy input was of nearly 34 GJ/inhabitant/year, while the final energy was close to 14 GJ/inhabitant/year: 80 % of the domestic extraction was dedicated to feeding herds that provided both the needs for animal protein of the population, and manure for covering the fertilizer requirements of the agrarian system (González de Molina and Guzmán-Casado 2006, p. 89). Finally, several case studies have been recently published about extant agrarian societies with predominant organic metabolism: Campo Bello, in the Bolivian Amazon (Ringhofer 2010); Sang Saeng, in northeastern Thailand (Grünbühel et al. 2003); Trinket Island, between Indonesia and India (Singh et al. 2001); and Nalang, in Laos (Mayrhofer-Grünbühel 2004). The only differences found were in the input of external subsidized fossil energy, and on the flow of services (medical, educational, etc.) that are typical of industrial metabolism, which makes these to be hybrid systems with predominance of the basic features of agrarian metabolism.

10.9 Organization and Functioning of the Organic Metabolism

Because combustion or ingestion of biomass covered all the needs of animal traction, replenishment of soil fertility, fuel for domestic use, and for powering the crafts industry, most economic activities and transport, besides providing human food, required of a given extension of territory. The almost total impossibility of importing significant amounts of external energy to managed ecosystems, forced farmers to fulfill their own necessities and others demands with the available extension of land, which was fragmented for alternative uses. Peasants were obliged to establish a complementarity strategy between different uses of the territory. Croplands were devoted to production of foodstuffs for human consumption, fibers and other wanted raw materials. Pastures and grasslands were used for feeding animals, and finally, forests produced firewood and timber for building needs. As stated by Sieferle (2001, p. 20), the different land uses were linked to the various types of energy: croplands provided metabolic energy for feeding humans; grasslands for feeding animals were associated to the mechanical energy provided by traction animals; and forests were linked to thermal energy from fuels needed for cooking, heating, and manufactures. When one of the uses became insufficient for satisfying the demand, attempts were made for compensating the deficit with other land uses. For example, when working animal herds grew beyond the grassland capacity for feeding them, croplands had to provide fodder from a part of the harvest of cereal and legumes, or from crop wastes.

Of course, all three alternative land uses could be practiced within a single plot by combining crops and products (e.g., in agroforestry systems), but the feasibility of this solution depended on the particular conditions of soil and climate of the ecosystems, and on the productive capacity of the land. In climates in which productivity was limited by low precipitation or nutrient scarcity the costs of biomass production were higher than in more favorable environments. In dry, semiarid or arid regions in which water was scarce, land uses could compete between them and be practically excluding, which forced farmers to use more land. The useful agrarian surface (i.e., the surface suited for social metabolism) was thus divided according to the obtained products: agricultural, animal husbandry, and forestry, whose degree of incompatibility depended on the suitability of each agroecosystem. Such agrosilvopastoral systems implied the complex integration of several territorial units having different levels of energetic yield per surface unit (Margalef 2006); these systems through the establishment of the equilibrium between exploitation and conservation, evolved to generate a relevant type of agrarian landscapes adapted both to the environment and to social needs (Agnoletti 2006; Marull et al. 2008, 2010). An example is the traditional *three-field system* characteristic of central Europe and the typical landscapes this system generated (see a description from the perspective of Environmental History in Warde 2009, p. 74), which were surrounded by open grasslands and forests.

Territorial distribution in *ager*, *saltus*, and *silva* was dictated by two other reasons: on one side, the diversity of appropriations, i.e., spatial heterogeneity was the way to mimic the dynamic of natural ecosystems in order to maximize stability (Fig. 10.4). As established by Gliessman (1998, p. 304): *From this comparison we can derive the general principle: as more agroecosystems are more structurally and functionally similar to the natural ecosystems within their biogeographycal region, the more probable it is that agroecosystems are sustainable*; and on the other side, because the equilibrium between the different land uses becomes crucial for achieving socioenvironmental stability, thus avoiding dangerous territorial

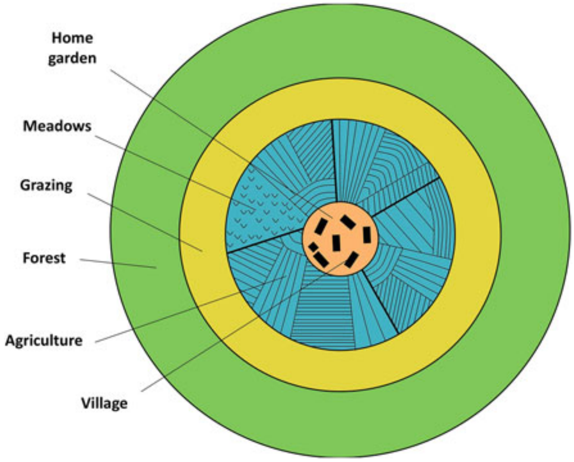


Fig. 10.4 Diagram of the concentric organization of space of peasant communities in Medieval Europe. The cropland area (ager) occupying up to two thirds of the used land was dedicated to sowing wheat, rye, barley, and oats, the latter generally used for feeding horses, and to a lesser extent, millet, sorghum, and several kinds of legumes. The more common modality was the triennial clearing rotation on stripes having equal areas: one for fall cereals (wheat or barley), a second one for spring cereals (barley or oats), and a third one left in fallow where herds were allow to graze and fertilize the land. Less frequently, meadows of cultivated grasses were established for grazing animals. In gardens close to houses, vegetables and fruit trees were cultivated. Another area was devoted to vineyards and olive grooves for production of wine and oil. Finally, the farthest areas were covered with grasslands and forest, usually of communitarian use. *Source* Cantera-Montenegro (1997)

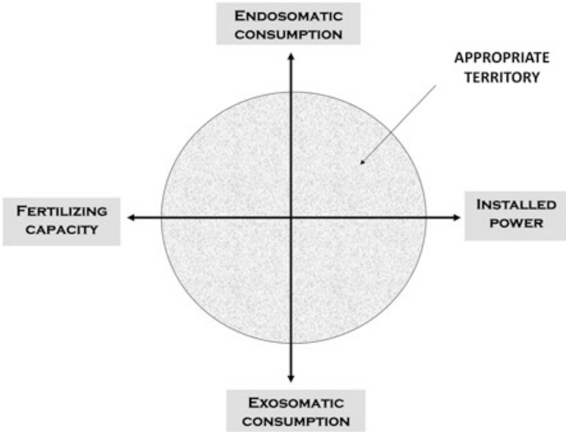
disequilibria forthcoming demographic adjustment, the appropriation of other territories, immigration, etc. These territorial allocations of use reduced the yields of what is nowadays understood as harvest, i.e., the volume of grains directly traded in the market or usable for confection of bread. Restoration of soil fertility required to assign an extension of land to fallow or to feed the animals that produced manure; working animals had to be fed with grasses and, when these were insufficient, with grain deducted from human food. Wastes from cereal and legume harvests were in many agrarian cultures an essential supplement for feeding animals. In fact, the traditional varieties of crops were selected with that function in mind, hence had harvest ratios in which the amounts of hay and grain more than favored the former. This and other characteristics of traditional agricultural production explain why yields were lower than at present. The goal of farmers was to optimize the net primary productivity of the system as a whole, rather than commercialization of a given crop, in order to guarantee the function of the system without deteriorating the environment. From the bulk of net primary production of the appropriated ecosystems, agroecosystems included, only a percentage was devoted to human consumption, and a smaller portion was destined for the market.

This equilibrium between land uses can also be appreciated at a more aggregate scale. The IFF of Vienna has made detailed studies of the territory of present Austria. One of these studies shows that in the early nineteenth century the country used 40 % of its total territory for food production, 10–15 % was used for working animals, and 30 % for heating fuel. The biomass for non-energetic uses, such as timber for construction, was produced in less than 10 % of the total land (Fischer-Kowalski et al. 2007, pp. 227–229). These studies also coincide with the case of Santa Fe in determining the maximum energetic density of Austrian ecosystems at 50 GJ/ha/year. To exceed such limit could only be feasible by an important subsidy of energy and materials from the outside, either as fertilizers or as mechanical traction. The average of about 30 GJ/ha/year could sustain a population density of nearly 40 inhabitants/km^2, with an annual average per capita energy use of approximately 70 GJ. The use of materials would oscillate at between 5 and 6 t per capita, corresponding to about 75 % of the total biomass (Krausmann and Haberl 2007, p. 32). Any attempt to increase these figures would have to be achieved by incorporating more labor, which irremediably tended to reduce the available energy per capita.

The distribution of land uses had to reflect the long-term equilibrium that each agrarian society had to maintain between the endo and exosomatic needs of the population within the extension of useful land. Figure 10.5 shows the main variables involved in creating this *fine* equilibrium. The level reached by one or several of these factors that are represented in Fig. 13.5 (population and its level of endosomatic consumption, the installed potency both in human labor as in animal traction, the capacity for fertilization) determined the amount of produced or appropriated biomass, i.e., the magnitude of the metabolism. It also works the other way around: the amount of appropriated biomass determined the size the population could reach, and its endo and exosomatic needs maintain the appropriate equilibrium between the size of the herds and the capacity for fertilization. The territorial strictness or dependency of organic metabolism could only be overcome through appropriation of more land or its products.

The amount of labor was a limited resource and quite socially distributed, its availability depending on the number of individuals in the community, their rates of reproduction, and its demographic structure (Giampietro 2003; Ringhofer 2010; Schandl and Grünbühel 2005, Fischer-Kowalski et al. 2010; Singh et al. 2010). Unlike the time allocation in hunter-gatherer societies in which adults invested little over 1 h per day in hunting and gathering, in agrarian societies the dedication to economic activities grew considerably, the involvement of children in farm labor becoming significant (Fischer-Kowalski et al. 2010, p. 25, 2011). Time investment grew as cropping was intensified and the yields per surface unit became higher. In traditional agriculture there has always been a close link between production and invested labor. The amount of cultivated land, and the intensity of cultivation depended on human and animal driving force. If the population grew, the possibilities for cultivating more land or doing it at a higher intensity also grew, and inversely, a decrease in population size could reduce the extension of cultivated land, or even resulted in abandonment of a fraction of cultivated land.

Fig. 10.5 In the regions with organic metabolism the size of the appropriated territory was determined by four main factors. See text



This was a rather common pattern in the demographic development of Europe since the beginning of the past century, accompanied by the expansion and contraction of the extension of cultivated land. If enough land was available, the increase in production could be achieved by means of the substitution of human labor for animal work. In both cases, productivity was limited, especially with the intensive use of human labor. For that reason, the productivity of labor was very low in this kind of agriculture, and there was a high correlation between demographic density and land cultivation, such that more intensive agricultures had to withstand high population densities and vice versa. Productivity could only be increased by the improvement of productive techniques, such as irrigation or a better combination of crops. Its feasibility was restricted by the chronic scarcity of organic matter and fertilizers, i.e., by a larger extension of land suitable for cultivation or grazing to feed a more numerous herd, and by the investment of a considerable larger amount of labor in confection and application of organic fertilizers.

The expansion of the appropriated territory had not only topographic but also physical limitations. As the extension of exploited territory increased, the costs of transport of materials, working animals, and human labor also increased. The increase in time lost in transportation reduced the time available for farm work. In consequence, the extension of the appropriated land could only be successful through the increment of the ratio of potency invested in transport or farm activities; both of which in turn depended on land availability (Giampietro et al. 1993, pp. 142, 151). Definitely, an increase in biomass productivity for any metabolic purpose could only be achieved by the exploitation of a more extended territory. But this solution had limits that were not only derived from the also limited land availability of each society, but also because it required of more labor per unit of surface, and hence, sooner or later a decrease in labor productivity occurred. Considering the territorial equilibrium organic societies needed to establish, the impossibility of indefinitely expanding production without human labor and territorial costs, little possibilities existed of having an economy in a *progressive state*, i.e., sustained economic growth. Therefore, the magnitude of organic metabolism *tended*—meaning it was always like that—to remain stable, and its economy to be in a *stationary state* (Daly 1973; Sieferle 2001).

All the above-mentioned means that societies with organic metabolism had to pay a high *territorial cost* for satisfying their needs. Because of this compromise between productivity and extension of appropriated land, technological innovation was primarily oriented towards saving land, given this was the limiting factor that could become scarce in the eventuality of demographic growth. The *land cost* expresses not only the *land requirements*, i.e., the extension of land needed for producing a given amount of biomass according to its edaphic and climatic conditions, but also the arrangement of the territory or the specific combination of land uses, or the *land functionality* assuring its long-term stability. The above implies biodiversity and land use heterogeneity. In the regime of industrial metabolism this equilibrium is replaced by *equivalent land* thanks to the use of fossil fuels (Guzmán Casado and González de Molina 2009; Guzmán Casado et al. 2011). So for any given society the land cost varied depending on population size and its metabolic profile, evolving through different steady states.

And this is another defining feature of the organic metabolism: the tendency towards equilibrium and stability (reproduction), leaving little margin for the physical continued growth of production. Anthony Wrigley, who introduced the term *organic economies*, refers to societies with organic or agrarian metabolism as societies in which […] *neither the process of modernization nor the presence of a capitalist economic system was capable of guaranteeing sustained growth* […] [Wrigley 2004, p. 29]. Nevertheless, agrarian regimes could also experiment periods of physical growth. Throughout history and in particular during the Modern Age, episodes of economic growth have occurred based on the productive specialization and urbanization (Wrigley 1987, 1988; De Vries 2008), but have actually been temporal and motivated more by *colonization* of new territories than by important technological leaps (Sieferle 2001). Some organic societies—e.g., the Roman Empire—ended in a collapse, and others returned to their initial state. This is, for instance, the case of the Chinese province of Lignan studied by Marks (2007), which experienced a clear process of agrarian specialization and foment of commercial crops, which caused important changes in land use and the partial mercantilization of peasant economies during the eighteenth and nineteenth centuries. But this growth did not give place to an appreciable metabolic transformation nor it opened the transition to an industrial metabolism: agrarian growth was discontinuous.

This tendency to a stationary state, also based on scarcity, imposed a strict regulation of those factors that could destabilize the system. In that context, social regulation mechanisms included emigration to more fertile regions, birth control, change in feeding habits, use of commercial trade, conquer of new territories, and the unequal distribution of resources (Fischer-Kowalski and Haberl 1997, p. 62). But we will discuss the dynamics of organic metabolism in a later section.

10.10 Common Features of Societarian Diversity

Under a same general mode of use of nature, the organic metabolic regime, a complex chain of societal configurations took place. From tribes to the seignorities or chiefdoms, and from these to several modalities having State characteristics, including antique, classical and modern civilizing developments that despite their marked differences were based on a single form of appropriation of nature that became perfected and gained in efficiency through time, always within a well-established scale of magnitude. The first empires, conceived as a configuration in which a state dominates another state, also rose within this type of social metabolism. Seen in perspective, most of the *historical facts* occurred under a metabolism having an organic foundation. All of the complexities of human nature, noble or terrible, transcending or insignificant, profane or sacred, sublime or vulgar, were always fed from the intermittent solar energy.

From the 6–13 million individuals inhabiting the world of the hunter-gatherers (Livi-Bacci 1992, p. 31), the population grew to the 940 millions of humans living in the world just before the Industrial Revolution (Cipolla 1978; Livi-Bacci 1990). Throughout the time period dominated by agrarian societies the population as a whole grew at a slow pace and with many fluctuations, a growth pattern coherent with the type of metabolism we have been describing. In recent years, Modelski (2007) created a detailed database of the ancient cities including information about 400 urban centers along a period of 4000 years going from 3000 BC to 2000 AD. His analysis reveals a strange pattern: the number of cities in the world grew between the years 3000–2000 BC, and from the year 1–1000 AD.

Throughout history organic based societies showed, however, a general trend of population growth. The population control practiced by hunter-gatherers had a much laxer modality so that population density quickly reached levels that favored the appearance of infectious diseases, epidemics, and pandemics caused by the proliferation of human pathogenic microorganisms (McNeill 1976, 1980; Cohen 1989; Ewald 1994; Crosby 2007). The high mortality rates resulting from such proliferation in a world holding a much closer relation between food production and available work force needed to be compensated by corresponding higher birth rates. Wars, famines and epidemics were common events in agrarian societies. In such conditions, the attempts made for controlling birth rates became more difficult or even senseless in face of such a high mortality. Large families were socially encouraged. Because of these and other reasons, population figures were not stable but fluctuated widely (Sieferle 2001, pp. 32–33).

At the beginning of the Christian era, the population had already reached 170 millions. By the fourth century the expansion cycles of both population growth and agrarian production broke down in coincidence with the bubonic plague of the years 441–444 AD—known as the Plague of Justinian—that afflicted China and Europe. A new expansion cycle would later be started with the clearing and cultivation of new lands, and a significant leap in human appropriation of net primary productivity. The combination of a series of events occurred during this years that decimated the human population: climatic fluctuations, volcanic eruptions, earthquakes, and devastating epidemics. The Great Famine of 1314–1322 created unfavorable conditions for the occurrence of the Great Plague striking the European continent that began in Sicily in the year 1347. Along the 300 years mediating between the twelfth and the sixteenth centuries, the population was capable of increasing by 12.4 % reaching 440 millions. A new cycle of expansion of population and agriculture would be interrupted by a new incidence of climatic and biological eventualities occurring during the seventeenth century. Epidemics continued to be responsible for demographic fluctuations and the reduction of the population, but would no longer cause the demographic catastrophes that took place centuries before (Cipolla 1993; McKeown 1990).

10.11 The Protagonic Role of Peasantry

In societies with organic metabolism most of the population lived as peasants, in consequence with the relevance of agrarian activities. That does not mean that the peasantry became a relict of the past, or that it represented an early stage of human history (Rostow 1960), as for a long time was held both by the liberal as by the Marxist tradition. The peasantry has not disappeared in today's world, despite the prophetic theories of the classics of agrarian thought (Calva 1988; Toledo 1990; Kearney 1996; González de Molina 2001; González de Molina and Sevilla Guzmán 2001; Holt-Giménez 2006; McMichael 2008). In view of that, it seems logical to define peasantry as a social category that is essentially historical, and whose features that have undoubtedly been transformed through time maintain a certain unity or *familiar air*. Attending to its socioecological nature, we may consider peasantry as: *owning a fragment of nature that is directly appropriated at a small scale by means of their own manual labor, having solar irradiation as their fundamental source of energy, and their own knowledge and beliefs as their intellectual means. Such appropriation constitutes their main occupation, from which they consume firsthand, in whole or in part the obtained fruits, and from which they either directly or indirectly through their exchange satisfy the needs of their families* [Toledo 1990]. The latter perspective allows for identifying peasantry as a social category associated to one of the forms of articulation of social metabolism. Thus, the common features that is possible to observe throughout space and time are better understood and contextualized by proposing an explanatory theory of their evolution, or as we understand it, of their transformation into other novel and distinct social categories. In other words, peasantry is the social group around which agrarian societies organized—and continue to do so in many regions of the world—the agrarian activities in societies based on solar energy. That implies establishing a rather strong identification between *organic metabolism* and peasantry (González de Molina and Sevilla Guzmán 2001).

Peasantry was thus the social group on which rested the responsibility of performing the most important metabolic functions of societies under organic metabolism, including the bulk of the appropriation process, which also explains why it was the more numerous social group (González de Molina and Sevilla Guzmán 2001). According to the features of organic metabolism, it is understood that the subject of the appropriation process would be: a cultivator having enough work force and knowledge about natural and agricultural cycles that was acquired through experimentation; a farmer that looked more for its sustentation than for maximizing his opportunities for consumption or benefits, limiting his consumption to the allocation of work he and his family required; an individual who persisted in his productive activity with a long term view, self exploiting himself if it became necessary, or consuming less than the indispensable to endure juncture difficulties regarding the environment, politics or economy. In sum, an individual who procured to maximize the net primary productivity of agroecosystems without overexploiting the land of which his self sufficiency and subsistence depended on (Toledo 1990). Most of the defining features of the peasantry (Calva 1988; Sevilla Guzmán and González de Molina 2004) were *functional* or were well adapted to organic based economies, which could only function with producers that could establish an identity between agrarian production with family economy, and which could mobilize all workers that could be available for agricultural labor, developing successional and marriage strategies that aggregated the factors of production as much as it was possible, thus ensuring the utility of appropriation for the survival of future generations.

The only way organic economies could function was through the existence of a network of mutual support between farmers that was mediated through kinship, neighborhood or friendship, in a way that families were guarded against adversities. Functioning depended on the generation of common culture and ethics, on an identity that gathered and codified the knowledge about the environment, the crops, the practices of animal management, the successful or unsuccessful practices of facing everyday challenges, etc.; that is, economic functioning depended on all that was indispensable for sustaining successful farming through the years. A necessary condition was adopting a diversified land use taking advantage of the required spatial heterogeneity imposed by complementarity and integration of agriculture, animal husbandry, and forestry, thus making the farming system possible. Multiple land use was also a strategy of diversification of the inherent risks of climatic or economic fluctuation, such that its maintenance in good conditions—for example, the respect for natural cycles and the systems of soil fertility restoration—became a *sine qua non* condition for the subsistence of farmers and the future survival of their children. It is for these reasons that the existence of an *ecological rationality* has been proposed (Toledo 1990; Toledo and Barrera-Bassols 2008).

With this **multiple use strategy** in mind peasants achieved their subsistence through manipulation of the geographical, ecological, biological, and genetic components (genes, species, soils, topography, climate, water, and space), and the ecological processes (succession, life cycles, and material flows). The same diversified arrangement was applied to each of the productive systems, e.g., terrestrial or aquatic multiple-cropping systems instead of monoculture, monospecific herds, forests, or fisheries. In sum, the domestic peasant units tended to practice an unspecialized production based on the diversity of resources and practices. This mode of subsistence promoted the maximization of use of all surrounding landscapes, the cycling of materials, energy, and wastes, the diversification of obtained products, and above all, the integration of different practices: agriculture, gathering, forest extraction, agroforestry, fishing, hunting, small scale animal husbandry, and crafts.

All peasant producers need *intellectual means* for appropriating nature. In the context of a subsistence economy, such knowledge of nature became a decisive component in the design and implementation of survival strategies. Such knowledge was orally transmitted across generations, and through it peasants refined their relations with the environment. Since this body of information follows a logic differing from that of current science, it has been called *saberes*, a Spanish term referring to a pool of particular (local) knowledges (Toledo and Barrera-Bassols 2008). Peasant societies own a repertoire of ecological knowledge that was generally local, collective, diachronic, and holistic. In fact, peasant groups have through time developed management strategies and generated cognitive systems about their surrounding natural resources, which are transmitted across generations (Fig. 10.6).

A number of social institutions tried to assure the maintenance of the group, protecting society from environmental or economic perturbations, its resilience and stability through time depending as well on the efficiency of the performance of such institutions. The role of domestic units is well known in the context of human reproduction and peasant economies, and in the development of strategies that eventually affects the size of the population and the capacity for generating productive work, reason because of which we will not deepen in this matter that has been sufficiently covered in historical and anthropological works (Goody 1986; Bourdieu 1991, 2004). More interesting to us is to underline other aspects related to the institutional framework and social behavior that had a relevant function for the continuity of metabolic relations.

The peasant group could only handle a small portion of suitable land, that of its own exploitation. The joint management and control—also being essential for survival of the domestic economy itself—corresponded to the peasant community. The community was the minimal unit of population of the territory and in it predominated peasant domestic groups specialized in agrarian activity, towards which were oriented—as auxiliary, complementary or dependent activities—all other crafts or professional activities. Given the localized and usually relatively closed dimension of the flows of energy and materials, the scarce external exchanges, and the patterns of population and distribution on the land, most social life took place in hamlets, villages, or small population nuclei, and from these flowed the information essential for the functioning of social metabolism. The peasant community was, therefore, the minimal unit of organization of production driven by solar energy.

From the political perspective, these basic cores of territorial occupation had ample capabilities upon all factors of agrarian production and of the whole of the

Fig. 10.6 Photograph of a contemporary peasant property in the periphery of Córdoba, Spain. The approximately one hectare plot shows patches devoted to a variety of horticultural products, a horse, and the family house surrounded by trees. The photograph was taken from the building of the *Escuela de Ingenieros Agrónomos de la Universidad de Córdoba*, for which courses the dynamics of the peasant family was repeatedly analyzed. Photograph taken by Julio Sánchez

appropriation process. To their political institutions—whichever these were—corresponded for instance the establishing of norms impeding overexploitation of forests or the land, or of overgrazing during the appropriation of firewood or manure; to them also corresponded the regulation of the changes in land use within the territory, fomenting or not the necessary equilibrium needed between the different exploitations within it; they were also in charge of guarding the *personal conditions of production* through the execution of actions in the context of public health, beneficence, instruction, defense against external threats, or provision of material aid in moments of crisis. Overall, the elaboration of collective norms in organic societies was aimed at the avoidance of both the use, as the excessive consumption of common resources (Warde 2009, p. 76). All these collective norms regulated, sometimes in a rigorous fashion, the functioning and practices of farmers. Nothing was more distant from the old ideas of the *tragedy of the commons* that Hardin (1968) propelled, identifying the open fields and the communal system with unrestricted access to them. Both access and use were under a strong regulation seeking cooperation and preventing free-rider behavior; i.e., that no neighbor took advantage of common resources such that these could be overexploited. In other words, these social institutions attempted to constrain socioecological entropy—given that the transferences from and to other territories was obligatorily limited—and to distribute it equally among all; because of that, societies tended to a steady state. In fact, as soon as the new capitalistic social network was established it immediately attempted to abolish these social institutions. As stated by Paul Warde (2009, p. 76) *the abolition of systems of collective constraint through the enclosure movement, that waxed most prominently and early in England but that would embrace most of the western Europe in the* *nineteenth century, remove the issue of the consequences of neighbourly action from the agronomist's purview. The system of agricultural action became the farm unit, the environment denoted as 'natural' or 'market' forces* [Warde 2009, 76]."

Precisely due to their ample and decisive capabilities regarding the stability of the metabolic relation, elites and dominant classes developed throughout history specific strategies for ensuring their control. Vassalage, patronage, and clientelism were profusely used instruments for guaranteeing such control. Local communities frequently had competence over the material administration of land, because of which, in practice, they ordered the metabolic process of appropriation and contributed to reaching equilibrium between the different forms of land use, ensuring the reproduction of the steady state character of the economy. Either because they regulated access to the land, possessed large surfaces of land or administered it—including natural ecosystems or even a part of the agroecosystems—the fact is that social institutions had a definite role in the functioning of social metabolism. They were, thus, essential instruments for preserving stability or for generating crisis.

Laws and other norms, either positive or consuetudinary, had a first order stabilizing role. Some of these regulations—either establishing individual or communal properties—were directly oriented towards the protection of large portions or the whole of the territory occupied by each community, in a way that the long term functions inherent to territories (of food or energy provision, beneficence, agrarian, etc.) were ensured, avoiding changing its land use or overexploiting it. For example, in the Crown of Castile during the early modern period, the protection of forests and grasslands from the real threats of clearing or private appropriation—for satisfying the needs of either agricultural production growth, or the ambition of feudal lords and local elites—was achieved through the figure of communal property (González de Molina and Ortega Santos 2000).

Defense of the appropriated land against attempts of raiding or exploitation, or from the procurement of new land to conquer or subjugate, was assigned to the different political entities of agrarian societies. When a society needed for its metabolic functioning of energy or materials unavailable within its territory, the need for obtaining them from elsewhere was imposed, either by pacific or by violent means, first in nearby, and gradually in further territories. Whenever this was impossible or inconvenient, subjugation to the dominant power was paid either in currency or in goods. In agrarian societies, the common way of exploitation of one community over other, or of one class over other class, was the appropriation of surpluses through force or legal coercion, as in tributary or feudal societies or in the wars of the ancient world in which there was ransacking, or tributary loads were imposed. This flow of resources became indispensable for supporting the colonizing power of the dominant society. Territorial expansion of agrarian societies was not always motivated by disequilibrium between population density and own resource availability, but it seems clear that expansionist adventures were physically impossible without the resources provided by the newly conquered territories, as is demonstrated by the well known case of the Roman Empire.

10.12 Unsustainability and Crisis of the Organic Metabolism

The expansion or contraction of organic metabolism was the result of the action of the factors we have herein reviewed. When population density, consumption, external demands, or other factors went down, the adjustment occurred without problem by a corresponding reduction either in the land extension under appropriation or in the intensity of its exploitation. More serious issues rose when adjusting larger demands from a limited land extension. Agrarian societies had access to, at least, three possible solutions. The first one was reverting to the previous state of equilibrium—although this was not reached in a short period of time—by means of social homeostatic mechanisms: emigration, birth control, wars, reduction of tributes and of social exploitation, etc. These mechanisms could not always be applied; there were societies in which the ideological changes and advancement of knowledge made their use more difficult, but these favored the search for alternative answers.

The second group of solutions was to increase production itself by several possible means, the most evident being to increase the surface of appropriated land, or to optimize the different land uses when it was possible. Nevertheless this was not always a feasible, or at least ideal, solution. The conflicts over communal resources, over unoccupied lands, or over land use as graze land or cropland were frequent among local communities (Pascua Echegaray 2011).

One other option was to enhance soil productivity, which could be achieved through crop rotation, more intensive cropping, shortening of fallow periods, or sowing more productive seeds. But all these procedures required of more labor, more water (in cases it was scarce), and application of more organic mater, and this was not equally feasible in all places (González de Molina 2002). Even in zones in which available work force was plentiful, replenishment of soil fertility was the main limiting factor of an increased productivity. Despite that the obtainable sources of organic mater could supply enough nutrients to sustain 12–14 persons per cultivated hectare, such limits could not be surpassed by traditional methods (Smil 1994, p. 80). In general, the strategies for intensifying production could only be successful if enough land was available for feeding the animals that would mobilize the needed nutrients for increased soil fertilization.

Another option that was particularly well suited for dry climates was to expand irrigated lands and to consolidate the sources of irrigation water. In fact, this was the more common solution in nearly all countries of the Mediterranean coast, China, Mesoamerica, and the Middle East. However, until the arrival of fossil fuels, the multiplication of the extractive capacity of groundwater, and the building of large reservoirs, extending irrigation was territorially limited and was subject to the seasonal regime of rivers and other water bodies. Finally, an improvement of the productivity of labor, which either liberated work force or made this more efficient, largely depended on the introduction of new implements or on substitution of human for animal work. But, given its high territorial cost, the latter solution depended on land availability.

The result of all the above-mentioned strategies was a slow increase of agricultural yield, which in certain zones of Earth was vital for the growth of cities, and, definitively, for the increase of social complexity. According to data of Smil (1994, p. 77), in more ancient societies agriculture had a given average of persons per cultivated hectare. Hundreds of years had to elapse before that figure was duplicated: apparently, 2,000 years were needed for that to happen in the Middle East, China, and Europe. Despite this data, traditional agricultures cannot be blamed of being inefficient. Important regional achievements occurred in which 10–14 persons could be sustained with one hectare of cropped land in some areas of Japan, Chine, Vietnam, and Java in association with rice cultivation under irrigation (McNetting 1993).

10.13 The Agrarian Empires

A third group of answers was based on appropriation of more land through either violent or peaceful means. These solutions, and the demand of tribute paid in goods or in currency, were profusely used to avoid the *Malthusian trap* of agrarian societies. Myrdal (2007) studied the formation of the Swedish Empire in the seventeenth century, finding that the main objective of expansion was—together with others having religious, commercial, or geopolitical character—the conquest of territories with surplus grain production. Agricultural production had become stalled just when population was growing, thus causing a severe food crisis. A similar pattern was followed by the Ottoman expansion in southeast Europe.

The creation, expansion, and consolidation of agrarian empires in antiquity have been profusely studied in Mesopotamia, Mesoamerica, and the Andean region. In the case of Mesoamerica, states expanded through the expansion of tribute acquired either by conquer or by agreements. By the sixteenth century, the Mexica or Aztec Empire—the most important in ancient México—had reached a huge dominium both in terms of territory as in number of subjugated or integrated peoples. Domination was usually realized over *seignorities* or *chiefdoms* that were sociopolitical entities known as *altepetl* governed by a lord or king (the *tlatoani*), which could be simple and little stratified, or plural, cosmopolitan, multicultural, and highly hierarchical. Each *altepetl,* as an organized corporation, ruled over five, ten or more localities or agrarian communities. By 1420, the Mexica Empire dominated between 600 and 700 of the total 1,200 existing seignorities (García-Martínez 1998). The codex known as the *Matrícula de Tributos* (Tribute roll) contains a detailed record of foodstuffs, raw materials, crafts, and diverse objects tribute to the Mexica Empire from 39 regions and 326 localities or towns, allowing for compiling the volumes of inputs received by the central power every day throughout the years (Bartra 1974).

The European conquest of many regions of Earth beginning during the sixteenth century must also be seen as the product of this territorial demand. Without the territorial expansion that followed the Age of Discovery the economic growth of the European organic metabolism would have been impossible, as exemplified by the relocation of European silver mines in the American colonies (e.g., Potosí) (Moore 2007). By the middle fifteenth century central Europe leaded the world production of iron and silver. The production of over 30.000 t of iron, a figure that grew rapidly during the first half of the sixteenth century, required massive access to forests. Between 6,000 and 8,000 ha of forest were cleared every year, i.e., between 440 and 600,000 ha in the period between the years 1424 and 1440. The expansion of metallurgic activities consumed the forests of central Europe at an unprecedented pace. During the sixteenth century the deforestation largely exceeded that occurred during the thirteenth century. The price of firewood quickly rose from the year 1470, so charcoal demanded the highest expenditure (over 70 %) in the process of metallurgic production.

The peasant opposition to deforestation, a large part of forests being of common use, slowed the process at the time it created more difficult conditions for the metallurgic industry. Social and environmental problems created by the metallurgic expansion made more viable the relocation of the activity to the New World where wood was plentifully available and work force was inexpensive. In the early seventeenth century Europe produced only one tenth of the silver ingots arriving to Seville. Similar arguments can be stated regarding other mining centers in Colonial America.

The issues associated with these expansionist solutions were their high cost in human, political, and administrative terms, which compromised its long-term feasibility. The development of commercial relations between countries became an excellent alternative. Through the market and commercial trade land was imported, transferring domestic demands to other territories having a less strict relation between population density and resource availability. As the radius of action of land imports became wider, the possibility of these being obtained by military interventions correspondingly decreased. In other terms, the farther away that energy and materials were exchanged from, more chances were there that such exchange was of a mercantile nature, i.e., mediated by money. As a possible complementary measure, population could be sent to colonize new territories, thus releasing the demographic pressures. In that way it can be explained that agrarian societies ended up colonizing most of the planet. By such means, some agrarian societies could maintain certain level of economic growth during a sufficient length of time. The above does not contradict what has been stated when underscoring the trend of agrarian societies to a steady state, or when we discarded that these could undergo a sustained or permanent economic growth.

But territorial expansion presented risks—beyond those derived from a continued political domination or the insecurities associated to transport—from the environmental damages caused by a more copious metabolic activity. McNeill (2007, p. 200) has, for instance, shown that the expansion of sugar cane cultivation in the American colonies created the conditions for the propagation of the yellow fever.

Impacts have been not only caused by the so-called *biological unification of the world* and its dramatic effects on the indigenous population (Crosby 1988). Throughout history the main waves of colonial and imperial expansion (both European and from other civilizations) have also occurred in detriment of ancestral languages and traditional cultures. The European conquest of America decimated up to 90 % of the native population (Denevan 1992), extinguished hundreds of cultures, and according to a study, reduced the regional linguistic diversity from 1,490 to 400 languages (Loukotka 1967). Independently, Lizarralde (2001) estimated that the number of indigenous groups in South America decreased by 34 % after contact with Europeans.

Marks (2007, p. 42) studied a prototypical case of the damages caused by the expansion of the agricultural activity: "During the middle sixteenth century the population substantially diminished and forests returned to Lignam (southern China), the range of tigers expanded, even in densely populated areas as in the of Guangzhou prefecture in the Pearl River Delta. When the population began to recover, the tigers and the people entered in contact. By 1700 the habitat of the tigers had probably been destroyed in and around Guangzhou, while the mountains in Guangdong and Guangxi became reforested, as was most of the southwestern littoral. When people moved to the mountains and burned the forests, tiger attacks became dispersed, ending at the beginning of the nineteenth century in the northernmost zone of Guangdong…If forest clearing destroyed the tiger's habitat, placing them at the verge of extinction, other kind of wild life expected the same fate [Marks 2007, p. 42]."

Indeed, the oscillations of population density allowed for recovery of the forest cover and of favorable conditions for certain species to thrive. Only when the growth of the population became restrained by the mechanisms keeping it under relative stability, and commercial relations became permanently established in the heart of societies, was that agrarian expansion began to create more durable damages, some of which became irreversible.

Despite all, environmental impacts of agrarian societies were mostly local and regional; they were localized and affected a limited zone. But, to the contrary of what occurs at present, the damages were so noticeable and they had such immediate repercussions that they quickly became social issues. Thus, seen from this perspective, the distinction between agrarian and industrial societies cannot be an issue of good or bad, but of different degrees of environmental damage capacity and tolerance to its consequences.

Maybe it is for this that the claims holding that agrarian societies are unable to develop long-term sustainability are untenable, such as stated by M. Fischer-Kowalski and H. Haberl: *They depleted many natural resources on which they depended, such as forests and croplands, and only offered rather miserable ways of life based on hard work and malnutrition for most of its members. The technological advances such as the use of iron plows and horses had only a temporary utility rapidly compensated by population growth* [Fischer-Kowalski and Haberl 1997, pp. 68, 69].

Such a negative view of agrarian societies precisely oversee that environmental damages had an eminently local dimension, and not a global scale as in the present. It also ignores that the continual adjustments that agrarian societies were obliged to perform in order to gain stability by recovering their steady state conditions, turns these into a pool of good practices (and also of bad ones) leading to sustainability. Surely enough, hard work and in some cases malnutrition are characteristic of the life in agrarian societies that are not desired, but the adjective of *miserable* given to life in them leads to the discussion of moral criteria with which to judge current material wellbeing used as a comparative standard, more so in a society in which we live beyond our material means.

10.14 The Collapses of Societies with Organic Metabolism

Sieferle (2003) made a thorough summary of the environmental damages that agrarian societies could cause, and of the sustainability issues they had to face. They cleared forests, crated agroecosystems, selected some species and sought for the extinction of others. Their strategy centered in monopolizing an area—together with the solar irradiation in it—for development of organisms useful for humans. They constantly had to struggle, with variable success, to sustain a fragile balance between population growth, performance of agricultural technology, and supply of the work force needed for maintaining the productivity of agroecosystems and soil fertility.

This placed agrarian societies in a situation of permanent risk, often rising from a combination of technological and political dependencies, and from fluctuations of natural systems. Maybe this is what allowed these societies to develop the arsenal of adaptive strategies and management practices that are nowadays of maximum relevance for designing sustainable productive systems. In fact, many of these practices were successful given that, as acknowledged by Sieferle, the socioecological regimes have in many places of Earth persisted for thousands of years until the present. As accurately stated by Paul Warde, a concept similar to that of sustainability was obviously inexistent, bit peasants had *some kind of ethic of sustainability, or perhaps less pejoratively, of durability* [Warde 2009, p. 87].

It is nevertheless clear that the expansion of some agrarian societies, noticeably those from Europe and some from Asia, multiplied the environmental impacts, and hence the possibility of unsustainability. For Fischer-Kowalski and Haberl (1997, pp. 66, 68), the way in which agrarian societies may be useful for understanding the "dramatic changes in modes of production, the resources used, the ways of population control, and the complex interaction of the elements… and throw some light about the question of why some cultures collapsed and others survived [Fischer-Kowalski and Haberl 1997, pp. 66, 68]". Definitively the issues of un-sustainability of the agrarian or organic metabolic regime derived from the disequilibrium between population and resources, particularly land, as the only way of capturing the net primary productivity from which everything else was dependent on. The provision of land owned by a local community was thus decisive. The increment of the population generated land scarcity and in the impossibility of acquiring new territories, the intensification of cultivation, and the consequent increase in productivity, was the only possible solution. But such an alternative was also limited by factors such as for instance the capacity of the community for soil fertilization, or the adequate integration of land uses. These limits could be surpassed breaking the agrosilvopastoral or nutrient mining equilibriums, causing chemical soil degradation. The latter event accompanied by physical soil erosion happened in the late nineteenth century in a community in southern Spain (Montefrío, province of Granada) studied by us, in which intensification was the answer chosen to face the increase in population (García Latorre et al. 2001; García Latorre and García Latorre 2007; Guzmán Casado et al. 2011).

In the past decades a plethora of works have been devoted to study the collapse of empires or cultures, many of which have been focused on environmental aspects. Some of these cases involving agrarian societies have received particular attention, as the examples of the collapse of ancient Mesopotamian cultures in which, according to these works, the overexploitation of hydric resources played a primordial role. Another example is the Mayan culture, which until the year 1000 AD reached a population of over three million inhabitants distributed in México, Guatemala, and Belize. By the arrival of Spanish conquerors, the region had a little over 100,000 inhabitants. Poor agricultural practices—mostly in terms of excessive erosion and failures in water management—could have originated the collapse of the Maya. However, over one hundred different hypotheses have been postulated about this collapse (Toledo and Barrera-Bassols 2008).

Assigning to a single cause—in this case, environment—the collapse of certain civilizations or societies would by historiographically inaccurate. Undoubtedly environmental variables played a relevant role in the decline of such societies, particularly of empires, among other things because of their strong dependency on territory, as we have seen here. But while environmental factors were not the only causes of these collapses, it is certain that these must have a relevant position in their explanation. All expansion of a political entity needed to be supported by a plentiful enough source of resources for maintaining stability. Likewise, it is logical to consider an increase in the costs of an empire that is proportional to its territorial extension. Such an assumption seems to be sustained by recent studies (Tainter 1988, 2007; Reale and Shukla 2000; Hughes 2007; De Vries and Bert 2007).

Regardless of the reductionism of their conclusions, studies such as that of Tainter (1988, 2007) contain hypotheses about social complexity of empires that could provide insight into the issues these societies experimented for surviving through time. The construction of empires was based on a first stage of conquest of smaller reigns and exploitation of their resources, because this was easier than increasing the yields of their own agriculture. To that means, empires invested a significant amount of their total energy in armies and administration, rather than in raising the life quality of their farmers. The conquest of reigns was a way for increasing the total energy ratio of metabolism beyond what could be harvested through exploitation of their domestic land.

But unlike the characteristic of uninterrupted flow deriving from agriculture itself, the resources obtained through conquest were merely stocks that would be exhausted by their use. When no more reigns remained for utilizing their stocks, the responsibility for sustaining the unproductive sector of the population depended exclusively on the surpluses generated by agricultural activities. At that moment, the uncoupling between the onerous costs of administration and supply, and the surplus produced by the primary sector became evident. This uncoupling could for a while be overcame by rising taxes on farmers, thus reducing their consumption, but this solution made life impossible for farmers in the long term, causing the loss of the sense of belonging to the empire that played such a central role. In that conditions the existence of social issues or imbalances, although small, could lead to the collapse of the system as a whole. That seems to have happened to the Roman Empire (Tainter 1988, 1994; Allen et al. 2003; Hughes 2007).

Nevertheless, works such as those of Tainter go beyond by proposing a practically automatic relation between the increase in social complexity and the consumption of energy, as occurred in the case of the Roman Empire. For Tainter, the Roman Empire is one more case study but it represents how societies solve their problems by increasing complexity, which in turn increases costs. In the normal course of economic evolution this process generates decreasing yields: *Once diminishing returns set in, a problem-solving society must either find new resources to continue the activity, or fund the activity by reducing the share of resources available to other economic sectors. The latter is likely to produce economic contraction, popular discontent, and eventual collapse* [Tainter 2011, 93]. However, as seen along the present Chapter, there is no connection linearly linking the increase in complexity with the consumption of energy and materials. Such a linear relation has been established in the heart of industrial metabolism, and is due to its particular institutional network that, as we will see, favors economic growth. In a sustainable world social complexity needs not to lead towards a greater consumption of energy and materials, something we will see in later Chapters.

10.15 The Environmental Conflicts of Organic Metabolism

If juridical and political institutions and social rules attempted to provide stability to social metabolism, the unequal distribution of power and wealth in agrarian societies made socioenvironmental conflicts to be permanent sources of instability. The main conflicts rose around the appropriation of net primary productivity and its social utilization. That does not imply that these conflicts were unique, but the most relevant from the environmental standpoint on which we are interested here. From this perspective placing land in the center of social relations—as a conditional for facilitating the photosynthetic process—it is essential to refer to the forms of organization of appropriation in each society. Hence, in societies having an organic energy support, the struggles for the access and usufruct of the different land uses—those making possible cropping, grazing, gathering from the wild, hunting, fishing or extraction of materials, and even the use of irrigation water—are placed in the center of the environmental conflicts.

Likewise, the amount of biomass or extracted materials was a matter of confrontation between communities and social groups. A number of written or consuetudinary juridical norms regulated the access and use of resources by means of assigning ownership and rights of use to certain social groups based on kinship, blood lineage, belonging to a caste or community, or simply by ownership rights. Only a few societies distributed such rights in an egalitarian way, thus becoming a source of conflicts.

Two general types of environmental conflicts were present in agrarian societies: those derived from unequal distribution of resources between territories or communities, and those derived from unequal distribution of resources between social groups within a community. The latter type is confused with conflicts traditionally considered as class conflicts, among other things. The income of dominant groups depended directly, and was often integrated by, natural resources, which explains why the control of natural resources was a source of power, and at the same time, that such control served to ensure a privileged access to resources.

It can be said that an important portion of class conflicts in preindustrial economies, or in present organic energy based economies, can also be considered as environmental conflicts. Many peasant revolts that tore the history of feudal and tributary regimes obeyed to this scheme. For example, the German Peasants' War in the 1320s were related, among other things, to peasant access to communitarian forests, which feudal lords attempted to restrict or even abolish when they realized that the growing metallurgical activity provided them with a profitable market for their products (Moore 2007, 128).

The territorial conflicts confronted communities or entire societies for the usufruct of a given territory. Such confrontations operate at several scales going from those between neighboring communities within the same space, to conflicts between States (city-states, empires, feuds, tributary seignorities, monarchies), and between peripheral imperial States, which could become wars. At the local scale, conflict was generated by struggles between communities for the control and appropriation of a territory, or by the pretensions of individuals or groups within a community of appropriating a larger fraction of the disputed resources.

For example, agrarian societies attempted to preserve their steady state social equilibrium by the communitarian appropriation of those resources that were basic for the continuity of agrarian activity: fodder for rental and transport animals, fuels, building materials, supplies of mobilizable nitrogen, refugee from natural enemies, other nutrient pools and biodiversity, indispensable raw materials for agriculture or industrial activities, etc. In other words, considering that importing the nutrients and energy needed for sustaining an imbalanced agrarian system was expensive, being easier to protect land from individual appropriation, communally owned or consumed assets that were vital for sustaining organic energy based economies were object of a special protection by communities. But that did not protect them from conflict.

If the *free-rider* attitude became generalized, disequilibrium and conflict rose. Therefore communal lands, far from being free access territories, were strongly regulated spaces. In fact, a significant number of the environmental conflicts of the epoch were fundamentally centered in these assets: be it against the usufruct of intruders (which unified the community), or against the appropriation of these by the landlords (seizure or limitation of appropriation), and even against poor members of the community. Access to communal resources was a regulated right possessed by one or several social groups organized as a community, class, or group of classes, and was often excluded from mercantile assignation but not outside juridical assignation through local or state political institutions.

At an ampler scale, territorial conflicts confronted political entities, i.e., city-states, seignorities, monarchies, and empires, for the exploitation of the natural resources in dispute. The ratio of population to the carrying capacity of a territory, or the need for acquiring enough resources to make the imperial expansion of a state to be possible were, among many others, the motivations of many environmental conflicts in the history of the past 10,000 years. The attribution of sovereignty to the seignorities or the State—understood as the capacity of reserving a given territory for the exclusive use of its subjects—favored a territorial *competitive exclusion* behavior, enhancing conflicts and their violent solution. Diplomatic and sometimes war conflicts confronting two or more political communities for the control of given territories and the resources these contained are of interest to environmental history, although being only part of the *international* conflicts occurring before the expansion throughout the world of forms of industrial metabolism.

The conflicts generated in the metabolic process of appropriation were, given their relevance for social metabolism as a whole, the most numerous but not the only ones. Also conflicts rose between and within the other metabolic processes, in particular those derived from the transformation of materials and the consequent disposal of wastes. Nevertheless, the intrinsically low intensity of the metabolic processes of transformation, transportation, consumption, and excretion explains the low number of conflicts that would at present be included in the category of environmental justice, and in particular those conflicts that have been named *nimby* (not in my back yard) conflicts (Guha and Martínez-Alier 1997). The location of activities that damage the environment, especially the transformation of minerals and the disposal of wastewaters were normally expressed in places nearby own resources.

References

Agnoletti M (ed) (2006) The conservation of cultural landscapes. CAB International, Massachusette
Allen TFH, Tainer JA, Hoekstra TW (2003) Supply-side sustainability. Columbia University Press, New Jersey
Bartra R (1974) Tributo y tenencia de la tierra en la sociedad azteca. In: Bartra R (ed) El Modo de Producción Asiático. Editorial Era, México, pp 212–231
Bourdieu P (2004) El baile de los solteros: la crisis de la sociedad campesina en el Bearne. Anagrama, Barcelona
Bourdieu P (1991) El sentido práctico. Taurus, Madrid
Burger J (1987) Report of the frontier: the state of the world's of indigenous peoples. Zed Books, London
Calva JL (1988) Los Campesinos ante el Devenir. Siglo XXI Editores, México
Cantera-Montenegro E (1997) La Agricultura de la Edad Media. Arco Libros, Madrid
Casas A, Caballero J, Mapes C, Zárate S (1997) Manejo de la vegetación, domesticación de plantas y porigen de la agricultura en Mesoamérica. Bol Soc Bot México 61:31–47
Cavalli-Sforza L (1996) The spread of agriculture and nomadic pastoralism: insights from genetics, linguistics and archeology. In: Harris D (ed) The origin and spread of agriculture and pastoralism. UCL Press, UK, pp 51–69
Cipolla C (1993) Contra un enemigo mortal e invisible. Crítica, Barcelona
Cipolla CM (1978) Historia económica de la población mundial. Editorial Crítica, Barcelona
Cohen MN (1989) Health and rise of civilization. Yale University Press, New Haven
Cox GW, Atkins MD (1979) Agricultural ecology. W.H. freeman and Company, San Francisco
Crosby A (2007) Infectious diseases as ecological and historical phenomena, with special reference to the influenza pandemic of 1018-1919. In: Hornborg A, Crumley C (eds) The world system and the earth systeam. global socioenvironmental change and sustenainability Since the Neolithic. Left Coast Press, Walnut Creek, pp 280–287
Crosby A (1988) Imperialismo ecológico. La expansión biológica de Europa, 900–1900. Editorial Crítica, Barcelona
De Vries, Bert J (2007) In search of sustainability: what can we learn from the past? In: Hornborg A, Crumley C (eds) The world system and the earth systeam, global socioenvironmental change and sustenainability since the neolithic. Left Coast Press, Walnut Creek, pp 243–357
Daly HE (1973) Toward a steady-state economy. W. H. Freem, San Francisco
De Vries J (2008) The Industrious Revolution: Consumer Behavior and the Household Economy, 1650 to the Present. Cambridge University Press, UK
Denevan DW (1992) The pristine myth: the landscape of the Americas in 1492. Ann Assoc Am Geogr 82(3):369–385
Denevan WM (1982) Hydraulic agriculture in the American tropics: forms, measures and recent research. In: Flannery KV (ed) Maya subsistence. Academic Press, Washington DC, pp 181–204
Donkin RA (1979) Agricultural terracing in the aboriginal new world. University of Arizona Press, Tucson
Ellis ECy, Wang SM (1997) Sustainable traditional agriculture in the Tai Lake region of China. Ecosyst Environ 61:177–193
Ewald P (1994) The evolution of infectious disease. Oxford University Press, Oxford
Fischer-Kowalski M, Haberl H (1997) Tons, joules, and money: modes of production and their sustainability problems. Soc Nat Res 10:61–85
Fischer-Kowalski M , Haberl H, Krausmann F (2007) Conclusions: likely and unlikely pasts, possible and impossible futures. In: Fisher-Kowalski M, Haberl H (eds) Socioecological transitions and global change. trajectories of social metabolism and land use. Edward Elgar, Cheltenham, pp 233–255
Fischer-Kowalski M, Haberl H (eds) (2007) Socioecological transitions and global change. trajectories of social metabolism and land use. Edward Elgar, Cheltenham

Fischer-Kowalski M, Simron JS, Ringhofer L, Grünbühel CM, Lauk C, Remesch A (2010) Sociometabolic regimes in indigenous communities and the crucial role of working time: A comparison of case studies. In: Social ecology working paper 121, Institute of Social Ecology, Vienna

Fischer-Kowalski M, Simron J, Ringhofer L, Grünbühel CM, Lauk C, Remesch A (2011) Sociometabolic transitions in subsistence communities: Boserup revisited in four comparative case studies. Human Ecol Rev 18(2):147–158

García-Latorre J, García-Latorre J (2007) Almería hecha a mano. Una historia ecológica. Cajamar Caja Rural, Sociedad Cooperativa de Crédito, Almería

García-Latorre J, Sánchez-Picón A, García-Latorre J (2001) The man-made desert. Effects of economic and demographic growth on the ecosystems of arid southeastern Spain. Environ. Hist. 6:75–94

García-Martínez B (1998) El altépetl o pueblo de indios: expresión básica del cuerpo político mesoamericano. Arqueología Mexicana 32:58–65

Garrabou R, González de Molina M (eds) (2010) La reposición de la fertilidad en los sistemas agrarios tradicionales. Icaria, Barcelona

Garrabou R, Naredo JM (eds) (1999) El agua en los sistemas agrarios. Una perspectiva histórica. Argentaria/Visor, Madrid

Guzmán Casado B, Iniesta-Arandia I, Martín-López B, García-Llorente M, Montes C (2011) Entendiendo las relaciones naturaleza y sociedad de dos cuencas hidrográficas del sureste semiárido andaluz desde la historia socio-ecológica. *VII Congreso Ibérico sobre Gestión y Planificación del Agua "Ríos Ibéricos +10. Mirando al futuro tras 10 años de DMA*. 16/19 de febrero de 2011, Talavera de la Reina; Spain

Giampietro M (2003) Multi-Scale integrated analysis of agro-ecosystems. CRC Press, Boca Raton

Giampietro M, Mayumi K, Sorman AH (2010) Assessing the quality of alternative energy sources: energy return on the investment (EROI), the metabolic pattern of societies and energy statistics. In: Working papers on environmental sciences

Giampietro M, Bukkens SGF, Pimentel D (1993) Labour productivity: a biophysical definition and assessment. Human Ecol 21(3):229–260

Gliessman S (2002) Agroecología.Procesos ecológicos en Agricultura Sostenible. CATIE, Turrielba, Costa Rica

Gliessman SR (1998) Agroecology. Ecological processes in sustainable agriculture. Ann Arbor Press, Chelsea

González de Molina M (2001) Condicionamientos medioambientales del crecimiento agrario español (siglos XIX y XX). In: Pujol J et al (eds) El pozo de todos los males. Sobre el atraso de la agricultura española. Editorial Crítica, Barcelona

González de Molina M (2002) Environmental constraints on agricultural growth in 19th century Granada (southern Spain). Ecol Econ 41:257–270

González de Molina M, Guzmán-Casado G (2006) Tras los Pasos de la Insustentabilidad. Agricultura y medio ambiente en perspectiva histórica. Icaria, Barcelona

González de Molina M, Ortega Santos A (2000) Bienes comunes y conflictos por los recursos en las sociedades rurales, siglos XIX y XX. Historia Soc. 38:95–116

González de Molina M, Sevilla Guzmán E (2001) Perspectivas socio-ambientales de la historia del movimiento campesino andaluz. In: González de Molina M (ed) *La Historia de Andalucía a debate*. I. Campesinos y jornaleros. Anthropos, Barcelona, pp 239–287

Goody J (1986) La evolución de la familia y del matrimonio en Europa. Herder, Barcelona

Grünbühel CM, Haberl H, Schandl H, Winiwarter V (2003) Socioeconomic metabolism and colonization of natural processes in SangSaeng village: material and energy flows, land use, and cultural change in northeast Thailand. Human Ecol 31(1):53–86

Guha R, Martínez-Alier J (1997) Varieties of environmentalism. Essays north and south. Earthscan, London

Guzmán Casado G, González de Molina M (2009) Preindustrial agriculture versus organic agriculture. The land cost of sustainability. Land Use Policy 26(2):502–510

Hardin G (1968) The tragedy of the commons. Science 162(3859):1243–1248
Harlan JR (1992) Crops and man. American society of agronomy. American Society of Agronomy, Wisconsin
Henshilwood CS, Marean CW (2003) The origin of human modern behavior. Curr Anthropol 44:627–651
Holt-Giménez E (2006) Campesino a Campesino: voices from Latin America's farmer to farmer movement for sustainable agriculture. Food First Books, San Francisco
Hornborg A (2007) Footprints in the cotton fields: the industrial revolution as time-space appropriation and environmental load displacement. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 259–272
Hughes D (2007) Environmental impacts of the roman economy an social structure: Augustus to Diocletian. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 27–40
Kearney M (1996) Reconceptualizing the peasantry. Westview Press, USA
Krausmann F (2008) Land use and socio-economic metabolism in pre-industrial agricultural systems: four nineteenth-century austrian villages in comparison. In: Social ecology working paper 72, Vienna
Krausmann F, Haberl H (2007) Land-use change and socieconomic metabolism: a macro view of Austria 1830-2000. In: Fisher-Kowalski M, Haberl H (eds) Socioecological transitions and global change. trajectories of social metabolism and land use. Edward Elgar, Cheltenham, pp 31–59
Livi-Bacci M (1990) Historia mínima de la población mundial. Ariel, Barcelona
Livi-Bacci M (1992) Concise history of world population. Blackwell, Oxford
Lizarralde M (2001) Biodiversity and loss of indigenous languages and knowledge in South America. In: Maffi L (ed) On biocultural diversity: linking language, knowledge and the environment. Smithsonian Institution Press, USA
Loukotka C (1967) Map Supplement 8. Ann Assoc Am Geogr 57(2)
Malanima P (1996) Energia e Crescita nell'Europa Preindustriale. La Nuova Italia Scientifica, Roma
Malanima P (2005) Che cos'è un'economia vegetales? Fonti di energia e sostenibilità. I Frutti di Demetra 5:15–18
Margalef R (2006) Ecological theory and prediction in the study of the interaction between man and the rest of biosphere. In: Ökologie und Lebensschutz in IntrenationalerSicht, 3d. H. Siolo, H. Rombach, Freiburg, pp 114–125
Marks RB (2007) Peoples said extinction was no possible: two thousand years of environmental change in South China. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. world-system history and global environmental change. Altamira Press, Lanhan, pp 41–59
Martínez-Alier J (2007) Marxism, social metabolism, and internacional trade. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 221–237
Marull J, Pino J, Tello E, Mallarach JM (2006) Análisis estructural y funcional de la transformación del paisaje agrario en el Vallés durante los últimos 150 años. Áreas (Revista Internacional de Ciencias Sociales) 25:105–126
Marull J, Tello E, Pino J, Mallarch JM (2008) El tratamiento del territorio como sistema. Criterios ecológicos y metodologías paramétricas de análisis. Ciudad y Territorio 157:235–249
Mayrhofer-Grünbühel C (2004) Resource use systems of rural smallholders. an analysis of two lao communities. Dissertation, University of Vienna
McKeown T (1990) Los orígenes de las enfermedades humanas. Crítica, Barcelona
McMichael P (2008) Peasants make their own history, but not just as they please. J Agrarian Change 8(2 and 3):205–228

McNeill JR (2007) Social, economic and political forces in environmental change: decadal scale (1900-2000). In: Costanza R et al (eds) Sustainability or collapse?. The MIT Press, Massachussette, pp 301–330
McNeill W (1980) The human condition. An ecological and historical view. Princeton University Press, Princeton
McNeill W (1976) Plagues and peoples. Garden City, New York
McNetting R (1993) Smallholders, householders: Farm families and the ecology of intensive, sustainable agriculture. Stanford University Press, Stanford
Modelski G (2003) World cities: -3000 to 2000. FAROS 2000, Washington
Modelski G (2007) Globalization as evolutionary process. In: Devezas T & Thompson W (eds), Globalization as Evolutionary Process. Modeling, Simulating, and Forecasting Global Change. Routledge, London
Moore JW (2007) Silver, ecology, and the origins of the modern world, 1540-1640. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 123–142
Myrdal J (2007) Food, war, and crisis: The seventeenth century Swedish empire. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 83–99
Neumann K (2003) New Guinea: a cradle of agriculture. Science 301:180–181
Odum EP (1992) Ecología: bases científicas para un nuevo paradigma. Editorial Vedrá, Barcelona
Pascua Echegaray E (2011) Communities and sustainability in medieval and early modern Aragon, 1200–1600. Intl J Commons 5(2):535–556
Reale O, Shukla J (2000) Modeling the effects of vegetation on mediterranean climate during the Roman classical period, part II: model simulation. Global Planet Change 25:185–214
Ringhofer L (2010) Fishing, foraging and farming in the Bolivian amazon. On a local society in transition. Springer, New York
Rostow WW (1960) The stages of economic growth: a non-communist Manifesto. Cambridge University Press, Cambridge
Sandor JA (2006) Ancient agricultural terraces and soils. In: Warkertin BP (ed) Footprints in the soil. Elsevier, London, pp 505–533
Schandl H, Krausmann F (2007) The great transformation: a socio-metabolic reading of the industrialization of United Kingdom. In: Fisher-Kowalski M, Haberl H (eds) Socioecological transitions and global change. Trajectories of social metabolism and land use. Edward Elgar, Cheltenham, pp 83–115
Schandl H, Grünbühel C (2005) (Guest Eds.) Southeast Asia in Transition. Intl J Global Environ Issues 5(3/4):115–118
Sevilla Guzmán E, González de Molina M (2005) Sobre a evoluçao do conceito de campesinato. Editora Expressao Popular, Sao Paulo
Sieferle RP (2001) The subterranean forest. Energy systems and the industrial revolution. The White Horse Press, Cambridge
Sieferle RP (2003) Sustainability in a world history perspective. In: Benzing B (ed) Exploitation and overexploitation in societies past and present. LIT Publishing House, Germany, pp 123–142
Siemens AH (1989) Tierra configurada: Investigaciones de los vestigos de agricultura precolumbiana en tierras inundablescosteras desde el norte de Veracruz hasta Belice. Consejo Nacional para la Cultura y las Artes, DF
Siemens AH (1998) A favored place. University of Texas Press, Austin
Singh SJ, Grünbühel CM, Schandl H, Schulz N (2001) Social metabolism and labour in a local context: changing environmental relations on Trinket. Popul Environ 23(1):71–104
Singh SJ, Ringhofer L, Haas W, Krausmann F, Fischer-Kowalski M (2010) Local studies manual: a researcher's guide for investigating the social metabolism of local rural systems. In: Social ecology working paper 120. Institute of Social Ecology, Vienna
Smil V (1994) Energy in world history. Westview Press, Denver

Smil V (2001) Energías. Una guía ilustrada de la biosfera y la civilización. Editorial Crítica, Barcelona
Smil V (2008) Energy in Nature and Society: General Energetics of Complex Systems. The MIT Press, Cambridge, MA
Smil V (2010) Energy transitions: history, requirements, prospects. Praeger, Santa Barbara (Cal)
Smil V (2013) Harvesting the biosphere. What we have taken from nature. The MIT Press, Cambridge
Smith BD (1998) Emergence of agriculture. Scientific American Library Publication, USA
Tainter JA (1988) The collapse of complex societies. Cambridge University Press, Cambridge
Tainter JA (1994) La fine dell'amministrazione centrale: il collaso dell'Impero Romano in Occidente. In: Guilaine J, Settis S (eds) Storia d'Europa, Volume Secondo: Preistoria e Antichità. Einaudi, Turin, pp 1207–1255
Tainter JA (2007) Scale and Dependency in World Systems: Local Societies in Convergent Evolution. In: Hornborg A, McNeill R, Martínez-Alier J (eds), Rethinking Environmental History: World System History and Global Environmental Change. AltaMira Press, Lanham MD, pp 361–377
Tainter JA (2011) Energy, complexity, and sustainability: A historical perspective. Environ Innovation Societal Transitions 1:89–95
Tello E, Galán E, Sacristán V, Moreno D, Cunfer G, Guzmán G, González de Molina M, Krausmann F, Gingrich S (2013) A proposal for a workable analysis of energy return on investment (EROI) in agroecosystems. In: Social ecology working paper, Institute of social ecology, Vienna, 2013
Toledo VM (1990) The ecological rationality of peasant production. In: Altieri MA & Hecht SB, Agroecology and small farm development. CRC Press, Boston, pp 53–60
Toledo VM (1993) La racionalidad ecológica de la producción campesina. In: Sevilla E, González de Molina M (eds) Ecología, campesinado e Historia. Ediciones La Piqueta, Madrid, pp 197–218
Toledo VM (1994) La Apropiación Campesina de la Naturaleza: una aproximación etno-ecológica. Ph.D dissertation, UNAM
Toledo VM, Barrera-Bassols N (2008) La Memoria Biocultural. La importancia agroecológica de las sabidurías tradicionales. Icaria, Barcelona
Van Zanden JL (1991) The first green revolution: the growth of production and productivity in European agriculture, 1870–1914. Econ Hist Rev 2:215–239
Vasey DE (1992) An ecological history of agriculture. State University Press, USA
Wallerstein I (1974) The modern world system. Capitalist agriculture and the origins of the European world-economy in the sixteenth century. Academic Press, London
Warde P (2009) The environmental history of pre-industrial agriculture in Europe. In: Sörlin S, Warde P (eds) Nature's end: history and environment. Macmillan Press, New York
Wilken GC (1991) Sustainable agricultura is the solution but what is the problema? In: Occasional paper 14. BIFADEC, Washington
Wrigley EA (1987) Urban growth and agricultural change: England and the Continent in the Early Modern Period. In Wrigley EA (ed), People, Cities and Wcalih. Blackwell, Oxford, pp 157–193
Wrigley EA (1988) Continuity, chance and change. The character of the industrial revolution in England. Cambridge University Press, Cambridge
Wrigley EA (2004) Poverty, progress, and population. Cambridge University Press, Cambridge
Wrigley EA (1989) Dos tipos de Capitalismo, dos tipos de crecimiento. Estudis d'Història Econòmica 1:89–109
Wrigley EA (1992) Cambio, continuidad y azar. Carácter de la Revolución Industrial inglesa. Crítica, Barcelona
Wrigley (1987)
Wynn T, Collidge FL (2008) A stone-age meeting of minds. Am Sci 96:44–51

Chapter 11
The Industrial Metabolism

11.1 Introduction

The third type of social metabolism appeared when humans extracted goods from nature by mobilizing not only solar, but other new types of energy mainly of mineral origin—including uranium, the fundamental substance of nuclear power plants. The shift from a mainly solar production to one based on fossil fuel or mineral energy as a product of the industrial revolution, generated a qualitative change in the degree of transformation of ecosystems. It can be said that it was the leap in the mode of transformation (energy capture) what unleashed a change in the modes of appropriation, circulation, consumption, and excretion, eventually transforming the whole metabolism. The use of machines powered by mineral energy (i.e., carbon, oil, and gas) amplified the transformation capacity in such a magnitude that a single producer could multiply several times its production by unit of time.

This economic and technological leap suddenly modified the interactions of producers with the phenomena and elements of nature, causing changes in demographic dynamics, circulation and consumption of products, worldview, territorial equilibrium, knowledge, and industrial development. The use of new forms of energy not only potentiated the producer's capacity for increasing the flow of goods from nature that resulted in a noticeable increment in labor productivity, but consequently also in the increment of surpluses. Also the scale of production was modified, producers became specialized and more dependent on external inputs, and above all, the supply to cities of foodstuffs, raw materials, water, energy, and materials became ensured as industry became consolidated (Debeir et al. 1986; Smil 1994).

Each time more oriented towards the demands and needs of cities and the industry, this third type of metabolism gave impulse and privileged systems that increased surplus, which in turn required specialized systems that pursued imposing to nature conditions similar to those in the industrial factory. From the metabolic perspective, this leap acting upon the appropriation process particularly amplified as never before in history the processes of circulation, transformation,

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consumption, and excretion. Circulation was boosted by the creation of increasingly fast and efficient transportation means—by land, sea, and air—that at present allow for the circulation of commodities at such distances, that it is now possible to move products to any point in the planet. This expansion of the realms of commerce has been amplified by the new capacities for transformation of produced goods, with particular emphasis in the conservation of perishable products. The new productive chains going from appropriation to consumption have also generated new energy expenses and have given place to massive production of wastes, as never before expanding the sphere of excretion. The synergies of metabolic processes were multiplied in the industrial metabolism, as its most noticeable and unexpected of consequences giving place to a massive increase in human population and to unimaginable impacts on the ecosystems, and eventually on the whole of Earth's ecosystem.

In spatial terms, industrial metabolism has induced the excessive growth of the TEN at expenses of the UEN, even in areas pristine or previously unused by humans. These spatial consequences can be confirmed by the existence of extended deforested areas appearing first in temperate countries, and more recently, also in the intertropical regions. At the same time, the specialized, monotonous, and extensive character of the TEN has transformed appropriators and extractors into productive units totally devoted to economic exchange, and in consequence, into units that are highly dependent on external inputs and trade, which has generated the net monetization of the act of appropriation.

All these changes took place so suddenly that in a few decades the technological transformation triggered by the shift in energy sources radically transformed countries, regions and landscapes. In the following sections we will analyze in detail this rapid transformation that drastically modified the planet's perspectives and the whole of humanity; so much so that many members of the human species have forgotten that what we know as modernity has only started, and that the preceding stage was ostensibly different.

11.2 The Origins of the Industrial Metabolism

A little over 200 years ago a series of social, economic, political, and technological transformation took place in Western Europe that changed the fate of humanity. One of the results of such transformation was the emergence of a new mode of organizing the relations with nature: the industrial metabolic regime. As other forms of metabolism, industrial metabolism rises from the contradiction between population and resources. European societies entered a new phase of expansion during the eighteenth century once they overcame to the climatic and environmental perturbations of the previous century (Pfister 1988; Grove 2007; Modelski 2007).

These expansion pressures could have led to the creation of new steady state equilibriums, if it was not for the long-term changes it induced in social organization. Indeed, after a long period of marked fluctuations and scarce development the European population began a general growth trend since 1750. In less than a century the number of inhabitants in the region was duplicated. Improvements made to public hygiene and health reduced the catastrophic mortality, practically eradicating the plague from Europe, and mitigating the damage from the still recurrent epidemics of cholera, measles, typhus, etc. Improvement of crops and market supply ended up raising the defenses against many diseases, which resulted in a reduction of mortality (Wrigley 1985, 2004; Livi-Bacci 1999). However, population itself does not seem to have been the main determinant of the metabolic change that succeeded.

Some historians—e.g., Pomerantz (2000)—have against the traditional view suggested that Europe and Asia had little differences in productivity and income during the seventeenth century hence, immediately before the occurrence of the Industrial Revolution, economic growth was similar in both regions. According to this proposal, the secret behind the great divergence between European countries, China, and Japan—all having similar levels of socioeconomic and cognitive development—was the appearance of modern States that encouraged the European territorial expansion. Several external phenomena contributed to such a divergence, such as slavery in Africa, the conquer of new territories thanks to the resistance to epidemics developed by their inhabitants, and even the global commercial networks held by the Chinese, which added to their craving for American silver; all, factors that were taken advantage of by the European economy.

Nevertheless, questions have risen in the recent literature regarding the assumption of Japan and China having similar standards of living and economic development than England or the Netherlands during the eighteenth century (Morris 2010; Allen et al. 2010). By the second decade of the nineteenth century the differences between the two most advanced European economies and China were substantial. The per capita GDP of the Netherlands was nearly 90 % higher than that of the Chinese Hua-Lou zone (Li and Van Zanden 2012). By 1700, the per capita GDP of Japan was less than half of that of Great Britain, decreasing to a 30 % by 1,800 (Bassino et al. 2011). It has even been said there was a small difference between the countries of northwestern Europe and the rest of European countries, with real salaries increasingly being deteriorated by the increase in the population. Anyway, most of the questions about the originating causes of the great difference in economic terms between Asia and Europe in the moments previous to the Industrial Revolution, or about which processes lead to the economic success of western European countries and the appearance of the industrial metabolism, continue to be a matter of debate among scholars insisting that the key answers are in the institutional aspects of the process.

In this regards, a discussion exists about possible relations of the Early Globalization in the West and the Great Divergence between East and West. Apparently, the Early Globalization required institutional economic and technological changes that made possible the expansion of national and international markets. It was the participation in the expanded markets what favored the divergence between countries and regions. The considerable profits derived from the Atlantic trade, particularly in the UK and the Netherlands, increased the power for political negotiation of commercial interests and induced significant institutional transformations. It was this Early Globalization what contributed to accentuate the original differences in terms of the GDP per capita of Eastern and Western countries by means of the direct and indirect economic advantages of international trade. In that way, the Early Globalization contributed to the Western Exceptionalism. Definitely, the institutional framework of Modern Europe allowed, although unequally, the ample diffusion of the positive effects on economic growth of commerce. The Atlantic trade substantially contributed to the First Great Divergence (Acemoglu et al. 2005; Dobado et al. 2012). In the same direction, Allen (2009) underlined the relevant role played by mercantile policies in the promotion of the British trade. Without mercantile policies it would be difficult to explain that London quadrupled the number of its inhabitants during the sixteenth century, peaking to 200,000 and reaching nearly a million by 1800. During that time period the urban population grew from 7 to 29 % and the active agrarian population decreased from 75 to 35 %. As a consequence, the British capital experienced a significant increment of real salaries, which as we will see, were of major importance in the origins of the Industrial Revolution (Allen 2009).

In any case, it is important to state that from a biophysical standpoint the Great Divergence could not have taken place without access to key natural resources through international trade (Pomerantz 2000; Hornborg et al. 2007), and probably neither would have the Industrial Revolution been possible. As held by several researchers, the Industrial Revolution would have faced serious problems without the coal from the subsoil and the ghost acreage available to the British economy through international trade, which allowed for its supply of foodstuffs and of plant and animal raw materials (Jones 1987; Pomerantz 2000); a question we will be examining further down.

Nevertheless, a sector of environmental historiography sustains opinions that neglect the importance of this fundamental shift in the history of humanity. Some consider that the present situation is the result of an accumulative process that began with the invention of agriculture, thus remarking the predatory nature of the human species and, therefore, showing certain indifference for social relations. Others such as McNeill (2000) consider that the multiple processes explaining the present ecological crisis took place during the twentieth century. This assumption equally dilutes the explanatory importance of social relations and of the processes that had their origin during the late seventeenth and the early nineteenth centuries. Finally, other historians trace the origin of the great transformation to the early sixteenth century, a period during which the World-system first appeared and many instruments of capitalism began to operate (Wallerstein 1974). Such a consideration faithfully reflects the genealogy of changes that took place, but it does not explain why these new social relations were unable of breaking their isolation and becoming generalized until the end of the eighteenth century. The new liberal regimes were responsible for opening the way for markets, individual freedom, private property, free trade, and the pursue of individual and collective wealth. Social richness was identified with the physical growth of the economy and with the idea of production and technological change being the expression of progress (Naredo 1987).

The main difference between the UK and its rival countries—France, Spain, or the Netherlands—was the form of government that emerged after the constitutional conflicts of the seventeenth century were settled in 1688, when aristocracy won the battle against absolute monarchy. The Glorious Revolution established a contractual monarchy in which the decisions about economic policy depended not on the monarch but on the consensus of the two parliamentary chambers. The House of Commons adopted numerous dispositions that fomented fluvial, maritime, and terrestrial communications, the security of transactions, tax rises, etc. The House of Commons was elected through a system allowing for the representation of the major interests of the elite, differently from what happened in other European absolute monarchies in which the business sector was unrepresented. Another difference was in healthy finances and capacity of debt derived from a tax reform including the most affluent classes—contrary to what happened in most European monarchies in which privileged classes opposed to tax reforms involving the weakening of their privileges and exactions.

What was really different in this articulated set of social relations was that, unlike agrarian societies based on a stationary conception of society, they favored the idea of growth, and a conception of the economy and social ethics in which the growth of the biophysical basis of the economy turned into the ultimate good, becoming an expression of social progress and human wellbeing to which any society should aspire. In that way, a shift was made from a cyclical conception—or at most, spiral—of time and history, to a totally lineal vision.

11.3 The Energetic Transition

Nonetheless, population and consumption growth exerted pressure upon forests, favoring the expansion of agricultural land for producing foodstuffs. In an opposite direction, the growing need of fuel for households also exerted a pressure, which generated a tension of great relevance for understanding social transformations. The increasingly frequent replacement of human labor by animal power (Wrigley 1993) threatened with neutralizing the improvements obtained from the agrarian revolution and increasing the costs of animal energy. At the end of the eighteenth century, the demand for rotary traction for cotton fabric factories also grew; no more were there adequate places along the river shores for establishing new waterwheels. The same can be said about metallurgy whose volume remained constricted—to a maximum of 2,000 t per year—within the narrow margins imposed by the very high cost of charcoal for its furnaces (Schandl and Krausmann 2007, pp. 104–105). Otherwise, the growing expansion of domestic commercial activities exposed the obsolescence of the road network and the cost of transport with animal traction. All these requirements converged to create a disproportionate demand for land that was impossible to be assumed by the British territory. The needs of urban dwellers and those of the incipient industry began a new competitive struggle for resources with the ancient, rural population.

The extreme scarcity of land caused by all these demands would be at the origin of the energetic transformation, the technological innovations, and ultimately of the metabolic change that began with the Industrial Revolution. That was the main thesis formulated by Wilkinson (1973) since the 1970s. Technological innovations were the result of the valiant struggle of society placed against the ecological wall. When land began to be scarce it became more profitable to produce machines that operated with fossil fuel instead of horses needing of land suitable for agriculture. Textile manufactures were able to expand without threatening agriculture for food production thanks to cotton imported from India, and later on, of wool from Australia, and similarly thereafter.

In 1660 only 35 % of the energy consumed in England and Wales came from coal, while by 1760 that figure raised to 64 %, and to 93 % in 1860. The transition was slow at first, but became accelerated during the eighteenth century. The reasons for such a fundamental change were explained by Allen (2009, 2010, 2013) based on the rhythm of invention and technological innovation occurring both in the industry as in the design of households and their heating systems, but above all, alluding to the combined effect of the relative costs of labor and coal. Wages peaked as the costs of energy plunged. These trends made profitable to use the new technologies that replaced labor for capital and energy.

Indeed, during the eighteenth century the UK was an economy with high wages, while in other countries of Europe and in Asia salaries approached to the poverty limit. To the contrary, the price of coal from the mines in the northern and western UK was one of the lowest in the world. According to Allen (2013, pp. 3–14), the successful process of economic globalization achieved by the Modern Age England favored such price behavior. The growth of trade also made cities to grow. As we mentioned above, London was the European city that grew most rapidly passing from 50,000 inhabitants in 1500 to nearly one million in 1800.

This sudden growth led to restricted labor markets and higher wages. It also increased the demand of fuel for household use. The raise of the demand for firewood and charcoal made the prices of these fuels to rise as a consequence of scarcity and of the growing distance needed to be traveled to supply it. The price of coal had for a long time been similar to that of firewood and charcoal, but the rise in price of these latter fuels made coal less expensive. Once the energy contained in charcoal and firewood became twice as expensive as that in coal, people made attempts to replace firewood for coal. This behavior of prices also stimulated the process of invention that eventually led to the energetic transition. According to Allen (2013), the small inventions that gave impulse to the industrial revolution took place in the UK because this was the only country in which they could be profitable.

The Netherlands also had high salaries and its domestic consumption had increased as a consequence of its commercial expansion. Amsterdam, as London, shared these factors favorable to the industrial revolution. However, a larger consumption of coal was delayed by the existence in the Netherlands of extensive deposits of turf and of a relatively larger availability of firewood and charcoal than in England, which was obtained from Nordic countries across the Baltic Sea. The price differential between coal and biomass was not as large as to favor their replacement, to an extent making unnecessary the invention of machines that used coal. China was experimenting an inverse process during that time period. Chinese real wages were comparatively much lower than in the UK or the Netherlands—among other reasons, because demographic growth and a relative abundance of labor—so that the costs of energy were very high. Of course, such combination of relative prices did not favor the introduction of innovations saving labor, despite China possessed abundant reserves of coal in the north of the country.

That explanation is appealing for environmental historians. It also gives a protagonist role to the ecological factors leading to the Industrial Revolution. According to this Boserupian thesis—because it strengthens the proposals of Boserup (1983)—the earliest innovations (among which is the energetic shift) were derived from the contradiction between population and resources, signifying the first serious attack on the stability of organic metabolism. Scarcity as an ecological phenomenon would have become a powerful economic factor raising the prices of natural resources, hence stimulating technological innovation. With it, it is assumed that market economy always existed and condemns to oblivion the political-institutional transformations experimented in the UK since the late seventeenth century, positioning these changes as the main mechanism of economic regulation. The technological innovation in the context of increasing prices would not require any further explanation, being the logical option for the rational choice of economic agents familiarized with monetary calculation and mercantile rationality; something consubstantial with human nature whose origins would not be necessary to explain.

As held by Worster (1988), there is enough accumulated empirical evidence to suggest that all the social relations and institutions that became known as the capitalist system appeared first, later favoring the expansion of western European population—and eventually of the whole world. The most acute contemporary observers, such as for instance Marx, had already said that. The development of capitalism brought with it transformations of such magnitude that they provoked, paraphrasing Polanyi (1990), the Great Transformation of interrelations with nature. Certainly, the increase of demands from the agrarian and manufacture sectors produced land scarceness that stimulated the energetic shift and the technological innovation associated to it. But that could only have happened in a society in which a new and growing segment sustained money, individual interest, and a worldview favorable to applied scientific development as its dominant values.

Land scarceness also occurred outside the UK in other countries and regions—and also in other times—where industrialization never happened or came later. Capitalism caused land scarceness and not the other way around. But industrialization and development of industrial metabolism would have been impossible without the generalized exploitation of fossil fuels—with incomparably greater energy density than biomass—and through their use in the exploitation of new sources of materials. A source of energy extracted from the subsoil should allow for detaching metabolic activities from the territory. This claim is admitted by nearly all environmental historians (Erb et al. 2007, p. 73), and by a growing number of economy historians (Cipolla 1994; Leach 1992; Malanima 2001).

The sustained extension of society—measured as economic growth based on massive consumption of natural resources—would have also never been possible without the appropriation of the then immense reservoirs of coal, and later, of oil. This energy sources eliminated the inherent restrictions of organic metabolism—or more precisely, changed their ecological scale. As stated by Sieferle (2001, p. 38), industrialization would have not existed without access to new sources of energy.

The new social relations of capitalistic nature that motivated economic agents to the chase of monetary profit ended up fomenting economic growth as a model of development. This promotion came with the concurrence of the business class with the interests of the State, concerned with incrementing public wealth, taxes, and its diplomatic and military power. Until then business profits had depended on the number of labor hours or on the effort of laborers, both factors with patent physical limits, but increasing the productive capacity of labor could surpass these limitations. Working instruments that were before limited to simple tools became pieces of a larger mechanism through the invention of machines. When the complexity and number of tools simultaneously used by a worker became greater, a new and more powerful traction mechanism became necessary; but that mechanism could not be operated by charcoal. Coal had been known since ancient times, but its use was limited despite it clearly presented energetic and hence economic advantages. From this perspective, the desire for incrementing profit beyond the physical limits of labor reproduction time led to an unprecedented increment of exploitation of nature (González de Molina and Sevilla Guzmán 1992). An increment that currently remains being the intimate, secret formula leading to industrial metabolism.

The mechanisms of maximum benefit and economic growth typical of capitalism led to a progressive mechanization of production, and to the growing relevance of the remaining metabolic processes. The distinctive sign of the Industrial Revolution was the appearance of the factory: a large, centralized, highly specialized production unit containing production instruments owned by an entrepreneur using the labor of wage workers and establishing a certain form of labor division within the productive process.

In the context of competition between enterprises the only way of remaining in the market, or of increasing sales was offering products at a lower price that the other competing companies. But doing that faced two problems: workers could not afford lowering of wages, and they could not work more than the 10 or 11 h they worked per day. Consequently, making laborers to be able of producing more merchandise during the workday was the only way of solving the issue; and such solution was achieved by the use of machines.

In fact, working media transformed from simple tools to pieces of a mechanism that could not be moved by the insufficient energy of labor, animal power, organic fuels or hydraulic power. As the volume of machines and the number of tools simultaneously used multiplied, a more potent motor mechanism became necessary. That power was found in fossil energy, namely on coal that presented economic and ecological advantages over firewood. Firewood needed to be gathered from large areas laying further away from the center where it would be burnt, which increased the cost of its gathering and transportation; scale economies were, from that perspective, difficult to obtain due to imposition of energetic restrictions to the size of productive units. As we already saw, the production of iron mills during the eighteenth century could not exceed 2,000 t per year.

Many technological problems needed to be solved first. A large part of the efforts of scientists was devoted to finding solutions to practical problems such as increasing the yield of mining, increasing navigation capabilities, and above all increasing and concentrating rotary energy by the invention of a revolutionary converter: the steam engine. The steam engine made possible to transform the chemical energy of coal into mechanical energy. From 1820, when the steam engine was applied to railroad transportation, the large-scale use of coal became necessary for numerous productive processes.

As warned by Marx, the expansion of machine tools was a need inscribed in the dynamics of capitalistic accumulation. If accumulation of capital was merely the transformation of surplus value into capital, the growing mechanization of labor processes was needed by the expanded reproduction characteristic of capitalism. In such way, production of commodities in constant growth and diversification was—and remains to be—the result of the growing consumption of energy and materials by the industrial system (globally considered) for its growingly more complex and sophisticated productive activities. The criterion governing economic development—in accordance to the dominant model of economic growth—was the pursuit of maximum labor productivity by means of the use of intensive capital technologies, i.e., using increasing amounts of energy and materials. In the same measure that workers were dispossessed from the product of their work—what permitted capitalistic profit—nature began to be exploited in order to increase the productivity of labor, irrespective of the increasing distance between the exploited terrains and the center of the production unit. Put in different terms, as labor began to be replaced by fossil energy and materials in order to increment profits, the need for finding new sources of energy and materials for production also grew. As held by Smil (2013) regarding the synergies between technological innovation and the energetic shift: "inventions and diffusion of new prime movers drove most energy transitions: just think what steam engines did for coal and what internal combustion engines have done for hydrocarbons (Smil 2013, p. 12)." The intensification of the exploitation of labor was only possible because of a corresponding increase in the exploitation of nature, which transferred to the environment the entropy generated during the process of production. From that same perspective, evolution in developed societies of the productive process characteristic of capitalism can be understood as the progressive transference towards nature of social entropy—that in the early times of the Industrial Revolution was sustained by laborers—generating a growing environmental impact.

By the end of the eighteenth century innovations in the fields of mining, metallurgy, and transportation became associated to coal in such way that the subsequent expansion throughout the world of the model of industrial economy was intimately linked to the consumption of that form of fossil energy. The energetic shift multiplied the per capita use of energy and materials by three or by five and the physical growth of the economy was multiplied by 15–25 times. At present, the use of materials may reach up to 50 t/ha/yr and that of energy up to 600 GJ/ha/yr (Schandl and Krausmann, 2007, p. 104). In front of such persuasive numbers and of the contradictions already present in organic metabolism, the transition to fossil fuel use can be seen as being unavoidable, given that the growth of European economies could not have been supported by solar energy alone (Sieferle 2001, p. 41; Fischer-Kowalski et al. 2007, p. 232). If something characterizes industrial societies, it is economic growth as the operational economic model producing a sustained growth of the volume of its social metabolism. According to data from Smil (2001, p. 255), of the 500 kg of wood yearly consumed per capita in 1850—when the predominant fuels remained to be firewood, charcoal, and hay, in 1990 that figure peaked to 1.5 t of oil, i.e., it was multiplied by twenty. This energy consumption made possible the development of a largely urban civilization with unprecedented levels of material consumption. Without speculating about what course things would have followed if an alternative technological development based on renewable energies would have occurred, the interesting fact is that the abundance and low price of coal—whose non-renewable character and noxious effects on the atmosphere remained unapparent until the publication of Jevons' (1865) work—set the path dependence, not only for England, but for practically all the industrialization process of Western countries. An unparalleled synergy was thus generated between technological transformation, economy, resources, sources of energy, and the size of the human population and its needs. A metabolic change of gigantic proportions was beginning.

11.4 A New Cognitive Framework, the New Cosmovision

This metabolic change occurred inside another revolution in the collective representation of nature, which replaced the former vision of solidarity between humans and nature—that induced cooperation and collectivity—by the idea of nature under the dominion of humans. Morris Berman (1987) describes this separation from nature as a sort of disenchantment, thereafter nature being seen as an external, desacralized machine that was amenable of analysis and exploitation for the benefit of human beings. The role of religions was substituted by science and its moral normative, Economy, radically altering the relation with nature. The elements of the natural world—seen as sacred throughout most of the history of the human species—ended up being considered as simple factors of the production of commodities that could be appropriated or exploited. Secularization triumphed and nature was made mute.

The highly entropic development of capitalism would be difficult to understand without the prevalence of an anthropocentric worldview, partial development of science and its technological outputs, and the progressive dominium of self-profit. These conceptions and cognitive achievements replaced collective or communitarian work, neglecting or minimizing it, suppressing or minimizing the same cooperation that was the key for the permanence and evolution of the human species during nearly 200,000 years (Bowles and Gintis 2011). The fact is that the eighteenth century European culture was based on the idea of reason and the progress this brought being the only capable of providing happiness for mankind. Science as the expression of the possibilities of reason became the instrument that would make human beings to owners of their own destiny. From thereon science replaced religion as the new discourse, seemingly laic, but actually as consecrated as the previous one as was brilliantly demonstrated by Koestler (1968) and other authors. Historians like Mokyr (2009) have underlined the narrow connection between the Industrial Revolution and the scientific revolution already underway since the seventeenth century, and that defined a phase in which scientific advances began to be applied for production of technological innovations and improvements, which was called the industrial enlightenment.

Progress eventually became identified with the achievement of an improved material wellbeing, and this in turn with self-interest, giving place to the dominant economic science we are familiar with. It was deemed natural that mankind—in correspondence with its preponderant role in the new cosmogony—looked for benefiting from its productive activities and that the product of human work should be private accumulation of wealth, its own work and natural resources becoming subordinated to this universal law. The goal was no longer to satisfy the needs of households, or of the community, but—based on the naturalness of human supremacy and of trade—the search of individual realization expressed as the accumulation of money through the market. Markets were also natural institutions spontaneously rising as soon as the restrictions and moral prejudices of religions and other traditional beliefs were broken, thus mankind recovering its freedom. The economic system should then eliminate all sorts of regulations in order to favor supply and demand; the market governing itself by freely assigned prices. A new productive rationality was thus created that would lubricate the new surging economic system and that would legitimize the dominion of humans over other humans, and over nature itself.

This metamorphosis occurred at increasing velocity, beginning in England and leaping into continental Europe, expanding towards its peripheries, carried to the colonies, and until the present it is expanding over all corners of the world with uncertain results. Industrial metabolism has not however been privative of capitalism. The so-called real socialism shared most of the productive premises of capitalism, particularly capital accumulation, albeit in the hands of the State. This confluence of the two contemporary great modes of production was incarnated in economic growth as the intimate functional mechanism of industrial metabolism. The main cause of the current ecological crisis has been precisely economic growth in its present form of sustained increment of the physical volume of production. That is the reason because the ecological crisis, as the depletion or degradation of natural resources, is intimately linked with this mechanism making economic growth and wellbeing of mankind totally dependent on the sustained growth of the physical basis of the economy, i.e., on the growing utilization of energy and materials. We will not here provide a detailed account of the whole evolutionary process that led us to the present day crisis, that would require of considerable space and time. However, we will underline the physical-biological aspects of that great transformation that clearly shows the levels of unsustainability to which we have reached.

11.5 Changes in the Metabolic Function of Biomass

Despite the loss of relative importance in monetary terms, during the onset of industrialization agriculture played the role of a determinant in physical terms. Industry required of large amounts of labor and animal power, and of the sustentation of a growing non-agrarian population. This was occurring before the new technologies could provide energy or material inputs outside of the agrarian sector. The British agriculture continued to be organic, and it would remain to be so for a long time. The main challenge was then to lift the production without depleting soil fertility. During that early stage of industrialization, as stated by Krausmann et al. (2008b), the satisfaction of the growing demand became a narrow bottleneck for economic growth.

Nevertheless, the pressures originated inside agrarian systems opened the door to the process of industrialization of agriculture; a process that in developed countries would be completed until the end of the Second World War.

Industrialization of biomass production was achieved in three major waves: the first one was fostered by institutional change towards capitalism and took place within the boundaries of the agrarian sector, signifying the optimization of its possibilities by raising biomass production; the second wave was the first metamorphosis in the configuration of the agrarian sector through the injection of artificial fertilizers, in other words, through the external subsidy of energy and materials from non-renewable sources; and finally, the third phase was the total penetration of fossil fuels within the agrarian sector (Krausmann et al. 2008a). These three waves match well with the canonical characterization made by Bairoch (1973, 1999) of the history of contemporary agriculture, discerning several other transformations that, as revolutions, led to its complete industrialization. But maybe calling these changes revolutions is excessive—according with the preferences historians had a couple of decades ago—but it is true that the diffusion of more decisive innovations was concentrated in precise moments during the eighteenth, nineteenth, and twentieth centuries.

The need for answering to a growing demand of human and animal foodstuffs derived from the growing process of urbanization and general demographic expansion was common to all countries that began to become industrialized during the nineteenth century. Many European countries had been suffering from internal and, to a lesser extent, external pressures on their agro-ecosystems for raising the volume of biomass production. The population increase beginning in the eighteenth century, the process of urbanization, the elevation in consumption of the upper classes, and the different demands being generated by the newly burgeoning process of industrialization, converged in a legal-political structure that protected the traditional configuration of the agrarian metabolism and the distribution of land uses. This facilitated institutional change (Liberal Revolutions), especially in the regime of feudal ownership, and the liberalization of agrarian markets.

11.6 The Four Routes of Agricultural Industrialization

From that point onwards, European agro-ecosystems could meet requirements by implementing one or several of the following four possibilities depending on their provision of land and their climate and soil conditions: (i) Pushing the agricultural boundary as far as possible. There can scarcely be any doubt that it was in the UK where the transition first began in the countryside. The effects of population growth and rising energy consumption, especially in the manufacturing sector, put pressure on forest and woodlands and favored the increase of croplands for the food production. In the other direction, there was pressure coming from the growing need for fuel for households and nascent industry. There was also an increased demand for pasture and fodder to feed traction animals on which an increasingly broad and voluminous transport system depended. These demands had contradictory repercussions on the agrarian sector. On one side, it put pressure on agriculture to provide more food for a growing population, particularly in urban areas, and for an equally growing number of animals for transportation. On the other side, however, it decoupled industrial activities from the land, which facilitated the growth of cropland. Undoubtedly, freeing up the energy functions of fallow and pastureland through the introduction of coal in economic activity, and even in domestic consumption, facilitated the reclamation of lands and their use for crop cultivation. Farmed land area grew by 58 % and the area of land dedicated to cereals by 62.8 % between 1700 and 1830 (Schandl and Krausmann 2007, p. 87). From this perspective, the growth possibilities of agricultural production in the UK depended not only on the innovations of the agricultural revolution but also on breaking away from the rigidity of the agrarian metabolism and, therefore, on the possibility of having access to more land to meet the endosomatic consumption of its population, particularly in urban areas.

The UK exhausted the possibilities of increasing biomass production using its own resources earlier than any other European country. According to the cited authors, this circumstance became evident in the mid 19th Century. Between 1750 and 1830 the yields of wheat rose from 1.2 to 3 t, the highest in Europe. Between 1830 and 1910 the population density doubled and could only be coped with by means of imports. Domestic production of cereals went from 6 to 3 GJ per capita in 1830 and in 1910, respectively.

This was not the situation in most European countries, which were still far from reaching the maximum growth potential offered by their agro-ecosystems. Such was the case, for example, of Austria (Krausmann 2001) or of the Swiss canton of Berne (Pfister 1990). As we have shown in the case of Andalusia in southern Spain (González de Molina et al. 2009), in the early nineteenth century the growth possibilities for agricultural production, and even for the production of biomass within an organic metabolic arrangement were far from reaching their limit. The work of Tello et al. (2010) in relation to Catalonia in northeastern Spain, suggests the same. There were even countries in which land was abundant and its agriculture could respond. The clearest example is the United States and many other countries in the Americas such as Argentina or Brazil (Garavaglia 1999; Padua 2002, 2004).

(ii) Saving land, increasing yield per land unit. The most well known innovations in this respect took place precisely in the UK and gave rise to the so-called Agricultural Revolution that, in the opinion of almost all historians, sustained the Industrial Revolution. The latest historiographical contributions, however, do not talk about sharp changes but rather of the slow introduction of improvements in the eighteenth century that boosted productivity (Overton 1991; Allen 2004; Warde 2009). New rotations, combining cereals with leguminous crops and fodder allowed for a better association between crop and livestock farming, the increase in livestock numbers, the substitution of human labor with animal traction, and an increased availability of manure, practically eliminating fallow. With the increase of production the farm income also grew and also improved the productivity by releasing manpower that could be employed by industry at the same time feeding a growing urban population.

According to Krausmann et al. (2008a, p. 194), the Austrian solution was similar to that of Britain: "New crops, above all leguminous fodder, potatoes and corn were gradually included into a new crop rotation and traditional fallow was abolished. The new crop raised the availability of fodder and allowed more livestock, improved feed supply and extended stall-feeding. These measures improved the availability of manure and did, in combination with the nitrogen enriching effect of leguminous crops, significantly enhance the nutrient supply on cropland. The shift to more intensive land use practices was largely compensated for by increasing employment of draught animals and more efficient iron tools. The optimization of agricultural production allowed almost a doubling of food output in Austria between 1830 and 1910, although the agricultural labor force remained more or less constant during this period… By and large, in Austria increases in food production kept pace with population growth during the 19th century".

The expansion throughout Europe of the market and private property created a favorable environment for the quick diffusion of these improvements. These innovations had effectively been dispersed to Denmark, Hannover, and to some other regions of Germany and Switzerland by the end of 1700, and during the early nineteenth century they had reached France and other countries. The increase in biomass production was an indispensable condition for the advancement of the urbanization process, as can be seen in the territory needed for supplying basic foodstuffs and other raw materials of agrarian origin to the rapidly growing European cities of that time. For centuries the size of cities had been limited by availability of nearby land and by the costs of animal transportation, which physically made transferring the necessary amount of biomass to be highly expensive. Vienna required in 1820 nearly 22,000 km^2 for providing the needs of a population of nearly 250,000 inhabitants. Ninety years later, in 1910, the city had almost one million inhabitants, but the extension required for its supply was of about 24,000 km^2 (Krausmann 2001). In 1784, just before the French Revolution, the food footprint of Paris was of 60,000 km^2 for a population of 660,000 inhabitants. A similar surface was still required for supplying Paris in the late 1920s, when its population reached nearly three million inhabitants (Billen et al. 2009). During the nineteenth century, the food footprint of Paris was reduced from 0.092 km^2 to only 0.02 km^2.

Kim and Barles (2012) have calculated the total energy requirement (TER) of Paris between the eighteenth century and the present. In the early eighteenth century the per capita consumption of energy of Parisians was 19 GJ and the average distance of supply (Davg) was of less than 200 km. By the early nineteenth century the per capita consumption had rose to 30 GJ and the Davg did not change much. During the latter century, the population quintupled and the change towards fossil fuels took place. Although consumption per capita remained stable, the changes in transportation increased the Davg to 1,870 km due to the distance to the coal deposits. During the twentieth century, in particular during the periods between the First and Second World Wars, the demand of energy grew considerably reaching 26 GJ per capita in 1910, 47 GJ per capita in 1946, and 126 GJ in the year 2006.

In many other parts of the world, the saving land solution (mixed farming) had either already been adopted as in Asia, or the soil and climate conditions did not make it practicable, which was the case in the Mediterranean world. In Asia land saving was already practiced in the early twentieth century: "Already in 1911, F. King described in his book Framers of Forty Centuries: permanent agriculture in China, Korea and Japan, the dexterity of Asian production techniques. By that time non-industrial systems allowed for feeding about 500 millions of human beings on a surface area smaller than all the agricultural area of the United States and on soils used for nearly 4,000 years. Chinese framers produced three times more cereals by unit of surface area than North American farmers and something similar occurred in Korea and Japan. The numerous techniques and strategies used by farmers of these countries included a complex system of channels and irrigation areas, organic fertilizers (including green manures, household wastes, manures, composts, and ashes) and cereal varieties well-adapted to the conditions of those regions (Toledo and Barrera-Bassols 2008)."

The cases studied in Catalonia and Andalusia are an example of other option, particularly suitable for dry climates: the expansion of irrigated land and the consolidation of water supplies. In fact, this was one of the routes chosen in practically all countries on the shores of the Mediterranean, as well as in China, Mesoamerica and the Middle East (Toledo and Barrera-Bassols 2008). However, until the arrival of fossil fuels, the multiplication of the extractive power of subterranean water, and the construction of large dams, the use of irrigation was limited territorially and subject to the seasonal conditions of rivers and other bodies of water. Improvements in the productivity of labor were, by their nature, limited. However, relatively important improvements were achieved with the introduction of new tools, always manual or powered by animals (which signified an added energy cost, often not practicable). The substitution of human labor for animal labor was one of the most frequently chosen paths to improve productivity. But given its high land cost of this solution, its adoption was dependent on land availability.

(iii) Specializing production, promoting one land use over others. The studies carried out in England, the canton of Berne (Pfister 1990), certain areas of Andalusia (González de Molina et al. 2010) and Catalonia (Tello et al. 2010) show that, in general, marketable production was increased through the promotion of agricultural crops and productive specialization which tended to break the balance between the different land uses that had characterized the organic metabolism.

In the practice of the three solutions outlined above, the replenishment of fertility became the crucial factor. Land imbalances made it essential to have a greater supply of organic matter. In view of the increased yield per land unit that took place throughout the nineteenth century, access to a higher amount of nutrients was in theory possible although not very significant. However, there are reasons to think that in many countries the expansion of the agricultural boundary, or the increase in yields, was achieved at the expense of nutrient reserves accumulated in the soil over centuries either naturally or through management of farmers. Our research about southern Spain shows that the agrarian sector responded to this growing market pressure by transferring not only the internal demands of the country but also the demand for food and raw materials from the British economy, specializing above all in the production of cereals, grapevines and oil (López Estudillo 2002; Garrabou and González de Molina 2010). In the case of grapevines at least, and possibly olive trees as well, greater crop intensity was achieved by extracting from the soil nutrient reserve (González de Molina et al. 2010), bearing in mind the structural shortage of organic matter in Spanish agriculture (González de Molina 2002). A similar occurrence was documented for the North American prairies by Cunfer (2005), so perhaps part of the agrarian growth experienced during the 19th Century and the first half of the 20th Century could be classified as extractive growth (of underlying assets) which did not have severe consequences due to the fast spread of chemical fertilizers.

(iv) Importing biomass that agro-ecosystems are unable to produce. The fourth solution was practiced abundantly—albeit only up until the late nineteenth century, and more so in inland areas of countries and between nearby countries rather than at a global scale—was to turn to the markets to import nutrients and foodstuffs for humans or animals. The Industrial Revolution was also sustained by the growing importation of food from other regions and countries. The old debate between protectionism and freetradeism, with diverse and complex arguments against and for either of the two options, can be better understood from the material perspective. Countries as the UK chose free trade because, among other things, the country was unable to sustain the urban demand of its industrialization process with its domestic resources. Opposite of what happened in Spain, where croplands were available, the urban demand was not large, and protectionist policies were present throughout most of the nineteenth century. In fact, the growing demand of biomass for feeding humans and animals was one of the main drivers of the First Globalization.

In around 1870, when the potential for modernization within the solar energy-based agrarian system had been exhausted, the UK changed its economic strategy by importing growing quantities of basic foodstuffs from other parts of the world (and by adjusting its surplus population via emigration). Hornborg (2007, p. 268) estimated that in the UK in 1850 the exchange of manufactured cotton fabrics for wheat, which obviously did not need to be grown inside its borders, represented the sparing of nearly three million hectares of cultivated land that could be assigned to crops other than wheat. In 1900, the land area equivalent to the imported cereals achieved a similar extension to that available for domestic farmlands (Krausmann et al. 2008a, p. 194). This flow of cereals even permitted the British agrarian sector to specialize in livestock production, which consumes a great deal of land but saves on manual labor, and produced lean benefits for large English landowners. But this appropriation of more land was not always peaceful; on a number of occasions, it was achieved with political-military means. Nineteenth Century colonialism is a good example of this.

Consequently, the industrialization of Europe was aided by trading with many peripheral countries; most of them net biomass exporters. The supplies of agrarian products (coffee, cocoa, sugar, cereals, fruits, livestock produce, etc.) was in practice a territorial subsidy provided by peripheral countries at a low cost (Schor 2005), which gave Europeans more available land for specialized production. The same happened with fertilizers and other agrarian inputs imported from poor countries. Poor countries exported their soil nutrient reserves (Mayumi 1991) as crops of sugar cane, cotton, etc. The cases of the Peruvian guano and the Chilean saltpeter illustrate well the effects of these uneven exchanges, not because the actual impact it had on European agriculture, but because the net loss of productive capacity (Leff 1986) implied in the exportation of these resources. However, Krausmann et al. (2008b) claim that the importation to Europe of these natural fertilizers was not decisive for sustaining the growth of domestic agrarian production or for increasing the offer of foodstuffs in Europe. According to Smil (2001), the global production of nitrogen as guano and mineral nitrates reached 240,000 t in 1990, which is actually a quite insignificant amount. Whatever be the case, the soils of industrialized countries could sustain a more intensive cultivation thanks to the exploitation of assets (Naredo and Parra 1993; Georgescu-Roegen [1971] 1996) from poor countries, which could not be invested in developing their own agrarian sector.

In fact, the guano from the Chincha islands became in 1847 the largest export product of Peru. In 1845, exported guano corresponded to 73.8 % of the total value of Peruvian exports. Throughout the guano period taking place between 1840 and 1880, Peru exported between eleven and twelve million tons of guano to be used as a natural fertilizer for benefiting European and North American soils. Depletion of the resource and the diffusion of synthetic fertilizers eventually put an end the business of guano (Tudela et al. 1990, p. 78). Similarly, export to Europe of Chilean saltpeter had an early start in 1830, and from 1879 to 1883 the struggle for the control of nitrate mines caused the War of the Pacific between Chile and Peru. The Chilean State obtained up to two thirds of its income from exports of saltpeter. To these two natural fertilizers a long list of colonial products could be added to illustrate the degree to which economic dependence and the primary exporter model exhausted the natural resources of poor countries, including among many others, indigo, sarsaparilla, cochineal dye, and rubber. Until the 1960s, coffee represented 59 % of the exports of Cameroon and 66 % of those from Colombia; coffee and cocoa represented 87 % of the exported products from Ghana, and 57 % from the Ivory Coast; 74 % of the exports of Cambodia were of rubber and rice, and so on (Palazuelos 1990).

In any case, productive extension and intensification caused the closed flows of local production to collapse, expanding their scope, and entering supralocal markets created in part by the expansive dynamic of specialization. In these broader markets, not only are products exchanged but also production factors, especially fertilizers, thereby initiating a process of commodification and the subsequent unrelenting specialization of production. Indeed, through commercial relations, major importations of land/soil occurred which, through different means, compensated for the imbalances in the agrarian metabolism of the origin societies. Whereas the first and longest-lasting balances were established in local spheres, the increase in the size of the metabolism obliged territorial integration on different scales. For example, in inland continental areas—where the means of transport was still land-based—territorial balances were established within districts or provinces, with flows still limited to a national scale. However, in areas with good sea transport links and their hinterland, balances could be established with far-off lands through commercial or colonial flows. Many port cities around the world specialized due to the fact that they could import energy and the materials they would no longer be producing under their new assigned uses.

The possibilities of maintaining the sustained growth of agrarian production through the progression of agricultural cultivation, or through the increase in the land's productivity were exhausted. In countries such as the UK, this occurred early on, in others, it came later, but most European agro-ecosystems had reached their productive limits by the end of the nineteenth century. Technologies associated with coal were not yet able to supply external energy to cultivation, but use of coal alleviated the pressure over forests. Agriculture would remain having an organic energy base even in countries adopting industrialization. However, the agricultural system needed to supply a growing demand for food from an increasingly limited extension of land, a limitation that was both in terms of surface area as of institutional measures. The cases of Catalonia and Andalusia certainly suggest that. The case of Andalusia, with the progression of woody crops, also compels us to analyze whether some of the processes of productive specialization and agrarian growth that took place in certain regions of Spain were achieved at the expense of the soil nutrient reserves, making the system even more unsustainable.

The exhaustion of the growth possibilities of agrarian production in the second half of the nineteenth century in many parts of Europe points to the threat of a Malthusian crisis. The technological change, or in other words, the arrival of synthetic chemical fertilizers, was still a way off, and it was spreading throughout the countryside. This hypothesis points to the need to revise from this perspective the emigrations that took place in Europe in the second part of the century, or the expansion of the international food market. It was precisely the need to import growing amounts of food from overseas what fostered improvements in transport and, paradoxically, provoked the agrarian crisis towards the end of the century.

In any case, the studies available about the replenishment of fertility (Krausmann 2006; Tello et al. 2010; Cunfer and Krausmann 2009; González de Molina et al. 2009) confirm that this became a key factor in the sustainability of the organic agrarian metabolism and which effectively played a key role in the process of transition towards an industrial agrarian metabolism. The emergence from the end-of-century crisis, based on productive specialization and the increase of yields per land unit, was only practicable when the structural shortage of fertilizers could be overcome, as argued previously elsewhere (González de Molina and Pouliquen 1996; González de Molina and Guzmán Casado 2006), through the manufacture of synthetic chemical fertilizers with fossil fuels.

From the aforementioned research, it is possible to draw an important conclusion: the end-of-century crisis might be explained not only by the entry to Europe of cheaper grain, but also by the frictions between two types of farming systems with different mechanisms for replacement of soil fertility. The land costs of European agriculture, and particularly in the Mediterranean, were higher than in America and Australia. In the absence of chemicals fertilizers, the replacement of soil fertility needed land devoted to producing manure or green manures. Since European agriculture had continuously cultivated soil for hundreds of years, agrarian growth could not be based on the soil nutrient reservoir for much longer. Moreover, the productive intensification experienced by European agriculture during the eighteenth and nineteenth centuries decreased the capability to replenish all harvested nutrients. Hence, the productive specialization and the increase in yields achieved during the first agricultural revolution were progressively exhausted. This was not the case in other countries such as the US or Australia, where the soil nutrient reservoirs of recently cultivated arable land were high. The land cost of replacing soil fertility in these regions was much lower. The end-of-century crisis that was reflected in lower prices for overseas agrarian products occurred when the revolution in maritime transport caused two types of agricultural systems with rather different land costs to come face to face. So, relative scarcity of nutrients, exacerbated by the failure of territorial equilibrium resulting from production growth during the nineteenth century in Europe, is one of the major reasons that caused the crisis at the end of the century, and initiated the second wave of the agrarian socio-ecological transition.

11.7 First Comers and Late Joiners of the Industrialization Process

The UK of the late eighteenth century had the two essential conditions for developing a coal based economy, because of which it was the first country that became industrialized: sufficient coal reservoirs in its subsoil, and a network of channels for its transportation. In the early nineteenth century the annual per capita use of energy reached 60–70 GJ, of which coal contributed with 50 %, firewood was already of minor importance providing less than 5 %, and biomass supplemented the consumption of primary energy with 45 % of the total. The use of coal nearly doubled the offer of energy per unit of surface area to 50 GJ/ha (or 60 GJ/ha in Great Britain), evidencing that the UK had already crossed the threshold of the agrarian metabolic regime (Krausmann et al. 2008b, pp. 189–191) (Table 11.1).

Industrialization processes extended throughout Europe, North America, and Asia, in some countries earlier than in others. The classical distinction between first comers, i.e., countries that had developed an important industrial sector by the third decade of the nineteenth century—including Germany, Belgium, the United States, France, and Switzerland—and the late joiners, i.e., countries that would become industrialized several decades later, such as countries from the Mediterranean and Oriental Europe, and Japan.

This diversity of industrializing rhythm has a convincing socioecological explanation. During that period, the implementation of the industrial metabolic regime depended on the capacity of each country to adopt the technological innovations that gave place to the industrial revolution in the United Kingdom (path dependence). Countries needed to gather a number of factors and an institutional framework that was similar to that in the UK, and a minimal capacity of demand. In different terms, during the first decades of the nineteenth century, a country that had abolished feudalism and implemented economic liberalism, and that possessed coal at affordable prices, had many possibilities of becoming industrialized.

Such characteristics can be appreciated by comparing the UK with Italy, two countries having similar sized economies and belong to the G-8. Table 11.2 shows the physical expansion underwent by the economy of the UK until the First World War, assessed in terms if coal consumption, the main source of energy of the Industrial Revolution. Such consumption was multiplied by 3.5 between 1853 and 1912, reaching to the coal peak just before the First World War. Contrastingly, the contribution in Italy of traditional energy sources—mainly biomass—to the consumption of primary energy did not fall bellow 50 % until the late 1930s. In fact, Italy lacked domestic sources of fossil fuels, which made the country dependent upon their importation. In 2009 the energetic dependence of Italy was still of 84 % (Bartoletto 2013). The scarcity of energy determined the Italian process of industrialization, leading it through a different path than that followed by British industrialization. Italy specialized in industries having high labor intensities. Between 1903 and 1912, the UK consumed an average of nearly 260 million tons

Table 11.1 Indicators of industrialization in the United Kingdom between 1750 and 1910

United Kingdom	1750	1830	1870	1910
Population density (In/km^2)	34	76	99	143
GDP/per capita ($/capita)	1.478	1.779	3.205	4.611
Agricultural population (%)	54	28	16	8
DEC/cap (GJ/cap/year)	63	68	122	148
DEC/area (GJ/cap/ha)	19	52	122	212
% Biomass	81	54	26	19
Coal consumption (kg/cap/year)	417	1.100	3.175	4.505

Source Krausmann et al. (2008b, p. 192)

Table 11.2 Historical availability and consumption of coal between 1853 and 1952 (millions of tons)

Year (*)	Total domestic consumption	Overseas shipments and bunkers	Total consumption and shipments	1853–1862 = 100
1853–1862	65	6	72	100
1863–1872	96	10	106	148
1873–1882	120	20	140	194
1883–1892	139	33	173	240
1893–1902	158	48	207	287
1903–1912	181	77	258	358
1913–1922	187	58	245	333
1923–1932	171	68	239	331
1933–1942	185	40	225	312
1943–1952	197	12	208	289

Source Historical coal data: coal production, availability and consumption 1853–2012. Department of Energy and Climate Change, UK Government

of coal while, during the same time period, Germany consumed 150, and Italy only 3. In 1911, 58 % of the industrial potency of Italy was derived from hydraulic energy and only 29 % from steam. The lack of coal made it to be imported, mainly from England, since the early nineteenth century and made the energetic costs to be between three and five times higher than in the most competitive economies of northwestern Europe.

Austria is another similar case of late joiner. Surprisingly, the annual per capita use of energy of Austria in 1830 was similar to that of the UK, but in the former country coal amounted to only 1 %, and agricultural biomass to 45 %—about 35 GJ per capita—of the primary energy. In Austria as in the UK the amount of used biomass was of about 30 GJ and was within the limits of the renewable energetic potential. In Austria, coal consumption was also increased but at a slow pace. After 1850, when the railroad connected Austria with the coal mines of the northern provinces, consumption grew quickly peaking to 50 % of the supply of energy in 1900. Coal was used in Austria mainly as domestic fuel and in some industries. The abundance of wood in the rural zones and for the metallurgic

Table 11.3 Composition of energy consumption in Sweden, the Netherlands, Italy and Spain between 1850 and 1900 (%)

	Sweden		The Netherlands		Italy		Spain	
	1850	1900	1850	1900	1850	1900	1850	1900
Food (human and animals)	25	17	28	15	41	39	50	31
Firewood	73	45	13	2	51	34	46	26
Wind, water	<1	<1	12	3	1	1	2	5
Fossil fuels	2	38	47	80	7	26	2	38

Source Gales et al. 2007, pp. 224–225

industry explains why firewood remained to be a relevant source of primary energy for house heating until the second half of the nineteenth century. The per capita use of energy increased only by 2 % between 1830 and 1930, while the use of energy per hectare more than doubled to 70 GJ/ha.

The Netherlands, Sweden, Italy, and Spain, four countries studied by Gales et al. (2007), followed that same pattern despite all have different climatic contexts, different amounts of natural resources, and different industrialization trajectories. The traditional sources of energy were consumed in these four countries until late times. In the Netherlands, only until 1863 was the total input of traditional energies lower than 50 % of the total, until the late 1920s in Sweden, and just prior to World War Two in Italy and Spain. In Sweden firewood was the dominant source of energy (75 %) in 1850, while human and animal foodstuffs comprised the remaining part except for less than 1 % of hydraulic energy. By that year in Spain human and animal foodstuffs corresponded to 50 %, firewood 46 %, coal 1.7 %, and hydraulic energy 2 % of the total energy supply. Spain, therefore, had more animal traction and less thermal energy than Sweden (Table 11.3).

Coal arrived late to these countries, even to the Netherlands where fossil fuels were already important because of the use of turf. Coal belonged mostly to the twentieth century, its relevance varying considerably. At its peak during 1913, coal provided 82 % of the energy consumed in the Netherlands, but in Sweden in 1909 that proportion was of only 45 %, in Italy from 1935 to 1940 it was of 40 %, and in Spain between 1927 and 1930 coal provided 46–47 % of the total energy consumption.

Overall, the development and rapid diffusion of a series of innovations in manufacturing processes and adaptations in the forms of organizing production led to an unprecedented increase of productivity in the group of industries that were protagonist of the industrial revolution. The cotton, steel, machinery, and transportation industries provided the support to this growth phase. Since its earliest stages (1760–1800), productive innovations multiplied in less strategic industries, nevertheless opening the access to a totally new level of modernity, as for example in the ceramics or paper industries. The cotton industry is a good representative of such fundamental transformation from a dispersed, putting-out system of manual biomass based work, to a centralized process within a factory housing large-scale steam engines powering the spinning Jennies and fueled by inert, fossil energy (Fig. 11.1).

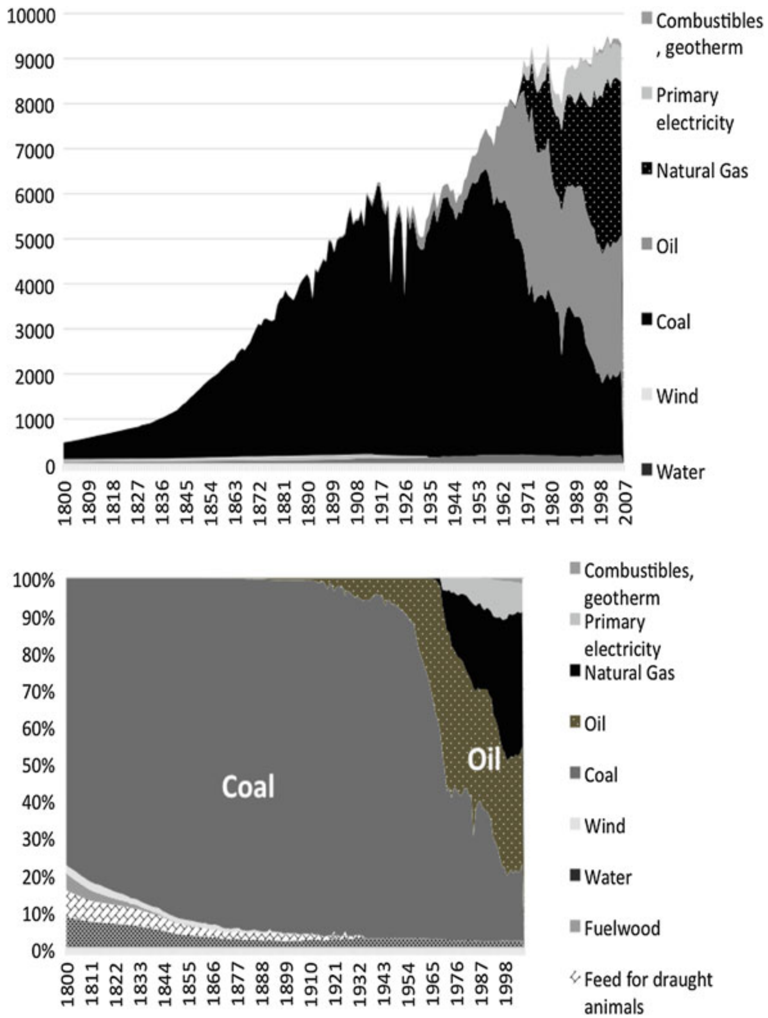

Fig. 11.1 Total energy consumption (PJ) of the United Kingdom's economy. *Source* Warde (2007); http://www.histecon.magd.cam.ac.uk/history-sust/energyconsumption/

The rigorously novel feature of production to be emphasized was the accumulative character of the innovations and of economic growth. By the middle nineteenth century England was the World's workshop, becoming the richest nation in terms of per capita income, the fastest growing economy, and the technological paradigm for accessing to industrialization. The model was a global technological proposal giving comparative advantages or disadvantages to participating countries regarding education, innovation, natural resources and other key factors.

11.8 The Subterranean Forest Effect

Peter Sieferle (2001) coined the term subterranean forest to refer to the process of energetic transition that decoupled production of goods from its territorial origins. The limits to continued economic growth expressed as the sustained growth of economic activities that were imposed by organic metabolism, which as any other biophysical phenomenon required the consumption of energy and matter. The relatively low energy density of firewood and charcoal hampered the continued economic growth from primary productivity within British lands. By 1850, the economic activity of the UK had already exceeded the provision of firewood possibly extracted from a forest the size of its territory. In 1900 a forest three times larger than the surface area of the UK was needed to provide the demand of biomass energy. In Austria that trend was less pronounced, but even with a slower and late industrialization, the subterranean forest consumed by the Austrian economy surpassed the extension of its own territory by the early twentieth century. The metaphor provides a graphical picture of the physical impossibility for economies to sustain incipient processes of industrialization without resourcing to fossil fuels contained in the subterranean forests.

The new technologies for energy conversion and railroad transportation facilitated industrial production allowing for spatial concentration and differentiation of production. However, growth continued to be a responsibility of the industrial sector in a way that the use of energy per capita was determined by the size of the energy-intensive industries and of the stretch of the transport network. The rise in available energy based on the abundance of coal barely contributed to increasing the consumption of energy in households, the consumption of energy by final consumers barely somewhat rising. Because of its energy density value and its association to technology needed for its use as fuel, coal as an energy carrier difficultly could have been massively consumed as final energy: something that would later on be possible thanks to oil and its products, but above all to electricity. Because economic growth was more focused on new markets than on domestic consumption due to the nature of its products—with the exception of some textiles—during that period there were no links between salary levels, acquisition capacity of workers, and economic growth. It would be until the surge of the labor movement, labor unions, and labor political organizations that the frequent rise in labor costs tended to be compensated by technological innovations and consequent rises in productivity.

But resourcing to the subterranean forest did not totally decouple economic activity from the territory. The main segments of the energetic system continued to be dependent on the territory in socioeconomic terms during the transitional phase to the use of coal. First, coal use released forests from pressure and provided mechanical energy that decreased the relevance of animal work and of human labor itself. But the steam engine was useful only for mechanical processes requiring large power inputs; so most down-stream processes depended on large amounts of human labor. The new steam engines boosted the industrial output, but despite the spectacular increment in productivity, the absolute human labor demand also increased. Similar effects can also be seen in transportation. The spanning of the transport network drastically lowered the costs, increasing the volume of payload and passengers transported. But even at a density of one hundred meters of railroad for every square kilometer, the railroad network of the nineteenth century continued to be a coarse knit of interconnections, the transport to and from the stations continuing to be made by animal traction. The railroad did not replace carriages; contrariwise, the increase of economic activity reproduced the demand for draft animals. So against what the subterranean forest metaphor may suggest, the use of biomass did not experience an inversely proportional descent to the increase in coal consumption. As has been demonstrated by Iriarte-Goñi and Ayuda (2008, 2012) for England and Spain, the consumption of lumber as a raw material for a diversity of industrial processes—including for railroad ties—continued to grow over that of firewood.

In fact, the first wave of industrialization based on coal promoted a considerable use of human labor and animal power, a growing demand which had important consequences: on one side, it stimulated demographic growth and urbanization favoring the beginning of the demographic transition; on the other side, it generated the proletariat as a social group and created favorable conditions for the appearance of the labor movement and its subsequent politicization.

11.9 The First Globalization

Economic growth during the nineteenth century was made evident in the evolution of both absolute and per capita GDP. Although eventually population grew throughout the nineteenth century, the GDP grew more, raising the GDP per capita. This economic growth was accompanied by a structural change in the sectorial composition of economy, giving place to a progressive but constant trend to the decrement of the agrarian sector and a sustained augmentation of the GDP from the industrial sector.

Considering the nineteenth century as a whole, the regions with greatest increments in GDP per capita were Europe, the US, and New Zealand. The GDP in the rest of the World experimented a below global average growth. The result was that economic divergence between countries increased, because the inequalities in per capita income between countries became larger. In 1800, China and India concentrated 80 % of the World's manufacture potential and by 1913 that proportion had been reduced to 46 %. As has rightly been stated elsewhere, western industrialization was coincident with deindustrialization of important areas of the World's periphery (Tables 11.4 and 11.5).

In either case, the human population multiplied thanks to the impressive technological and productive development achieved through industrialization, and the transformations occurred in the agrarian sector. The nineteenth century was marked by an unprecedented population growth. The number of inhabitants of

Table 11.4 Annual rates of GDP growth in the world economy by period from 1700 to 2008

Years	GDP	Population	GDP per capita
1700–1820	0.5	0.5	0.1
1820–1913	1.5	0.6	0.9
1820–1870	0.9	0.4	0.5
1870–1913	2.1	0.8	1.3
1913–2008	3.1	1.4	1.7

Source Maddison in www.ggdc.net/maddison/

Table 11.5 Annual rates of GDP growth in the world economy from 1780 to 1913 by region

	1780–1820	1820–1913	1820–1870	1870–1913
Western Europe	0.2	1.1	1.0	1.3
Eastern Europe	0.1	1.0	0.6	1.4
Ancient USSR	0.1	0.8	0.6	4.0
New Europe	0.8	1.6	1.4	1.8
Latin America	0.2	0.8	−0.0	1.8
Western Asia	–	0.6	0.4	0.8
Eastern Asia	0.0	0.3	−0.1	0.8
Africa	0.0	0.5	0.3	0.6
World	0.1	0.9	0.5	1.3

Source Maddison in www.ggdc.net/maddison/

Europe went from 187 millions in 1800, to 266 millions in 1850, 410 millions in 1900, and 468 millions in 1913. At the beginning of the nineteenth century Europe was probably the most populated area of the world, with a density of approximately 18.7 inhabitants per square kilometer, while in Asia the population density was of 14, and in Latin America of below 5 inhab/km^2. With population growth, territorial occupation density of Europe also grew, in 1850 averaging 26.6 inhab/km^2 and in 1900, 40.1 inhab/km^2, nearly twice the population density of Asia in the same years. Consequently, the European population went from a little over one fifth at the beginning of the nineteenth century, to one fourth of total world population in 1900.

Migratory flows went from underdeveloped countries to unpopulated areas, or to where industrialization began to be deployed. However, the most important migratory flow was oriented towards the colonies and to the rest of the non-European world. Between 1841 and 1880 over 13 million Europeans emigrated, a flow that was proportionally increased until 1910 when two million people emigrated from Europe. Between 1871 and 1914 a total of 34 million Europeans arrived to America, 25 millions of them becoming settled in the colonies.

Foreign trade had until then limited to high price objects—such as coffee, textiles, gems, and precious metals—that could support the elevated costs of transportation. International commerce was stimulated by specialization, higher production, and the improvement of transport. Countries with more economic growth and seeking in the international market the indispensable raw materials they needed for continued growth were the leaders of foreign trade, at the same time looking for relocating commodities and capital that did not find a profitable position within the metropolis. Transport systems transformed from lines connecting a few locations to national or even international communication networks. Transport infrastructure was initially held by private investment of large anonymous societies, but during the 1880s the magnitude of the investments and the frequent deficits of exploitation forced the States to invest in the sector. The expansion of transport infrastructure was also a powerful pull in both directions of industrial growth (fabrication of rails and locomotives, specialized labor, etc.). Since 1890 the introduction of the steam turbine and diesel made it possible to build larger ships with iron and steel hulls. This would mark the definitive triumph of steam over sails. In the meantime, two new navigation routes were opened that shortened the trip and lowered the fares, the Suez Canal in 1869 and the Panama Canal in 1914. In addition, steam ships with higher hull drafts made it obligatory to make strong investments in ports. The value of trade multiplied by 20 between 1830 and 1914, from 10,000 million Francs-gold in the former year to 58,000 in 1870 and 200,000 in the latter one.

As foreign trade began playing a strategic role in the economic growth of western countries, the control of markets and the security of supply of basic raw materials became foreign policy priorities for western powers, irrespectively of these having or not colonies. The risk of building railroads in a foreign territory, buying land, building ports, discovering and exploiting mines, is much higher than the risk of simply buying and selling commodities. The search for raw materials and inexpensive and abundant foodstuffs gave a strong impulse to colonial expansion during the nineteenth century. England, France, the Netherlands, and Belgium, all European powers at that time, attempted to build their own extensive imperial colonies under their exclusive control. Countries more recently becoming industrialized as US and Germany were relegated to a second plane in the territorial division of the world, but nevertheless participated in the international market in alliances with colonial powers, or directing its exports to independent countries such as those of Latin America.

Colonial policies peaked in the early twentieth century with the shearing out of Africa and Polynesia. In that time, 90 % of Africa, 98.9 % of Polynesia, 56.6 % of Asia, all of Australia, and 27.2 % of America were colonized by the European potencies and the US. A few years before First World War, all of the unoccupied land in the planet had been seized by colonial states. For the first time the world became completely shared out, so the only possible future change was that territories changed hands among possessing colonial powers. The struggle for control of territory and thus, for accessing sources of energy and raw materials that were shared out, was one of the many reasons of the armed conflicts between the economic potencies of the twentieth century.

11.10 Centers and Periphery: Trade and Colonization

The advances of Western colonization consolidated an extraverted and disarticulate economy that satisfied metropolitan demands. Most colonized or commercially dependent countries became primary exporters of agrarian products and minerals. From the beginning of trade between metropolis and colonies, a constant and progressive deterioration of the ratio of real exchange value began to be experimented that was due to the comparative added values of constantly increasing price manufactures—having higher added value of labor, raw materials and energy—and of continuously devaluated raw materials imported from poor countries. In such way, it was possible to lower the costs of the productive processes of metropolis, favoring its diversification and growth, and thus boosting economic expansion (Table 11.6).

Not only was the transference of economic surpluses started, but also of natural resources in need of being extraction at higher volumes in order to cope for the increased prices of manufactured commodities. This model determined the peripheral countries to become specialized in the production of a reduced number of export commodities, which were either depleted or their misappropriation caused irreversible environmental damage. The afore-mentioned case of exploitation of guano is paradigmatic of the harmful effects of commercial exploitation and export of inputs for the European agriculture. Such trend was aggravated by the imperialist burst of the late nineteenth century and by a new mode of natural resource control: direct foreign investments made by rich countries in colonies or poor countries with the intend of ensuring the volumes of raw material supply demanded by their industrial and technological development. A large number of poor countries developed under this capital flow from the metropolis in virtual mining enclaves with modern technology and intensive extraction, or in large tropical plantations, both having the only objective of entering to international markets. Such enclave economies were perhaps among the most harmful because its benefits for local economies was null, while the involved countries faced the fluctuations of a market over which they had no control. Also, agrarian specialization determined that the best lands in colonies were dedicated to cultivation of a handful of export products, thus altering the structure of local traditional agriculture and the autochthonous forms of social organization. In that way, in the periphery private property advanced over communal property, commercial trade over barter, and intensive and exhausting exploitation over pre-colonial traditional management of agroecosystems, among other transformations. The dispossessed peasants had to occupy marginal lands causing erosion, overgrazing, and deforestation. At the same time the richness of colonies was being plundered, their territories were used for settlement of the overpopulation that was beginning to affect rich countries. Colonies were also used as locations in which to eliminate the social entropy of metropolis.

Many countries in the economic and political periphery adopted the primary-exporter model based on agrarian products and raw materials in order to finance

Table 11.6 Colonial possessions of the powerful countries

Potency	1876		1914	
	Surface in millions of km^2	Millions of inhabitants	Surface in millions of km^2	Millions of inhabitants
England	22.5	251.9	33.5	393.5
Russia	17.0	15.9	17.4	33.2
France	0.9	6.0	10.6	55.5
Germany	–	–	2.9	12.3
US	–	–	0.3	9.7
Japan	–	–	0.3	19.2

Source Alonso et al. (2001)

manufactured imports from the profit of exports. During that period and until the 1950s, nearly 40 % of all exports were of oil and raw minerals, 20 % of derived products, and the remaining 40 % of agrarian products, foodstuffs, and raw materials of industrial use. For instance, 90 % of the Burmese exports were of rice, rubber, and cotton; a similar percentage of Philippine exports were of oilseeds, sugar, and lumber; in Kenya of maize and coffee, and in Mozambique of peanut. Libyan exports were 99.4 % oil; those of Mauritania were 95 % iron; those of Zambia were 91 % copper; of Chad 87 % was cotton; exports from Algeria were 78 % oil and citric fruits, etc. (Palazuelos 1990). The list of colonial products can be extended with products such as indigo, sarsaparilla, cochineal dye, rubber, among many others in order to show the degree to which economic dependence and the primary-exporter economic model plundered the natural resources of poor countries. Until the 1960s coffee represented 59 % of the exports from Cameroon and 66 % of those from Colombia; coffee and cocoa comprised 87 and 58 % of the total volume of commodities exported by Ghana and the Ivory Coast, respectively; 74 % of shipments from Cambodia were of rubber and rice, etc. (Palazuelos 1990).

On the other side, during the last quarter of the nineteenth century occurred what some authors call the second technological revolution, characterized by the appearance of new energy carriers, new technologies and industrial sectors, and new ways of organizing production and product distribution. Such change was stimulated by the exhaustion of the benefits derived from technology that played a protagonist role during the Industrial Revolution. The transformations also stimulated the close links that were beginning to be established between technological innovation and scientific knowledge, giving place to what is known as scientific-technical rationality (Garrido 1996).

The old model of industrial growth based on the expansion of production and low productivity systems, requiring abundant labor, suppression of trade union organizations, and, consequently, low salaries, had been weakening during the second half of the nineteenth century. The new model was possible thanks to the surge of increasingly competitive markets and ever-larger territorial realms, incentivizing better productivity constants through machinism and new systems of labor organization within factories (Taylorism 1914). The lowering of transport costs and the exploitation of sources of energy other than coal were making possible the industrialization of regions without coal reservoirs, hence, allowing the extension of the Industrial Revolution to a larger number of nations. By the end of the nineteenth century industrialization had amply extended in Europe, new industrial powers appearing also in Japan and the US.

That relevant transformation was the result of the strong acceleration of economic development that was enhanced both by the formation of the large European nation states (national markets, economic policies, and institutional reforms), as by similar institutional changes in Japan, Russia or the US (abolition of slavery). If the preceding period (first industrialization wave) was characterized by the leadership of the textile and steel industries, from the 1860s the lead would be taken by new industrial sectors (heavy industry): metallurgic, shipbuilding, machinery, and chemical. The effects over labor processes and size of industries were quite important, such as the reduction in manual labor and its growing substitution by machinery, investment concentration, and shareholding societies, among others.

In fact, between 1870 and 1913 production experienced an unprecedented growth that in the US was twice that of Germany and four times that of England. Such growth can be explained by the strong demand originated by the shipbuilding, railroad, and arms industries. The huge costs of investment gave impulse to industrial concentration. But new industrial sectors became leaders of this second technological wave (or technological paradigm), in particular, the metallurgic and chemical industries, both of high energetic intensity. Coal thus became the main source of energy and its global consumption multiplied by 5.5 between 1860 and 1900.

At the same time, oil began to be exploited at a large scale. Oil was until then mainly used for public urban lighting, but the invention of the internal combustion engine opened wide possibilities for its use. The global extraction of oil went from 800,000 t in 1870 to 19.5 million t in 1900. The use of oil as a primary source of energy and the invention of electric power as a secondary energy source had relevant consequences, which at large would change industrial metabolism. The first real electrical power plant based on coal combustion developed by Thomas Edison began to operate in New York in 1882, powering household lamps.

But coal would not be replaced by oil as the main source of energy until the second half of the twentieth century, fueled by the rapid growth of the transport sector. Despite that, coal remains to be fundamental in the energetic supply of the planet, covering 23.5 % of the needs for primary energy in 2002, and 39 % of the total generation of electric power in the world, over twice of the next source of energy, and covers an essential 64 % of the world's steel production (WCI 2005; World Economic Forum 2013).

Oil has a higher energy density than coal, is more flexible in its treatment, and is easier to transport. In 1900, oil accounted for only 1.5 % of the primary energy consumed in the world, firewood continued to provide 51 %, and coal 47 %.

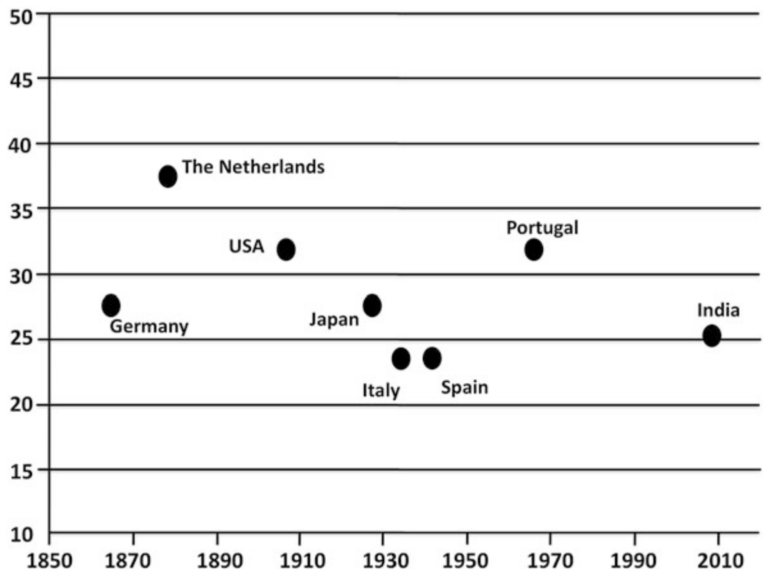

Fig. 11.2 Graph showing the 1 year in which the mentioned countries for the first time consumed more inorganic than organic energy. The *vertical axis* indicates the per capita energy consumption during the year of transition (GJ/inhab). *Source* Infante (2014)

The great discoveries associated to oil were yet to come. Despite all, by the end of the nineteenth century the main oil market—that of lighting—became threatened by the development of the light bulb of Edison and Swan. Electricity was clean, provided a better lighting, and it did not require the attention of its end users. The internal combustion engine entered the market as a competitor of steam engines by around 1876, but several decades needed to pass before it could have an impact on the demand of oil. In 1908, Henry Ford perfected the automobile, which facilitated a revolution in consumption and individual mobility (Fig. 11.2).

Until the arrival of the automobile, gasoline had been a subproduct of kerosene distillation and had a limited output to the market. However, the automobile turned gasoline into the main market of oil products, followed by fuel oil used in furnaces of factories, trains and ships. The advantages of oil over coal were evident: speed, flexibility, and no need for human labor to move it. In 1919 over US citizens owned three quarters of all automobiles. After the Second World War, car owning became a global phenomenon. By 1945 there were 64 millions of privately owned cars, while in 1972 that number grew to 280 millions, and by the end of the twentieth century that number grew to nearly one billion. Finally, in 1964 oil became the main source of energy surpassing coal. Oil prices lowered due to the large accumulation of supplies from the Middle East (Smil 2013) (Fig. 11.3).

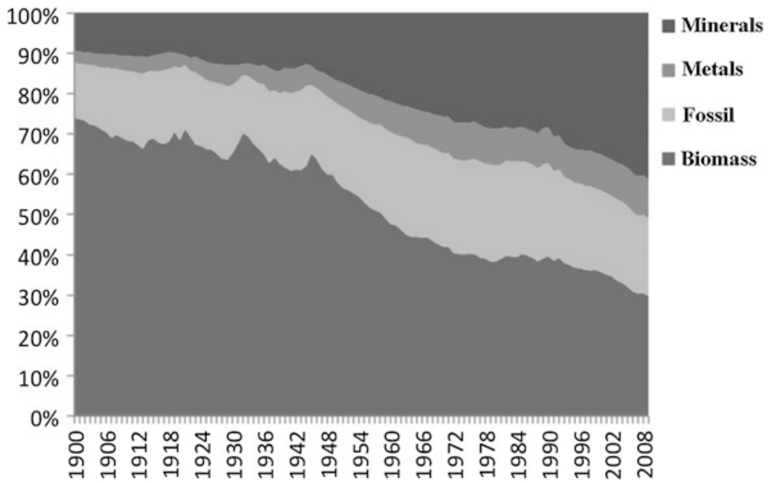

Fig. 11.3 Percentages by product of global direct consumption of materials between 1900 and 2009. *Source* Krausmann et al. (2009)

11.11 The Great Acceleration or the 50s Syndrome

The world economic system experienced a new forward leap as a consequence of the transformations occurred and of the policies fomenting demand and full employment that followed the 1929 crisis. Such forward leap became known as the great acceleration (Constanza et al. 2007; Hibbard et al. 2007), a name accounting for the rapid growth of population, production, and consumption of commodities that took place at a scale that had not been experienced before; and which brought with it a corresponding increments in the energy and materials consumed, in the generation of wastes, and in environmental damage. A new model of economic development that some authors call Fordism began to become dominant in industrialized countries. Until the early twentieth century economic growth had been based on successive increments of production achieved mainly by increasing the amount of laborers and industrial facilities, and to a much lesser extent by changes in the labor processes and methods (so many hands, so much money); a model that was more labor intensive than capital intensive. But that model quickly entered in crisis as soon as the markets became more integrated and competition considerably augmented. In the mean time, the surging of the labor movement forced salaries to rise. The strategy deployed by most corporations was based on the reduction of labor costs and the increase in capacity for productivity to sell at more competitive prices. Technological innovation became crucial for competitiveness and business profit.

Production suffered important changes with the introduction of scientific forms of labor organization, incarnated in the methods of Taylor. It was Henry Ford who introduced such changes at a large scale, not only to his assembly lines, but also considering workers in their dual condition of producers and consumers. Ford rightly thought that salaries were the immediate future profit, because they allowed other companies to sell, which eventually would benefit his own enterprise. Rising salaries fomented consumption. Such a bet agreed well with the needs of the new capitalism. Production necessarily required of massive consumption, and that could only be possible by increasing the purchasing power of workers. In fact, the viability of the system depended on constant market expansion and an increase in the effective demand, which would nullify the costs of salary at the end of the cycle. What until then had been considered to be luxury commodities became accessible to massive consumption. A large number of new products appeared that did not respond to real demands of the population, but that ended creating their need by their mere existence. The level of development and wellbeing became confused in the mind of citizens and in the statistics of politicians and economy analysts as the numbers of telephones, laundry machines or televisions per inhabitant. By 1971 there were over 270 million telephones in the world, a figure that would currently seem preposterous, but that was then a reflection of a revolution in the way of life of people; 10 years later, that number had tripled.

That new model of economic growth could only be possible by scientific research being put to the service of technological innovation. This science-technology couple became the natural modus operandi of science, thanks to the scientific-technical rationality, a paradigm that was at the center of the world of ideas. Some dubbed this organic connection between science and technological as a scientific-technical revolution, a concept filled with a sort of candid optimism about the indefinite viability of economic growth. Productive processes tended to have increasingly more machines and fewer workers. The expansion of the model, the appearance of new economic activities, and the vigorous economic growth, made that for 30 years such continued destruction of employment was not apparent as unemployment levels; in fact the full employment characterized that golden age of wealthy countries, and even initiated the integration of women to the labor market. Japan had in the 1960s an unemployment rate of 1.3 %, while in Europe unemployment was less than 1.5 %.

The key factor for such an impressive economic growth was the continued supply of low cost energy and materials as had never been witnessed until then, i.e., because of the very different ways of use of energy and materials relative to the coal phase. For instance, the consumption of energy in the US tripled between 1950 and 1973 and the average price of Saudi barrel of crude oil was rarely of above two dollars. In the same years, the per capita use of energy rapidly increased in industrialized countries. For example, in Austria the per capita consumption of energy increased by 123 %, and in the UK by 54 %, in both economies peaking to around 200 GJ. Simultaneously, coal was displaced by oil, and later on, by natural gas, both energy carriers with much higher energy densities than coal, and once appropriate conduits were established (oil and gas pipelines), easier to transport (Fig. 11.4).

In the early 1970s, and since before the Second World War, the use of coal had decreased in the UK to about 40 %. Currently in the UK only 28 GJ of coal are

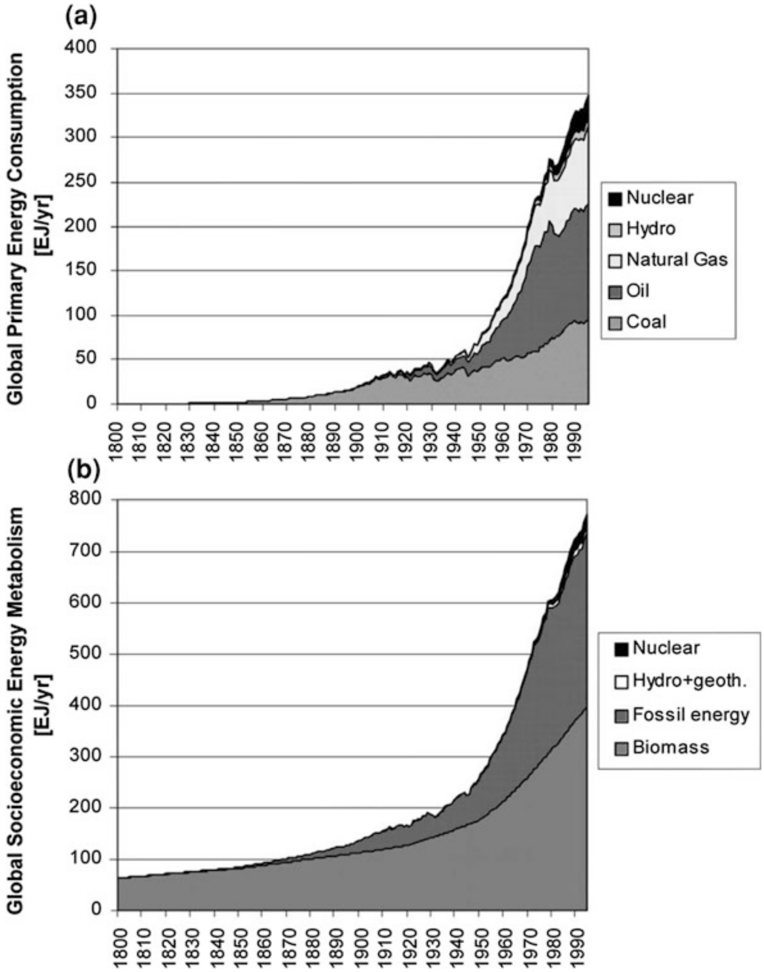

Fig. 11.4 Annual global consumption of primary energy from 1800 to 1990. *Source* Haberl (2006, p. 93)

used per capita and 17 GJ in Austria, mostly for its combustion in electric power plants and the steel industry.

This new phase was not only characterized by oil and natural gas, but also by the technological cluster oil-steel-automobile in combination with electrical power. Internal combustion and electrical engines rapidly replaced steam engines, and electricity provided more flexibility in the utilization of energy. Such technologies appeared much earlier, but were only adopted in Europe after the Second World War. We already mentioned that such a development was made possible thanks to the fall in the prices of energy (Smil 2003), but it was also promoted by States when building infrastructure in the for of highways and electricity networks,

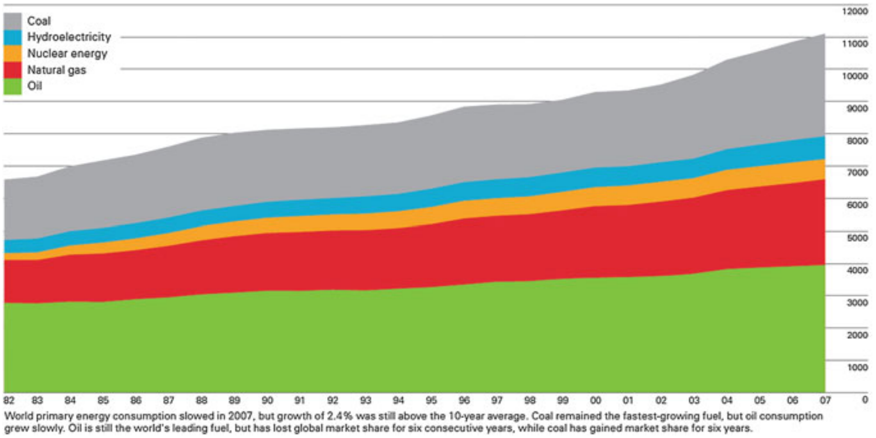

Fig. 11.5 World consumption of primary energy from fossil fuels, hydroelectric power, and nuclear power in millions of oil equivalent tons. *Source* BP Statistical Review of World Energy, June 2008, 42

or when developing and promoting the Green Revolution in agriculture. The expansion of the transport network infrastructure—from a railroad network of 100 m/km^2 to a highway network of 1,000–2,000 m/km^2—was crucial, making it possible to achieve an increase in transportation of passengers and cargo as never before experienced. Mass production and the fall in energy prices turned luxury commodities, such as automobiles and many electric appliances before the Second World War into massive consumption commodities (Fig. 11.5).

In contrast with the previous period of energy consumption by the supply sectors, in this phase a massive increment of direct energy consumption by end consumers taking advantage of central heating, electrical household appliances, and automobiles in nearly every home. Transport and households currently consume 30 % of the total energy consumed in Australia and the UK, while consumption by industry decreased from 50 to 25 %. Overall, domestic austerity was replaced by consumerism; a phenomenon Pfister calls the syndrome of the 1950s (Fig. 11.6).

The average metabolic profile of the human species grew at a rate of 0.2 %, which explains the low levels of exosomatic consumption prevailing until after the Second World War. An economic growth concentrating in production goods rather than in consumption goods explains why consumption of materials was scarce in biomass, and moderate in fossil fuels and metallic minerals. But after the Second World War per capita consumption of energy suddenly raised, its growth rate reaching up to 3.3 %, while per capita consumption growth rate of construction materials was higher at around 6 %. Per capita consumption of materials grew from 4 t to over 9 t, irrespectively of the demographic explosion happening in those years, which caused an unprecedented grow of the human population. The 1973 oil crisis put an end to three decades of acceleration, initiating a period of

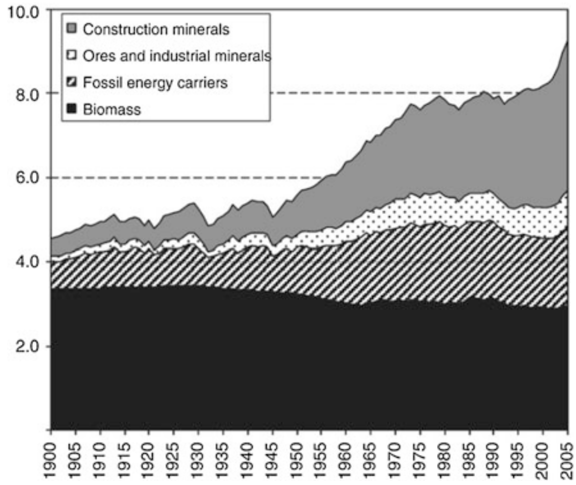

Fig. 11.6 World consumption of materials in Gt and consumption of materials per capita between 1900 and 2005. *Source* Krausmann et al. (2009, p. 2698)

slower growth. With the exception of biomass—which kept growing at a moderate rate—consumption of materials plunged down by nearly 50 %, reaching 2.13 %, shortening the distance with the rate of population growth and lowering the consumption per capita down to 0.56 %. Such moderate rate has prevailed until the beginning of the present century, in which absolute and per capita consumption of material is again growing.

The ultimate causes of the constant increments of productivity reached during the post-war period were the abundance of energetic and mineral resources, and the propagation of the consumer way of life epitomized by the lifestyle of US citizens in those years. The most emblematic symbol of the period, and what brought with it the worst consequences for the environment, incarnated as the automobile—responsible for one third of the CO_2 emissions and thus of climatic change—that had already been expanding throughout the US before the Second World War. From the US, the automobile later became diffused through Europe and at a more modest rate in the countries of real socialism and of Latin America, where the middle class acquired them.

All these economic and social transformations occurred in a new sociopolitical framework that took form mainly after Second World War, and that would not show weakness until the oil crisis of the 1970s came; this time with social subjects that underlined the fissures opening in the pre established social and political structures. According to Claus Offe (1988), such framework was configured by the post war constitutional agreement endorsed by most social agents of European countries, with contents that did not differ much from what had been applied in the US since the 1930s. The treaty materialized in an ample consensus about the most convenient distribution of social roles during a phase intended to be of sustained economic growth. Economic activities, and production in general, would be based on the good criterion of economic agents led by their own personal interest and the signals they send to the markets. Economic policies should only provide the most favorable conditions for economic growth not to stall, or in any case, correct disequilibria created by free private initiative and the market. Thus production—despite its fundamental relevance for social relations—became confined within the realms of private interests and guided by economic efficiency and business profits, which consequently affects not only the concrete structure of the labor processes, but also the characteristics and foreseen effects of technologies, and the decisions made about destination sector, amount, and location of investments.

Labor organizations of industrial trades, and of waged workers in general, should become mechanisms for correcting any disequilibrium derived from economic growth. Trade unions should also redistribute the benefits from growth by making full employment possible and creating better laboring conditions, at the same time improving the living standards of workers through the creation, among other actions, of an as universal as possible social security system. In exchange for a decisive and institutionalized participation in the distribution of wealth, unions resigned to revolutionary futilities and to vindicating any control on production. Institutionalization of the class conflict and distancing from revolutionary ideological assumptions would result from a trade union practice that would in the future emphasize economic over political struggles. In coherence with its reformist ideology, socialist and social democrat parties would hold the ideological hegemony (Beck 1998).

The three decades in which this system was enforced were not exempt of conflicts, but the main concern was economic growth, higher salaries and standard of living, and the indispensable security for the perpetuation of the system. The subjects of protests, highly institutionalized, were the established classes and, of course, political parties. Conflict resolution mechanisms were thus practically narrowed to collective negotiation and competition among political parties. Support for the system came from a sort of civic culture that emphasized the values of social mobility, private life, consumption, authority, order, and others. Class profiles began to become diluted, and with them, also revolutionary ideologies were reduced to intellectual minorities, and to a sector of the working class under the hegemony of communist parties, wherever these managed to survive.

11.12 Industrialization of Agriculture

The possibility given by oil and its associated technologies of injecting large amounts of energy and materials radically changed the world's agricultural scenario. The main transformations took place after the Second World War in the form of the Green Revolution consistent in improved seeds, chemical fertilizers, mechanical traction, and pesticides. But in fact, the industrial metabolic regime had penetrated agriculture half a century earlier during the late nineteenth century, when chemical fertilizers manufactured by means of fossil fuels and chemical procedures made their appearance. Their introduction meant overcoming the most common limiting factor in production thus far, the lack of soil nutrients, and a break from the dependence on replenishing land fertility. In other words, reducing the land cost of fertilization (Guzmán Casado and González de Molina 2009; Guzmán Casado et al. 2011). A long transition process commenced in which agrarian production shifted from depending on soil to depending on subsoil, in other words, on fossil fuels and minerals, as is the case today.

It began in this area because the critical point in terms of the resilience of the agrarian metabolism was precisely the shortage of nutrients or the depletion of the soil. The successive land arrangements, designed in the nineteenth century to produce new essential balances, became expensive and impracticable owing to their growing size. From the second half of the eighteenth century onwards, the expansion of crops for industrial purposes or human consumption required the importation of soil/land in the form of organic matter or animal feed. But the continual increase of agricultural surface area and its productive intensification aggravated the nutrient deficit to such an extent that it increasingly cost more money and effort to cover this deficit by importing organic fertilizers. This created a favorable context for the spread of land-saving technologies, especially chemical fertilizers, where the process of intensification had consumed the land's own resources, which would explain the irregular use made of this technology in the early 20th Century. In places where there were still lands with which to generate new balances there was no need to use chemical fertilizers, and that was only carried out on a partial basis. A similar pattern was observed in large extensions of land, such as the latifundios of some Latin American countries, or in the southern Spain, Italy and Portugal, where draught livestock could be used to obtain the fertilizer required for the total or partial sowing of fallow land, thereby increasing crop intensity (see González de Molina 2002). More intensive rotations, without fallow and with successions of crops that would have been previously impossible, were now possible, stimulated by the integration of the international markets for agrarian products at the end of the nineteenth century.

Saving land was the most logical option and it was derived from its dependence (Liebowitz and Margolis 1995) relative to the former rupture of the agrosilvopastoral equilibrium (Tello 2005), i.e., the rupture with the peasant multiple use strategy (Toledo 1990). A different course was taken where land was abundant and the equilibrium between alternate land uses was unthreatened by intensification. For example, in the US mechanization of farming chores preceded the introduction of chemical fertilizers. The first agricultural machines were powered by animal traction or even by steam (Fig. 11.7). North American colonists had more than enough land to feed their draught livestock, and were not limited by scarcity of firewood for generating steam, something that was practically impossible to do in an overpopulated Europe or in most of Asia. The significant increase in labor productivity these productive possibilities brought made US exploitations more profitable than those from Asia or Europe. Some specialists of technological change of agriculture even claimed that since technical solutions saving labor were more effective than those saving land, poor countries should follow the former alternative (Hayami and Ruttan 1971). However, due to the territorial costs of replacing human labor for animal power in organic agriculture, where land was

Fig. 11.7 The almost desperate attempts for increasing animal traction could be achieved in two ways: adding animals to a single plow (*top photograph*), or multiplying the number of two horse plows (*bottom photograph*). The photograph at the *top* shows Wilber T. Banting of Macrori Sask, Canada in his eight-horse plow. The photograph at the *bottom* was taken by Haynes F. Jay in 1880 and shows 16 two-horse plows

scarce, labor saving technologies were unable to be implemented until the arrival of motor vehicles.

Towards 1904, the German chemist Fritz Haber began to experiment the possibility of synthesizing ammonium, a nitrogen derivative, whose shortage in soils poses a strong limitation to agricultural soil productivity (Smil 2001). First, chemical nitrogen fertilizers and other agrochemical contributions, and afterwards advances in genetics, contributed during the early twentieth century to promote a socioecological transformation in crop fields. However, Krausman, Schandl and Sieferle (2008b) put back the introduction of fossil fuels in agriculture until after the Second World War. But if we approach this issue from a broader perspective, which includes the Mediterranean world, the energy change in agriculture began in the first few decades of the twentieth century, not only because synthetic chemical fertilizers entailed high energy consumption from fossil fuels, but also because these fuels were an intricate part of agrarian labor processes. In the early decades of the twentieth century, the energetic change took place in Spanish irrigation systems with underground water: waterwheels and animal drawn mechanisms were replaced with systems powered by fossil fuels (irrigation water hoisting pumps powered by electric or internal combustion engines fuelled by producer gas or oil). In Italy this was even more so, bearing in mind the spread of drainage pumps powered by fossil fuels in processes of Bonifica. The appearance and spread of these technologies were crucial to the agrarian modernization of both countries (Calatayud and Martínez Carrión 1999; Bevilacqua and Rossi-Doria 1984; Bevilacqua 1989–1991; D'Attorre and De Bernardi 1994).

But the big leap forward was associated with the change in energy pattern that replaced coal with oil and natural gas, which offered higher energy densities.

Table 11.7 Some indicators of industrializations process of agriculture

	Units of measure	1963	1978	1993	2008
Fertilizers (N)	1,000 t	15,011	53,327	74,493	105,738
Rural population	Millions	2,106	2,656	3,134	3,385
Mechanization	Tractors (total)	12,389	20,557	26,003	–
Cereal yields	kg/ha	1,321	1,946	2,502	3,149
Food energy	Petajoules	11,027	16,075	22,393	29,060
Energy intake per capita	kcal/day	2,253	2,451	2,636	2,822

Source FAOSTAT and own elaboration

Associated with them, two basic innovations for the industrialization of agriculture permitted the mass subsidization of agriculture with external energy: electricity and the internal combustion engine. This began during the 1930s in the US and reached Europe after the Second World War. It began with the mechanization of many agricultural tasks and culminated in most rich countries with the spread of the technological package of the Green Revolution at the end of the 1950s.

Crop intensification had come up against new ecological conditioning factors, as had occurred in the late nineteenth century. Agricultural activity had been growing relentlessly and livestock, the main source of traction, could not keep up in terms of traction demands or the change of diet, richer in animal proteins. Competition between the allocations of land to growing food or fodder will still be as much of an issue as ever. The presence of animal traction impeded further expansion of agriculture and intensive livestock farming. It was necessary to develop a kind of technology that would once again save land, freeing up the labor livestock productive areas, and a kind of technology that would replace animal traction with mechanical traction. Added to that was the convenience of saving costs to achieve a minimum threshold of profitability, situated at a lower level than the average profitability of other economic activities. The reduction of manual labor, replaced by machines or by chemical means that made certain tasks easier (weeding, for example) was the solution. In some countries, emigration from the countryside to the city and the development of movements of paid farm laborers pushed wages up and sped up the substitution process (Table 11.7).

Although the process of decolonization made possible for many peripheral countries to regain sovereignty over their sources of natural resources, in practice control remained in the hands of the former metropolis. Many countries adopted a policy of import substitution (see review in Bruton 1998), which was financed by the agrarian sector that experienced a new intensification process. Such was the objective of the modernization policy that accompanied the Green Revolution in peripheral countries. Surface area of cultivated land expanded, particularly in that dedicated to commercial crops. Permanent grassland also extended at the expense of forested areas. Between 1970 and 1985 alone, the surface area of forest in Latin America and the Caribbean region went down by nearly one million square kilometers. In 1987, 80,000 km^2 of Amazonian forest were converted to grassland, a figure only slightly larger than that of the previous years. Beyond doubt, the case of Haiti is most relevant. By 1923, 60 % of Haiti was covered by arboreal vegetation, but 60 years later that surface area was drastically reduced to fewer than 2 %, of which 30 % was degraded and hence totally unproductive. The expansion of cropping and irrigating land unsuitable for agriculture also had severe consequences. The map of soils of FAO in 1990 included 400 million hectares of degraded soils only in Latin America (GLASOD/PNUMA 1991).

The novel crops depended on improved seed varieties needed large doses of fertilizers and pesticides, and needed to apply agricultural technology that was beyond the reach of poor countries. In 1984, 20 times more fertilizers and 25 times more pesticides were used in Latin America than in 1950. From 1950 to 1972 the annual rate of average consumption of fertilizers grew by 14 %. By 1980, Latin America spent 1.2 billion dollars in pesticides. In exchange, the results of the Green Revolution were rather modest in terms of productivity, hunger, poverty, and malnutrition not disappearing, but technological dependence and debt grew in an unusual way. In fact, the translation of the western model of intensive agriculture to countries having different edaphic and climatic conditions opened a huge market for transnational agrochemical and food corporations.

In parallel, an important destruction of the sector of agrarian subsistence took place that conditioned the loss of alimentary self-sufficiency (Toledo et al. 1985). The expansion of the livestock industry during the post war period is a good example of such a phenomenon. As the standards of living rose in industrialized countries, the consumption of animal protein also grew, in particular that of meat and dairy products. In order to supply the demand in continuous growth, peripheral zones were devoted to raising livestock or fodders. The world export of meat grew from 2 million t in 1950 to 11 million t in 1984. Many countries in Africa and Latin America converted extensive cropping areas to grazing land for cattle—in particular, large surface areas of forests were converted to grasslands, while in other countries traditional crop varieties were replaced by monoculture of forage crops. In both cases the result was a growing production deficit of cereals and other foodstuffs formerly grown domestically (see review in Barkin et al. 1991). In addition, modernization of agriculture was made at the expense of traditional farmers that were forced to migrate to cities to live in conditions of extreme poverty, or remain farming marginal land. The extraordinary wave of farmer emigration that took place between 1950 and 1980, transformed the urban dwellings of poor countries into ecologically unmanageable spaces. At the beginning of that period, in Latin America 200,000 people lived in cities, but by the early 1980s urban population had increased by 50 %. Slum settlements (a phenomenon called chabolismo in South America), endemic unemployment, and the poor sanitation conditions of this historical process of urban concentration, spawned the manifestation of flagrant environmental injustice.

Those who remained being farmers enjoyed no better living conditions. The biased distribution of property, the trend for concentration in a few hands of land tenure, and the destructuralization of rural communities brought over by modernization, forced farmers to cultivate forested and marginal lands. Many deforestation processes, overgrazing, cultivation of slopes that in some zones accelerate

Table 11.8 Weight of biomass in total energy use (%) in organic metabolism (1750–1830) and industrial metabolism (2000)

	Organic metabolism 1750/1830	Industrial metabolism 2000
Developing countries	–	92
Developed countries	–	50
European union-15	–	23
Austria	99	29
United Kingdom	94	12

Source Fischer-Kowalski et al. (2007, p. 231)

erosion and desertification—Sahel, India, Panama, Brasil, etc.—are associated with that practice.

In sum, we may state that the agrarian sector has been expelled from the energy system and has become a recipient of energy and materials from elsewhere. The nucleus of the agrarian metabolism is still domestic extraction (DE), but the importation (I) of energy acquires a decisive importance. Agriculture went from being at the heart of the metabolic process to constituting an apparently marginal segment of the same, thanks to the exploitation of fossil fuels. This metamorphosis, which occurred at an accelerating pace, began in England, made the leap to continental Europe, expanded towards its peripheries, was taken to the colonies and today is still spreading to every corner of the globe (Table 11.8).

In fact, the production of biomass no longer provides the bulk of the energy that allows society to function. The domestic extraction of biomass represented between 95 and 100 % of the energy consumption in organic metabolism societies, whereas in societies where the industrial metabolism has become the dominant way of organizing relations with nature, biomass only produces between 10 and 30 %. Furthermore, the energy balances show that agriculture has changed from being a supplier to a demander of energy (Leach 1976; Pimentel and Pimentel 1979; Naredo and Campos 1980, Carpintero and Naredo 2006; Cussó et al. 2006; González de Molina and Guzmán Casado 2006; Tello et al. 2014). Without the subsidy of external energy, a part of global agriculture could not function.

This major injection of energy and materials explains why yields per land unit have multiplied, offering the capability of feeding a population that has grown six-fold since the start of the nineteenth century, giving rise to one of many paradoxes. According to Smil (2001, p. 256), the total area of farmland in the world grew by a third during the twentieth century; however, because productivity has multiplied by four, the harvests obtained in this period multiplied by six. But as Smil himself acknowledges, this gain is partly due to the fact that the amount of energy used in farming is eight times larger (see also Pimentel and Pimentel 1979).

It also, and particularly, explains the exponential growth registered in terms of the productivity of agrarian labor. The cases studied conducted for Austria by Krausmann et al. (2003) and for Santa Fe (González de Molina and Guzmán Casado 2006) mostly concur that the industrialization of the agrarian metabolism led to a spectacular increase in the productivity of labor, due to the mass use of new technologies and the mass entry of external energy. Interestingly, both cases, built on the same methodology albeit at a different scale, coincide that this increase caused yields to augment fivefold (Guzmán Casado and González de Molina 2008)

Agrarian activities have changed their metabolic functionality. They constitute another input in the metabolism of materials and, although the market does not reward this task, they offer essential environmental services (carbon sinks, climate regulation, water purification, maintenance of certain levels of biodiversity, etc.) for the stability of the industrial metabolism. Perhaps for that reason they have tended to become degraded through the very industrialization and commodification of agriculture (De Groot et al. 2002; Pagiola and Platais 2002; Pagiola et al. 2004).

But perhaps the most decisive change, owing to its impact on the species itself, has been the change in diet. Rich countries increasingly consume more meat and livestock products such as milk and its derivatives, causing livestock numbers to grow to unsuspected levels. To feed these animals, land has been taken away from growing food for human consumption, or part of it has been dedicated to growing feed to fatten livestock. According to Krausmann et al. (2008b, p. 471), the global appropriation of land biomass in the year 2000 reached 18,700 million tonnes of dry matter per year, 16 % of the world's net primary production, of which 6,600 million were indirect flows. Of this amount, only 12 % of the vegetable biomass went directly on human food; 58 % was used to feed livestock; a further 20 % as raw material for industry, and the remaining 10 % continued to be used as fuel.

The importance acquired by importations of energy and materials have led agriculture to become partially uncoupled from the agro-ecosystems that sustain it and its spatial configuration to become radically different, being based on simplified landscapes, single-crops, the loss of spatial heterogeneity and biodiversity. Basic functions that in another time were fulfilled by the land (production of fuels, food for livestock, basic foodstuffs for the human diet, etc.), and to which a fairly large portion of land was dedicated, disappeared, giving rise to a specialized landscape, essentially and almost exclusively agricultural, peppered with constructions and areas used for urban-industrial properties (Agnoletti 2006; Cussó et al. 2006; Tello et al. 2008; Guzmán Casado and González de Molina 2006 and 2008).

11.13 Dematerialization or Relocation: Is There a 1970s Syndrome?

During the early 1990s the full crudeness of the debate about the sustainability of economic growth emerged, at a time in which environmental concerns had gained a relevant public dimension, and immediately before the Earth Summit of 1992. In that context, economists studying the long-term behavior of GDP relative to consumption of materials and energy (Goldenberg and Reddy 1990), postulated that both variables had increased in different proportions, and that the energy intensity was shaped as an inverted U, known as the environmental Kuznets curve (EKC): i.e., increasing during the onset of industrialization and declining during the subsequent post-industrial phase. Such result allowed for predicting a mature industrial metabolism gradually consuming fewer resources, but generating a higher GDP value, or what is the same, economic growth achieved by means of gradually decreasing energy intensity. Indeed, such assumptions would conclusively lead us to conceive industrial metabolism as increasingly sustainable while going through the route towards sustainable development, as contained in the Brundtland Report (WCDE 1984).

This thesis was questioned many times since its postulation. The Economy Nobel Price Kenneth J. Arrow and other prominent scholars from several disciplines stated in 1995 that the EKC was in some cases met, but in most cases it was not (Arrow et al. 1995), which depended upon the chosen environmental variable, country, historic period, and other factors. Research results published since then agree with Arrow et al. (1995) in that only some cases adjust to the EKC (Dinda 2004; Stern 2004; Mazzanti et al. 2006). In a recent work, Gales et al. (2007) claim that research made attempting to approve or disapprove the interpretation of the EKC overlook the traditional sources of energy used before the introduction of fossil fuels. When taking into account traditional fuel sources such as firewood, food consumption by humans and animals, eolic and hydraulic energy, the result may differ considerably from those predicted by the EKC. Gales et al. (2007) based their criticism of the EKC by studying the energy consumption in four developed countries between 1850 and 2000: Sweden, the Netherlands, Italy, and Spain. Their results show a much larger initial consumption of energy, but what was really occurring was a process of replacement of traditional for modern fuels. For example, in Sweden no long-term inverted U shaped curve was discernable. Rather, in the early nineteenth century there was a descent in energy consumption. Something similar happened in Italy, where the energetic intensity decreased since the middle nineteenth century, as happened in the Netherlands and Spain. Despite the differences in energetic consumption patterns of the four countries, they displayed long-term similitudes: they all experimented modest increases in energy consumption until the Second World War, an intense, rapid growth from the end of the war until 1973, and a descent in the growth rate between 1973 and 2000.

Gales et al. (2007) also deny assuming that the progressive lowering of the energetic intensity was due to the growing participation of services in the economy, instead holding that it was due to relative cost increments stimulating energy savings, changes within the industry sector, the development of industrial branches having a lower energy costs such as informatics and communications technologies or biotechnology, and the savings brought to other industrial branches from the introduction of these technologies.

The data and graphics we compiled in the previous section regarding consumption of energy and materials would in any case indicate a weak dematerialization, given that in fact resource consumption has grown at a lower rate than the size of the economy, but they also point to a strong dematerialization (De Bruyn and Ospchoor 1997) because in absolute terms resource consumption has continued to grow. Juan Infante (personal communication 2014; in press) applied the model of Bringezu et al. (2004) for studying 149 countries between 1980 and 2008. His results confirmed that along the three decades the global GIP increased by 154 points while the materials consumption gained 88 points, i.e., a weak materialization was produced. Out if the 149 studied countries, 24 of them—representing 11 % of the world's population with 716 million inhabitants—experienced a strong dematerialization, i.e., their consumption of materials went down irrespectively of their economic growth rate. Other 73 countries representing 75 % of the total world population with 4,888 million inhabitants showed a weak dematerialization characterized by resource consumption rates growing at a slower rate than economic growth. Finally 52 countries increased their resource consumption at a faster rate than economic growth, in which 926 million people are concentrated, representing 14 % of the total world population. There seems to be a relation between the level of dematerialization and the income level: countries strongly dematerializing in absolute terms had an annual per capita average income of US$2,888, those with a weak dematerialization level of US$1,434, and rematerializing countries in relative and absolute terms of only US$499.

In conclusion, during the past three decades economy has grown faster than resource consumption, a trend more evident in richer countries. Despite all, most countries continue to consume more resources in absolute terms, independently of the evolution of their economy. In fact, total consumption in the world grew by 88 % between 1980 and 2008. We are thus far from witnessing a strong dematerialization.

The behavior of more industrialized countries has led some authors (Wiedenhofer et al. 2013) to suggest that the industrialization process—the transition from the organic to the industrial metabolic regime—follows an S-shape curve model (based on Rotmans et al. 2001) with a pre-development trend ending in a sudden takeoff stage, followed by a vertiginous acceleration phase, and apparently ending in phase of slowdown and stabilization. Wiedenhofer et al. (2013) made a long-term analysis of the processes—taking centuries or a few years—of expansion of the industrial metabolic regime based on the cases of Austria, UK, Japan, and US from the end of the eighteenth century until the year 2000, concluding that the process fits the S-curve model.

In the case of the UK, the transition has lasted 350 years. Since the seventeenth century the use of coal began to replace the use of firewood in households and textile shops. Much later, the diffusion of the iron-steam-engine complex generated a takeoff period followed by a first phase of acceleration from the nineteenth century onwards. A second acceleration phase began after Second World War caused by the expansion of oil, the automobile, and electrical power, which resulted in rapid biophysical and economic growth. Since the 1970s the metabolic indicators of interest have become stabilized, while the GDP has continued to grow (Fig. 11.8).

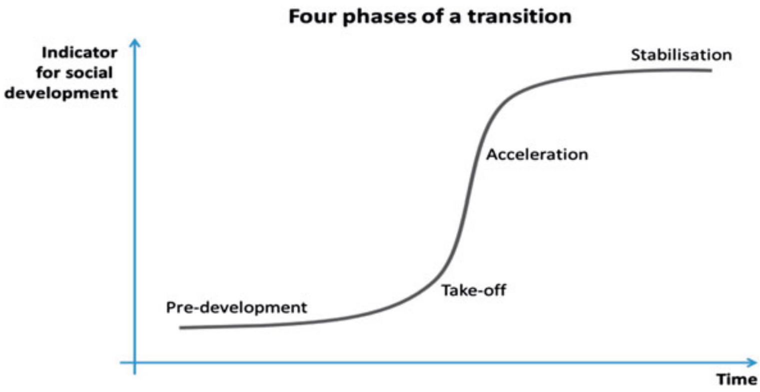

Fig. 11.8 Phases of socioecological transition following the S-shape curve model of Wiedenhofer and collaborators. *Source* Wiedenhofer et al. (2013, p. 184)

In Austria the transition took off during the second half of the nineteenth century. Because of the abundance of firewood in Austrian fields and metallurgic regions, biomass was an important source of heat until the acceleration phase after Second World War. As in other industrialized economies, the use of resources stabilized as economic growth continued. In Austria as in the UK the per capita energy use has oscillated around 200 GJ. This slowing down of growth has been said to have been possible thanks to the maturity of the car industry, and to the steep decline in domestic energy use in the UK during the 1980s—due to, among other things, the deindustrialization during the Thatcher period.

In the US, the takeoff began with the end of the Civil War (1861–1865) also based on coal, steam engines, iron works, and the extension of railroads. After the Great Depression during the acceleration phase the annual per capita consumption of materials duplicated, going from 13 t/inhab/yr in 1932 to the 29 annual per capita tons of 1970. The per capita use of energy multiplied by 1.6, in 1930 being of 306 GJ and in 1979 of 484 GJ.

Japan is interesting because it is one of the few cases in which there was an absolute decoupling of economic growth and use of materials. Japan remained under the organic regime longer than other industrialized countries, industrialization beginning until the late nineteenth century and the takeoff of the process occurred during the middle twentieth century. Japan never experienced a phase of metabolic growth based on coal, but did go through a strong acceleration after the Second World War and the predominance of oil.

Since the end of the Second World War, late comer and early joiner countries have clearly tended to a convergence to a similar metabolism, metabolic profiles being also quite similar. In fact, western countries behaved in practically the same way after the oil crisis, marking a turning point in the per capita use of energy and materials, which in absolute terms remained stable as the GDP continued growing. That change in trend was so strong, that between the 1970s and 1990s the global consumption of energy and materials became stabilized at a high level after two and a half decades of rapid growth.

Aside from the particular factors in each country explaining that change in trend, it seems evident that it is related to the higher of efficiency from high prices of energy and the effects of globalization. Globalization has allowed for the externalization to southern countries of the most material and energy intensive industrial processes; developed economies have concentrated more in provision of services than in industrial processes, supported by information technology. Nevertheless, as in Austria and the UK, the use of energy and materials continues to grow in absolute terms (Krausmann et al. 2008b).

11.14 Globalization and Unequal Interchange

In the preceding sections we assumed that economic growth experimented by developed countries could not have sustained its rate without the appropriation and consumption of low-cost natural resources from less developed countries, and the consequent deterioration of their standards of living and environmental quality conditions. This pattern rising from unequal economic development and aggravated by socioecological effects of international trade, resembles the old dichotomy between development and underdevelopment of the economics literature during the 1960s and 1970s, today rescued by the metabolic analysis of world economy. As shown in Fig. 14.8, resource use is distinctly unequal. While the global annual per capita average consumption of materials is around 9 t/inhab/yr, the US consumes 25 t/inhab/yr, while Ruanda barely surpasses 2 t/inhab/yr, Many of the top consumers of resources do it beyond their means, i.e., their domestic extraction is lower than their total consumption of energy and materials. The fact has been verified by studies made of moderately industrialized, more agrarian, and fully industrialized countries (Muradian and Alier 2001; Giljum and Eisemenger 2004; Fisher-Kowalski and Amann 2001). What makes such behavior possible is the dynamics of international trade. Since decades ago, sources of energy and materials generally, but not necessarily, located in less developed and peripheral countries are being essential for sustaining the metabolic process of developed economies. That explains the resolute pursue of rich countries for assuring their control over such sources of raw materials.

This relatively recent phenomenon became known as unequal economic exchange (Hornborg 2011). In strict sense, as seen in Chap. 5, it is not an ecological exchange, but a commercial or economic exchange process. In the previous Chapter we saw that before the Industrial Revolution physical limitations restricted international trade to low-weight, high value products or preciosities (Martínez-Alier 2007). But the development of transport and colonial policies made industrialized countries growingly dependent on resources from peripheral territories, to the point of their economies began to increasingly depend on external inputs (Martínez-Alier 2007; Hornborg et al. 2007). With globalization,

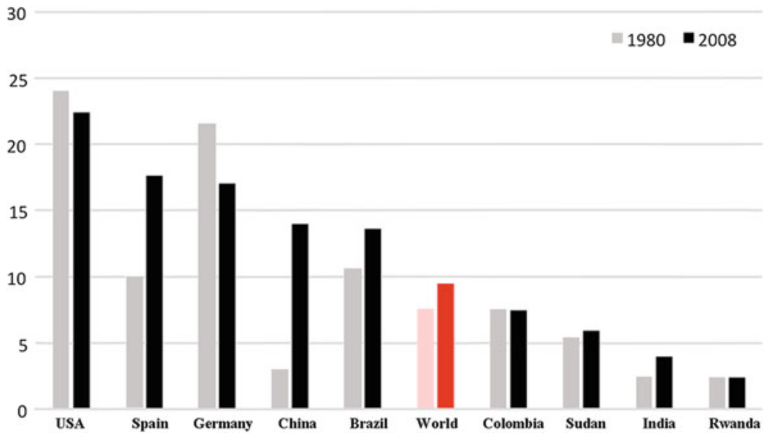

Fig. 11.9 Average annual per capita consumption of materials in US, Spain, Germany, China, Brazil, Colombia, Sudan, India, Rwanda, and the world between 1980 and 2008. *Source* Infante (2014)

international trade has become a crucial instrument for nearly every country in the planet. The larger the metabolism of a country is, the greater its dependency on international markets for provision of natural resources not available from their own domestic extraction. Stated in different terms, since the Great Acceleration the import of energy and materials has become evermore essential for the sustained economic growth of the north.

Supporters of the theory of unequal ecological exchange hold that poor zones of the planet contribute with their resources to the development of the more affluent zones. Poor countries export resources having a low value but representing a large volume in the world's economy. That conclusion was reached to by studying the physical trade balance (PTB) of several developed and underdeveloped countries (Giljum and Eisemenger 2003; Muradian and Martínez-Alier 2001; Muñoz et al. 2009). A recent analysis was made of the PTB of most world countries between 1962 and 2005 (Dittrich and Bringezu 2010; Dittrich et al. 2011), the conclusions agreeing with previous works: Since the 1960s, more industrialized zones had positive PTB values, while developing zones had negative PTB values. Such pattern has become accentuated in a progressive way until 2005 (Dittrich and Bringezu 2010). In other terms, resource flow continues to be from south to north.

But the premise is not always met as revealed by data from SERI (2008). As shown by Infante (2014), 50 countries have negative PTB, i.e., are net resource exporters and their annual per capita income is of about US $8,300. In contrast, the remaining 90 countries have positive PTB values, being net importers and have an average annual per capita income of US $8,355. This deviation is because some of the net exporter countries are highly developed as Canada, Australia or Norway (Fig. 11.9), which suggests that the assumption of rich countries being net importers and poor countries net exporters of materials and energy may not always

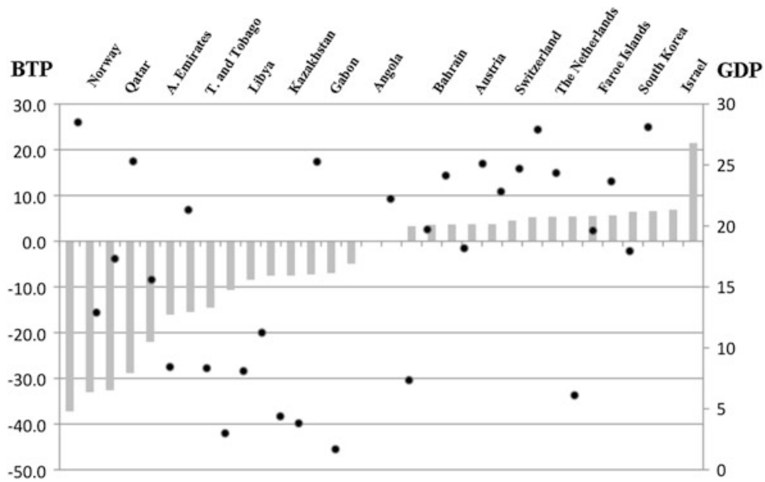

Fig. 11.10 Relation between GDP and PTB in Norway, Qatar, Arab Emirates, Trinidad and Tobago, Libya, Kazakhstan, Gabon, Angola, Bahrain, Austria, Switzerland, the Netherlands, Faroe Islands, South Korea, and Israel. *Source* Infante (2014)

be valid: there are relevant exceptions to the norm (Weisz 2007; Moran et al. 2013). The MEFA methodology from which PTB is estimated has obvious limitations that impede knowing when a country has or not depleted its resources—and thus needs imports, or if its resources are plentiful, but the cost of their extraction exceeds the offer of the international market, at the same time avoiding the external costs of appropriation. Such is the case of Spain, described in Chap. 7, that imports large volumes of livestock foodstuffs at a low price, while abandoning a significant amount of the available biomass—mostly of grasses—because of the relatively higher cost of their appropriation. Maybe more detailed studies of countries being an exception will allow for arriving to a more robust demonstration of this assumption claimed by the theory of unequal ecological exchange (Figs. 11.9,11.10 and 11.11).

But in the meantime, the work of Bruckner et al. (2012), provides us with a clue from the study of world extraction and consumption of materials and the indirect flows of international trade, from which the authors confirm the growing important role of international trade in the distribution of resources at global scale. International trade is contributing to widen the breach between countries with low and high consumption rates, because it assigns to industrialized countries the resources extracted from developing countries. The phenomenon is further made visible by talking into account the indirect costs of the process of material extraction in the calculation of physical trading balances. Data show that index underestimates the amount of materials required for supplying domestic consumptions of most OECD countries and overestimates the consumption of materials of exporter countries.

In this perspective, Bruckner et al. (2012) estimated the flows of international trade of countries in the OECD with high and low population densities (Table 10.2).

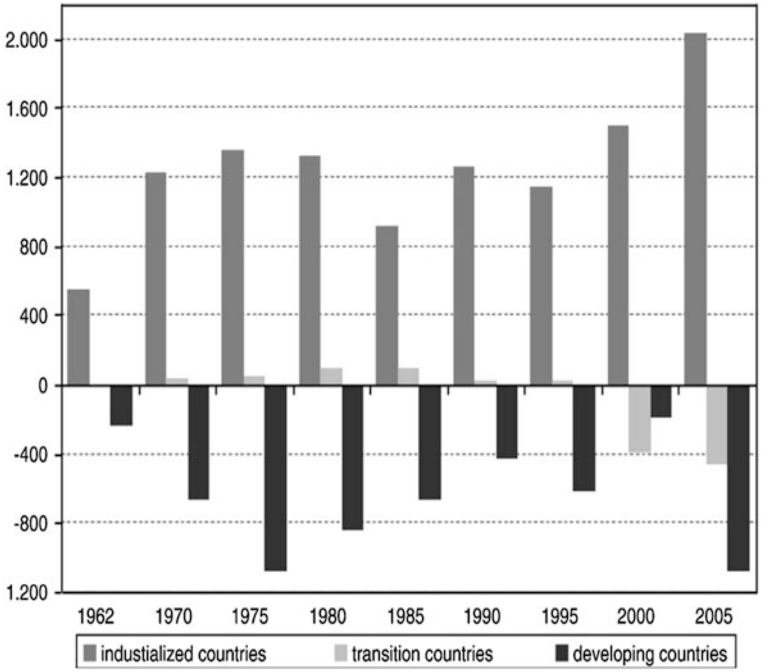

Fig. 11.11 Physical deficits of industrialized countries. *Source* Dittrich and Bringezu (2010)

The amount of materials embodied in international trade increased by 50 % during the decade of 1995–2005, and is expected to increase further during the years to come. Their data corroborate the thesis of Krausmann et al. (2008b) holding that, from a historical perspective, the OECD countries have depleted most of their mineral resources, consequently seeking for them in third party countries. However, Australia, Canada, and Norway are OECD net exporter countries. There is logic behind this, the OECD countries having low population densities require less external energy and materials and may even be resource exporters. Likewise, the remaining countries with high population density export less because they consume large parts of their domestic extraction. Contrariwise, ROW (rest of the world) countries with low population densities and abundant resources can export a large proportion of not consumed domestic extraction. The general trend is thus to compensate with imports a growing demand that cannot be supplied by domestic extraction.

In any case, the decisive data is that the per capita consumption of materials of OECD countries has continued to increase. Beyond in these countries the economy has improved its energetic efficiency, and lowered the energetic intensity per GDP unit, the decisive fact is these countries continue to be high consumers and their metabolic profile continues to grow. In most cases, such growth is only made possible by importing energy and materials compensating for their decreasing own resources.

11.15 Industrial Metabolism: A High Entropy Regime

The industrial metabolic regime ended up being a high entropy regime, i.e., based on high energy and materials consumption, requires building and maintaining large infrastructure (buildings, highways) and high volumes of physical stocks (e.g., cars), have high person and commodity mobility, and very high level of material (exosomatic) consumption. Densely populated industrialized societies have reached energy densities of up to 600/GJ/ha, way beyond the potential of the organic system linked to the territories. Such energy consumption explains how the socioecological industrial regime, at the expense of a three to five times larger per capita consumption of materials and multiplying the total energy consumption by 10–30 times relative to organic metabolism, has been capable of sustaining hundreds of persons per square kilometer, while agrarian metabolism allowed for densities of between 30 and 40 persons per square kilometer. Maybe also because of its high entropy regime, industrial metabolism has generated steeper social and economic inequalities—also expressed as material and metabolic disparities—than in the organic metabolic regime. The industrialized processes, as we have shown here, has only reached a reduced number of richest countries and only 20 % of the total world population lives in societies characterized as of advanced industrial metabolism. These countries produce 80 % of the global GDP, own 25 % of Earth́s land, and consume 38 % of all the primary energy and 37 % of all the materials globally supplied. In contrast, it has been estimated that nearly 600 million people still live under an organic metabolic regime (Toledo and Barrera-Bassols 2008). Around two thirds of the world's population live in economies placed along the different transition stages we have described. Some of these newly industrialized countries—including China, India, Brazil, Russia, and others—are following a route towards industrialization that in physical terms resembles the historical path followed by the industrial center (Krausmann et al. 2008b). The question if these countries will complete their transition to industrial metabolism remains open, and we will examine at the conclusion of this book, but such outcome seems unlikely. The question is rather if the present trends will continue for a longer time, causing severe damages to socioenvironmental nature, or if as suggested by Wiedenhofer et al. (2013, p. 190), a new historical phase of transition to a more sustainable metabolism has already started. The transition to the supremacy of industrial metabolism implied fundamental changes in natural systems and the magnitude of environmental problems, and in consequence, it led to scenarios of unsustainability. In its beginnings, industrial metabolic regimes enjoyed a—temporal—abundance of energy and materials, while the impacts of its outputs, the loss of habitat, and social inequalities threatened its sustainability. Environmental problems have varied along time from smog events caused by the smoke from chimneys during the coal-intensive period of steam engines, to acid rain and water pollution, and eventually anthropogenic carbon emissions and their impact on global climate. Some of these problems have been technically solved, but others have worsened. As we saw in Chap. 10, the severe and extensive occurrence of unsustainability situations generated the conditions for the onset of large-scale socioecological changes and the transition to industrial metabolism. Will the same happen again? The effects of the ecological crisis combined with the economic-financial crisis evoke the full crudeness of the matter, as seen in the following Chapters of this book.

References

Acemoglu D, Johnson S, Robinson J (2005) The rise of Europe: Atlantic trade, institutional change, and economic growth. Am Econ Rev 95(3):546–579

Agnoletti M (ed) (2006) The conservation of cultural landscapes. CAB International, Wallingford/Cambridge

Allen RC (2004) Revolución en los campos. La reinterpretación de la revolución agrícola inglesa. SEHA/ Prensas Universitarias de Zaragoza, Zaragoza

Allen RC (2009) The British industrial revolution in global perspective. Cambridge University Press, Cambridge

Allen RC (2010) The British industrial revolution in global perspective. Proc Br Acad 167:199–224

Allen RC (2013) Energy transitions in history: The shift to coal. In: Unger RW (ed) Energy transitions in history global cases of continuity and change. Rachel Carson Center, Münich, pp 11–16

Allen RC, Bassino JP, Ma D, Moll-Murata C, Van Zanden JL (2010) Wages, prices, and living standards in China, 1738–1925: in comparison with Europe, Japan, and India. Econ Hist Rev 64(1):8–38

Alonso ME, Vázquez E, Giavón A (2001) Historia. El mundo contemporáneo. Buenos Aires: Aique

Arrow K, Bolin B, Costanza R, Dasgupta P, Folke C, Holling CS, Jansson B, Levin S, Mäler K, Perrings C, Pimentel D (1995) Economic growth, carrying capacity, and the environment. Ecol Econ 15(2):91–95

Bairoch P (1973) Agriculture and the industrial revolution, 1700–1914. In: Cipolla C (ed) The industrial revolution, vol III. Fontana Economic History of Europe, Collins/Fontana, London

Bairoch P (1999) L'Agricultura des pays développés, 1800 à nous jours: productivité, rendements. Paris

Barkin D, Batt R, DeWalt BR (1991) Alimentos versus Forrajes: la sustitución entre granos a escala mundial. Siglo XXI Editores, Madrid

Bartoletto S (2013) Fossil fuels consumption and economic growth in Italy in the last two centuries. In: Unger RW (ed) Energy transitions in history global cases of continuity and change. Rachel Carson Center for Environment and Society, Munich, pp 37–41

Bassino JP., Broadberry S, Fukao K, Gupta B, Takashima M (2011) Japan and the great divergence, pp 730–1870. http://www2.lse.ac.uk/economicHistory/pdf/Broadberry/JapanGreatDivergence.pdf. Accessed 16 Nov 2013

Beck U (1998) The risk society: Towards a new modernity. SAGE Publications, USA

Berman M (1981) The reenchatment of the World. Cornel University Press, USA

Bevilacqua P (ed) (1989–1991) Storia dell'agricoltura italiana in età contemporanea, 3 vols. Marsilio, Venezia

Bevilacqua P, Rossi-Doria M (1984) Le bonifiche in Italia dal '700 a oggi. Bari-Roma, Laterza

Billen G, Barles S, Garnier J, Rouillard J, Benoit P (2009) The food-print of Paris: long-term reconstruction of the nitrogen flows imported into the city from its rural hinterland. Reg Environ Change 9:13–24

Boserup E (1983) Población y Cambio Tecnológico. Crítica, Barcelona

Bowles S, Gintis H (2011) A cooperative species: human reciprocity and its evolution. Princeton University Press, Princeton
Bringezu S, Schütz H, Steger S, Baudisch J (2004) International comparison of resource use and its relation to economic growth: the development of total material requirement, direct material inputs and hidden flows and the structure of TMR. Ecol Econ 51(1):97–124
Bruckner M, Giljum S, Lutz C, Wiebe KS (2012) Materials embodied in international trade—global material extraction and consumption between 1995 and 2005. Glob Environ Change 22:568–576
Bruton HJ (1998) A reconsideration of import substitution. J Econ Lit 36:903–936
Calatayud S, Martínez Carrión JM (1999) El cambio técnico en los sistemas de captación e impulsión de aguas subterráneas para riego en la España Mediterránea. In: Garrabou R, Naredo JM (eds) El agua en los sistemas agrarios. Una perspectiva histórica, pp 15–39. Argentaria/Visor, Madrid
Carpintero O, Naredo JM (2006) Sobre la evolución de los balances energéticos de la agricultura española, 1950–2000. Historia Agraria 40:531–554
Cipolla C (1994) Historia económica de la población mundial. Crítica, Barcelona
Costanza R, Graumclih LJ, Steffen W (eds) (2007) Sustainability or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts
Cunfer G (2005) On the great plains: agricultural and environment. A&M University Press, Texas
Cunfer G, Krausmann F (2009) Sustaining soil fertility: agricultural practice in the old and new worlds. Global environment. J Hist Nat Soc Sci 4:9–43
Cussó X, Garrabou R, Olarieta JR, Tello E (2006) Balances energéticos y usos del suelo en la agricultura catalana: una comparación entre mediados del siglo XIX y finales del siglo XX. Historia Agraria 40:471–500
D'Attorre P, De Bernardi A (eds) (1994) Studi sull'agricoltura italiana. Società rurale e modernizzazione. Feltrinelli, Milano
De Bruyn SM, Opschoor JB (1997) Developments in the throughput-income relationship: theoretical and empirical observations. Ecol Econ 20(3):255–268
De Groot RS, Wilson MA, Boumans RMJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol Econ 41:393–408
Debeir JC, Déleage JP, Hémery D (1986) Les Servitudes de la Puissance: une Histoire de L'Energie. Flammarion, Paris
Dinda S (2004) Environmental kuznets curve hypothesis: a survey. Ecol Econ 49(4):431–455
Dittirch M, Bringezu S (2010) The physical dimension of international trade. Part 1: direct global flows between 1962 and 2005. Ecol Econ 69:1838–1847
Dittrich M, Bringezu S, Schütz H (2011) The physical dimension of international trade, part 2: Indirect global resource flows between 1962 and 2005. Ecol Econ 79:32–43
Dobado R, García-Hiernaux A, Guerrero D (2012) The integration of grain markets in the eighteenth century: early rise of globalization in the West. J Econ Hist 72(3):671–707
Erb KH, Haberl H, Krausmann F (2007) The fossil fuel-powered carbon sink. Carbon flows and Austria's energetic metabolism in a long-term perspective. In Fischer-Kowalski M, Haberl H (ed) Socioecological transitions and global change, pp 60–82. Edward Elgar, Cheltenham
Fischer-Kowalski M et al (2007) Conclusions: likely and unlikely pasts, possible and impossible futures. In: Fischer-Kowalski M, Haberl H (eds) Socioecological transitions and global change. Edward Elgar, Cheltenham, pp 223–225
Fischer-Kowlaski M, Amann C (2001) Beyond IPATS and Kuznets curves: globalization as a vital factor in analysing the environmental impact of socioeconomic metabolism. Popul Environ 23(1):7–47
Gales B, Kander A, Malanima P, Rubio M (2007) North versus South: energy transition and energy intensity in Europe over 200 years. Eur Rev Econ Hist II:219–253
Garavaglia JC (1999) Pastores y labradores de Buenos Aires. Una historia agraria de la campaña bonaerense. Ediciones de la Flor, Buenos Aires, pp 1700–1830
Garrabou R, González de Molina M (eds) (2010) La reposición de la fertilidad en los sistemas agrarios tradicionales. Icaria, Barcelona

Garrido F (1996) Ecología Política como política del tiempo. Granada, Editorial Comares
Geogescu-Roegen N (1996) The entropy law and the economic process. Harvard Univerity Press, Massachusetts
Giljum S, Eisenmenger N (2003) North-South trade and the distribution of environmental goods and burdens. SERI Studies2
Giljum S, Eisenmenger N (2004) International trade and the distribution of environmental goods and burdens: a biophysical perspective. Journal of Environment and Development 13 (1):73–100
GLASOD (The Global Assessment of Human Induced Soil Degradation) (1991) PNUMA
Goldenberg J, Reddy AKN (1990) Energy for the developing world. Sci Am 263:111–118
González de Molina M (2002) Environmental constraints on agricultural growth in 19th century Granada (southern Spain). Ecol Econ 41:257–270
González de Molina M, Guzmán-Casado G (2006) Tras los Pasos de la Insustentabilidad. Agricultura y medio ambiente en perspectiva histórica. Barcelona, Icaria
González de Molina M, Pouliquen Y (1996) De la agricultura orgánica tradicional a la agricultura industrial: ¿una necesidad ecológica? Santa Fe, 1750–1904. In: Garrabou R, Naredo JM (eds) La fertilización en los sistemas agrarios. Una perspectiva histórica. Fundación Argentaria/ Visor, Madrid, pp 127–169
González de Molina M, Sevilla Guzmán E (1992) Una propuesta de diálogo entre socialismo y ecología: el neopopulismo ecológico. Ecología Política 3:121–136
González de Molina M, Guzmán Casado G, García Ruiz R, Soto Fernández D, Herrera González de Molina A, Infante Amate J (2010) Claves del crecimiento agrario: la reposición de la fertilidad en la agricultura andaluza de los siglos XVIII and XIX. In: Garrabou R, González de Molina M (eds) La reposición de la fertilidad en los sistemas agrarios tradicionales. Editorial Icaria, Barcelona
Grove R (2007) Revolutionary weather. The climate and economic crisis of 1788–1795 and the discovery of El Niño. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 152–167
Guzmán-Casado GI, González de Molina M (2006) Sobre las posibilidades de crecimiento agrario en los siglos XVIII, XIX y XX. Un estudio de caso desde la perspectiva energética. Historia Agraria 40:437–470
Guzmán-Casado GI, González de Molina M (2008) Transición socio-ecológica y su reflejo en un agroecosistema del sureste español (1752–1997). Revista Iberoamericana de Economía Ecológica 7:81–96
Guzmán Casado GI, González de Molina M (2009) Preindustrial agriculture versus organic agriculture. The land cost of sustainability. Land Use Policy 26:502–510
Guzmán Casado GI, González de Molina M, Alonso Mielgo A (2011) The land cost of agrarian sustainability. An assessment. Land Use Policy 28:825–835
Haberl H (2006) The global socioeconomic energetic metabolism as a sustainability problem. Energy 31:87–99
Hayami Y, Ruttan VW (1971) Agricultural development: an international perspective. Johns Hopkins Press, Baltimore
Hibbard KA et al (2007) Decadal-scale interactions of humans and the environment. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 341–377
Hornborg A (2007) Footprints in the cotton fields: the industrial revolution as time-space appropiation and environmental load displacement. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 259–272
Hornborg A (2011) A lucid assessment of uneven development as a result of the unequal exchange of time and space. Lund University Centre of excellence for integration of social and natural dimensions of sustainability (LUCID). LUCID assessment no 1, Nov 2011
Hornborg A et al (eds) (2007) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan

Infante J (2014) El consumo de recursos en el siglo XX en el mundo. Una revisión. *Economía Crítica* (forthcoming)
Iriarte-Goñi I, Ayuda MI (2008) Wood and industrialization evidence and hypotheses fromthe case of Spain, 1860–1935. Ecol Econ 6(5):177–186
Iriarte-Goñi I, Ayuda MI (2012) Not only subterranean forests: wood consumption and economic development in Britain (1850–1938). Ecol Econ 77:176–184
Jevons WS (1865) The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines. Macmillan and Co, London
Jones EL (1987) The European miracle: environments, economies and geopolitics in the history of Europe and Asia. Cambridge University Press, Cambridge
Kim E, Barles S (2012) The energy consumption of Paris and its supply areas from the eighteenth century to the present. Reg Environ Change 12:295–310
Koestler A (1968) The Ghost in the Machine. Mc Millan, New York
Krausmann F (2001) Land use and industrial modernization: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830–(1995). Land Use Policy 18:17–26
Krausmann F (2006) Una perspectiva biofísica del cambio agrícola en Austria: dos sistemas agrarios en las décadas de 1830 y 1990. Historia Agraria 40:501–530
Krausmann F et al (2003) Land-use change and socioeconomic metabolism in Austria Part I: driving forces of land-use changes 1950–1995. Land Use Policy 20(1):1–20
Krausmann F, Gingrich S, Eisenmenger N, Erb KH, Haberl H, Fischer-Kowalski M (2009) Growth in global materials use, GDP and population during the 20th century. Ecol Econ 68(10):2696–2705
Krausmann F, Haberl H, Erb KH, Wiesinger M, Gaube V, Gingrich S (2009) What determines geographical patterns of the global human appropriation of net primary production? J Land Use Sci 4(1):15–34
Krausmann F, Schandl HY, Sieferle RP (2008a) Socioecological regime transition in Austria and United Kingdom. Ecol Econ 65:187–201
Krausmann F et al (2008b) Global patterns of socioeconomic biomasss flows in the year (2000): a comprehensive assessment of supply, consumption and constraints. Ecol Econ 65:471–487
Leach G (1976) Energy and food production. IPC Science and Technology, London
Leach G (1992) The energy transition. Energ Policy 20(2):116–123
Leff E (1986) Ecología y Capital. Siglo XXI Editores, México
Li B, Van Zanden JL (2012) Before the great divergence? Comparing the Yangzi Delta and the Netherlands at the beginning of the nineteenth century. J Econ Hist 72(4):956–989
Liebowitz SJ, Margolis SE (1995) Path dependence, lock-in and history. J Law Econ Organ 11:205–226
Livi-Bacci M (1999) Historia de la población europea. Editorial Crítica, Barcelona
López Estudillo A (2002) Crisis finisecular, transformaciones agrarias y atraso económico. Andalucía 1870–1930. In: González de Molina M (ed) Historia de Andalucía a debate II, 137–178. Bracelona, Anthropos
Malanima P (2001) Energy basis for early modern growth, 1650–1820. In: Prak M (ed) Early modern capitalism. Economic and social change in Europe, 1400–1800. Routledge, London, pp 51–68
Martínez-Alier J (2007) Marxism, social metabolism, and internacional trade. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds.) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 221–237
Mayumi K (1991) Temporary emancipation from land: from the industrial revolution to the present time. Ecol Econ 4:35–56
Mazzanti M, Musolesi A, Zoboli R (2006) A Bayesian approach to the estimation of environmental Kuznets curves for CO2 emissions. Nota di lavoro, Fondazione ENI Enrico Mattei
McNeill JR (2000) something new under the sun: an environmental history of the twentieth century world. Penguin Books, London
Modelski G (2007) Ages of organization. In: Hornborg A, Crumley C (eds) The world system and the earth system. Left Coast Press, California, pp 180–194

Mokyr J (2009) Review essay: the enlightened economy. An economic history of Britain, 1700–1850. Yale University Press, New Haven
Moran DD, Lenzen M, Kanemoto K, Geschk A (2013) Does ecologically unequal exchange occur? Ecol Econ 89:177–186
Morris I (2010) Why the West rules-for now. Farrar, Straus and Giroux, New York
Muñoz P, Giljum S, Roca J (2009) The raw material equivalents of international trade. J Ind Ecol 13(6):881–897
Muradian R, Martínez Alier J (2001) Trade and environment: from Sourthen perspective. Ecol Econ 36:286–297
Naredo JM (1987) La economía en evolución: historia y perspectivas de las categorías básicas del pensamiento económico. Siglo XXI Editores, Madrid
Naredo JM, Campos P (1980) Los balances energéticos de la agricultura española. Agricultura y Sociedad 15:163–255
Naredo JM, Parra F (1993) Hacia una ciencia de los recursos naturales. Siglo XXI Editores, México
Offe C (1988) Democracy against the welfare state. Responsibility, rights and welfare. Westview Press, Boulder
Overton M (1991) The determinant of crop yield in early modern England. In: Campbell B, Overton M (eds) Land, labour and livestock. historical studies in European agricultural productivity. Manchester University Press, Manchester
Padua JA (2002) Um Sopro de Destruiçao: Pensamento Politico e Critica Ambiental no Brasil Escravista, 1786–1888. Jorge Zahar editor, Rio de Janeiro
Padua JA (2004) A ocupação do território brasileiro e a conservação dos recursos naturais. In: Milano M, Takahashi L, Nunes M (eds) Unidades de Conservação: Atualidades e Tendências, 12–19. Fundação O Boticário, Curitiba
Pagiola S, Platais G (2002) Payments for environmental services, environment strategies, no 3. The World Bank, Washinton
Pagiola S, Ritter KV, Bishop J (2004) Assessing the economic value of ecosystem conservation, Environment department, paper no 101. The World Bank, Washington
Palazuelos E (1990) Estructura económica capitalista internacional: El modelo de acumulación de posguerra. Akal, Madrid
Pfister C (1988) Fluctuations climatiques et prix céréaliers en Europe du XVIe. au XXe siècle. Annales ESC, pp 25–53
Pfister C (1990) The early loss of ecological stability in an Agrarian region. In: Brimblecombe P, Pfister C (eds) The silent countdown. Essays in European environmental history. Springer, Berlin, pp 37–55
Pimentel D, Pimentel M (1979) Food, energy and society. Edward Arnold, London
Polanyi K (1990) La Gran Transformación. Madrid Ediciones La Piqueta
Pomerantz K (2000) The great divergence: China, Europe, and the making of the modern world economy, 2000. Princetton University Press, Princeton
Rotmans J, Kemp R, van Asselt M (2001) More evolution than revolution: transition management in public policy. Foresight 3:15–31
Schandl H, Krausmann F (2007) The great transformation: a socio-metabolic reading of the indusrialization of United Kingdom. In: Fisher-Kowalski M, Haberl H (eds) Socioecological transitions and global change. Trajectories of social metabolism and land use. Edward Elgar, Cheltenham, pp 83–115
Schor JB (2005) Prices and quantities: unsustainable consumption and the global economy. Ecol Econ 55(3):309–320
SERI (2008) Global resource extraction 1980 to 2005. Online database. Sustainable Europe Research Institute, Vienna. http://www.materialflows.net/mfa/index2. Accessed 3 Oct 2013
Sieferle RP (2001) The Subterranean forest. Energy systems and the industrial revolution. The White Horse Press, Cambridge
Smil V (1994) Energy in world history. Westview Press, Denver

Smil V (2001) Energías. Una guía ilustrada de la biosfera y la civilización. Editorial Crítica, Barcelona
Smil V (2003) Energy at the crossroad. Global perspectives and uncertainties. MIT Press, Cambridge
Smil V (2013) Energy Transitions. In: World Economic Forum (ed), Energy Vision 2013. WEF, USA. p 12
Stern DI (2004) The rise and fall of the environmental Kuznets curve. World Dev 32:1419–1439
Tello E (2005) La Historia cuenta. Del crecimiento económico al desarrollo humano sostenible. El Viejo Topo, Barcelona
Tello E, Garrabou R, Cussó X, Olarieta JR (2008) Una interpretación de los cambios de uso del suelo desde el punto de vista del metabolismo social agrario. La comarca catalana del Vallès, 1853–2004. Revista Iberoamericana de Economía Ecológica 7:97–115
Tello E, Garrabou R, Cussó X, Olarieta JR (2010) Sobre la sostenibilidad de los sistemas agrarios. Balances de nutrientes y sistemas de fertilización en la agricultura catalana a mediados del siglo XIX. In: Garrabou R, González de Molina M (eds) La reposición de la fertilidad en los sistemas agrarios tradicionales. Icaria, Barcelona
Tello E, Galán E, Sacristán V, Moreno D, Cunfer G, Guzmán G, González de Molina M, Krausmann F, Gingrich S (2014) A proposal for a workable analysis of energy return on investment (EROI) in agroecosystems. Social ecology working paper 14, Vienna
Toledo VM (1990) The ecological rationality of peasant production. In: Altieri M, Hecht S (eds), Agroecology and Small Farmer Development. CRC Press, Boston, pp 53–60
Toledo VM, Barrera-Bassols N (2008) La Memoria Biocultural. La importancia agroecológica de las sabidurías tradicionales. Icaria, Barcelona
Toledo VM et al (1985) Ecología y autosuficiencia alimentaria. Siglo XXI, México
Tudela F et al (1990) Desarrollo y Medio ambiente en América Latina y El Caribe. Una visión evolutiva. MOPU, Madrid
Wallerstein I (1974) The modern world system. Capitalist agriculture and the origins of the European World-economy in the sixteenth century. Academic Press, London
Warde P (2007) Energy consumption in England and Wales, 1560–2000. http://www.histecon.magd.cam.ac.uk/history-sust/energyconsumption/ Accessed 17 Aug 2010
Warde P (2009) The envrionmental history of pre-industrial agriculture in Europe. In: Sörlin S, Warde P (eds) Nature's end: history and environment. Pañgrave Macmillan Press, New York
WCDE (1984) The Report of the Brundtland Commission, Our Common Future. Oxford University Press, USA
Weisz H (2007) Combining social metabolism and input-output analyses to account for ecologically unequal trade. In: Hornborg A, Mcneill JR, Martínez-Alier J (eds) Rethinking environmental history. World-system history and global environmental change. Altamira Press, Lanhan, pp 289–306
Wiedenhofer D, Rovenskaya E, Haas W, Krausmann F, Pallua I, Fischer-Kowalski M (2013) Is there a 1970s syndrome? Analyzing structural breaks in the metabolism of industrial economies. Energy Procedia 40:182–191
Wilkinson RG (1973) Poverty and progress: an ecological model of economic development. Methuen, London
World Coal Institute (2005) Coal as resource. A general view. World Coal Institute
World Economic Forum (2013) Energy vision 2013. Energy transitions: past and future. World Economic Forum
Worster D (1988) The end of the earth. Perspectives on modern environmental history. Cambridge University Press, New York
Wrigley EA (1985) Historia y Población. Introducción a la demografía histórica. Crítica, Barcelona
Wrigley EA (1993) Cambio, continuidad y azar. Carácter de la Revolución Industrial inglesa. Barcelona, Editorial Crítica
Wrigley EA (2004) Poverty, progress, and population. Cambridge University Press, Cambridge

Chapter 12
A Non-cybernetic Theory of Social Metabolism

12.1 Introduction

In this chapter we present and develop the minimal foundations of a proposal going beyond the essentially cybernetic methodology dominating studies of social metabolism. In such dominant view, systemic mechanisms appear as omnipresent forces, as immutable processes in front of which human beings are beyond the possibility of modifying its trajectories and trends. In agreement with *sustainability science*, the interpretations made of social metabolism until todays take into account *solely* the material dimensions of the functioning of societies and nature represented as flows of mater and energy, not considering the strictly social dimension, which is cultural and symbolic, represented by flows of information.

When flows of information are explored, in the form of intangible, symbolic, cultural dimension—i.e., the sociological interpretation of metabolism—we face the old dilemma of admitting that social processes are either exclusively social or are also encompassed by natural laws. If the former implies a paradigm of human uniqueness, the latter implies the risk of falling in a form of reductionism. However, the more recent advances of the complex systems theory are oriented towards solving such a dilemma by demonstrating that, regardless of their degree of complexity, systems—be these physical, biological or social—achieve higher levels of complexity without violation of the more general laws of mater, the laws of thermodynamics.

The above also implies the thermodynamic consideration of social practice: all human acts require of appropriation and consumption of a given quantity of energy and materials from nature and the expulsion of residues to nature. We thus assume that entropy is common to all natural processes, be these human or of any other nature. Even emotional, symbolic or merely conceptual processes are also subjects to the thermodynamic principle of entropy in their internal logic and not only in its biophysical basis (Haimovici et al. 2013).

Linked to this consideration is the recognition of the existence of other dimensions of human actions having different explanatory logics, and that cannot be reduced to a given biophysical or material scale. The latter scale is used for

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measuring the behavior of the levels of organization of mater or of less complex living organisms than the human species and its social relations. The complexity and autonomy of social and human processes make them not totally reducible to the computation of order and disorder of the entropic principle in its application to less complex degrees of organization of mater. We thus reach to a fundamental axiom: *social practice and social relations are not explainable by the analysis of energy and mater alone, but are not explainable without the analysis of such flows. Reciprocally, social relations represented by flows of information order and condition the material exchanges with nature*. In other words, the material relations with the natural world that connect human beings with their biophysical environment are a *dimension* of social relations, and as such, do not account for its entirety. The specific realm of socioecological relations is the space of intersection between the social sphere—whose structures and rules of function have a self-reference character—and the natural sphere also having its own evolutionary dynamic. Hence, we pretend to theorize about the material structure, functioning, and dynamics of human societies along history based on a thermodynamic understanding of human societies as biological systems, which they also are. Such thermodynamic conception lays on the key role played by entropy, both inside societies as in their relation with the biophysical environment, which leads us to distinguishing or describing several kinds of entropy: metabolic, social, and political or regulatory.

Overall, we are facing a strange paradox: when assuming we need to explore the flows of information—the *software* of the metabolic process—we are compelled to rely on the physical interpretation of the thermodynamics of social systems in order to fully understand their particularities or specificities as emergent systems or *evolutionary novelties*. Providing a sociological nature to the model, which is absent from cybernetic approaches, implies also providing it with a legitimate physical nature. What is being made is returning to the ideals of the knowledge from the nineteenth century, the analogical thought (see Chap. 3), and the pretension of building a general theory of reality that is equally coherent and pragmatic.

12.2 Society is Also Nature

In consequence with what we said in Chap. 2, we reject any form of *exceptionalism* assuming a separation between nature and society from the perspective of its physical and biological functioning, as was suggested by the founders of modern sociology (leaded by Emil Durkheim and Max Weber). Instead, because of the reasons exposed in Chap. 2, we have defended the conception of social systems as natural systems and society is also nature. We accept that the laws of nature operate on and affect human beings and the devices they build, the principle of entropy applies to social practice and social systems are subject to the laws of thermodynamics, maybe the physical law with most relevance for explaining the evolution along time of the human species.

In this book we assume the challenge of applying to social systems some of the physical attributes of adaptive complex systems—and of the theories surrounding this concept—without falling into a rustic form of physicalism, in particular regarding the concept of social entropy. In that context, the thermodynamic metaphor may be of help for elaborating a theory explaining the functioning and evolution of social systems—as natural systems—through an evolutionary interaction with physical and biological systems, without abolishing or excluding the complexity as an emergent system of social systems. The advantage of our approach is that is provides unity and coherence to a discourse elaborated from the ecological paradigm, or if it is preferred, the paradigm of complexity.

We would fall in *physicalism* by thinking that human behavior can only be explained by natural laws or that culture is largely explainable by concrete physical attributes (e.g., thermal). Such assumptions would otherwise be incongruities. Culture requires of cultural explanations that are self-referred to realms of human behavior that cannot be explained solely by natural laws in their present state of the art. That would be as absurd as trying to explain energy and mater exchanges between society and nature—a biophysical system—without the laws of physics. Maybe in due time the languages of social and natural sciences will become unified, but such achievement exceeds our pretensions in this book. In consequence, our proposal of a theory of Social Metabolism accounting for socioecological transformation is founded on the paradigm of the complex systems theory, and as we will see, in the dissipative structure theory of I. Prigogine (1983).

12.3 Society as an Adaptive Complex System

We will begin by assuming that human societies are *adaptive complex systems*. Social systems have a dual complexity: quantitative—have numerous components, and qualitative—have a dense connectivity through a network interconnecting numerous elements. Also our understanding of human societies is complex because their complexity is associated "with the impossibility of using an algorithm to compress the information required for a given representation without losing valuable information (Giampietro et al. 2011, pp. 65)." The interconnections in the system generate organization, so that complex systems are *autopoietic*—i.e., they are capable of self-maintenance and self-reproduction (Maturana and Varela 1980). The adaptability of complex systems is derived from feedback—connections between the system and its surroundings—that leads to the survival of the system through its adaptation to the environment (Marten 2001, p. 50). Societies as adaptive complex systems are non-lineal, dynamic systems capable of learning; therefore, of transforming themselves through cumulative experience. In that sense, societies are *animated* systems (Ruiz Ballesteros 2013, pp. 301–302). Social systems are also multiscalar because of the emergent properties they display at different scales of integration.

Complexity has to be understood beyond being the result of numerous variables of its function and beyond the impossibility of a comprehensive acquisition of all the information needed for its understanding. It should also be seen as the result of the thermodynamic laws ruling upon the system, in particular of the principle of entropy. As complex, evolving biological systems exchanging information, energy and mater with their environment, societies are also subject to the laws of thermodynamics. In his book *What is life?* Schrodinger (1944) stated that living organisms are neither exempt of nor in opposition to thermodynamic laws, but that they conserve or increase their complexity by exporting the entropy they generate. Human societies are also self-maintained (autopoietic) systems having emergent forms of stable organization in space and time, but in a process of dynamic configuration. The existence, configuration, maintenance, and reproduction of societies requires of a continued supply of energy and materials, and to *dissipate* part of that energy. Entropy is the key element of the functioning of societies. The Second law of Thermodynamics establishes that any transformation of energy (defined by the First law of Thermodynamics) is inefficient so that part of the energy is dissipated as heat. The dissipated energy remains as energy, but in a state that is incapable of generating work, moving objects or driving metabolic processes of plant and animal cells. Entropy is an indicator of the amount of energy that is unavailable (Tyrtania 2008, pp. 66). The implications of the principle of entropy derived from the Second law of Thermodynamics are decisive for the theoretical conception of social metabolism. Assuming that relevance of entropy implies a radical rejection of any concept from social sciences—and particularly from historiography—stating that social relations are beyond the laws of thermodynamics acting only on nature. The first and more important of these consequences is the irreversibility of physical and biological processes. Irreversibility rises from the energy loss predicted by the Second law in processes of energy transformation, the total amount of energy remaining constant. Thus all physical processes are irreversible due to heat loss. As a consequence of the Second law of Thermodynamics, physical time always proceeds forward in the same direction. As an example, the process initiated by the ignition of a piece of coal is impossible to revert; the resulting ashes cannot be burnt again (Swanson et al. 1997, pp. 46).

12.4 Social Dissipative Structures

The second relevant consequence of entropy on human societies is the natural trend of societies—as any physical and biological system—to a state of maximum entropy. Social systems depend on dissipative structures for balancing this trend and remaining away from maximum entropy. Dissipative structures transfer entropy to the outside environment and thus gain internal order or negentropy. In order to generate order, all human societies share with the rest of the physical and biological systems the need for controlled, efficient processing of energy extracted from the surroundings. Such is the proposal of Prigogine (1983) regarding non-equilibrium systems (thermodynamics of irreversible processes), which is one of the basic concepts of our metabolic theory: generation of *order from chaos*. Prigogine and his collaborators, during the 1970s elaborated non-equilibrium thermodynamics, the theorem of minimal entropy production, and the theory of dissipative systems. In front of classical or equilibrium thermodynamics for which dissipation of energy and mater causes disorder, Prigogine challenged his proposal of non-lineal thermodynamics that, in conditions of non-equilibrium, dissipation could be a source of order and of generation of structures. In states away from equilibrium, dissipation of energy can play a constructive role by generating order. We will return to this crucial matter further on, but in any case, understanding of social systems under Prigogine's view replaces the "mechanistic view of a perfectly ordered reality" for "the uncertainty of a world on the make; a visibly imperfect world, whose order emerges as a sort of subproduct of the dissipation created by itself (Tyrtania 2009, p. 18)."

A third crucial consequence derives from considering entropy in human societies. Assuming that the biosphere as a system is closed to material exchange but open to energy exchange, leads to considering that the planet provides human societies with a closed, but not isolated environment, and therefore the local reduction of entropy results in the rise of entropy elsewhere (Slesser 1978, p. 17). The generation of negentropy irreversibly increases the entropy of the system. This asymmetry has social consequences relating to poverty and social inequity that are crucial to our proposal, which we will discuss further on.

Finally, the thermodynamic approach to human societies also explains its levels of complexity. In fact, Prigogine and Stengers (1979, p. 201) said the thermodynamics is the science of complex systems, or of *complex behavior* (Prigogine 1987). Complexity results from the system avoidance of thermal equilibrium—in the case of living organisms, death—and it can be seen as a characteristic feature of energy-dissipating systems, i.e., that generates order and chaos at the same time; dissipative systems occur between order and chaos. As further away from the state of thermal equilibrium is a system, its complexity will become higher (Adams 1988).

However, the implication of thermodynamic laws goes beyond fuel combustion and use of materials for generation of negentropy. It is also possible to conceive thermodynamics in a useful way for studying the functioning of human societies lying on an ample conception of energy. As held by Adams (1988), all the efforts are in last instance made for staying away from thermodynamic equilibrium. Thermodynamic laws are implied in every social process, including cultural process that in this sense be considered as natural, and thus, irreversible processes. In 1871 L. Boltzmann formulated the Second law in statistical terms, widening the realms of thermodynamics from thermal machines to all complex systems. Boltzmann (1896/1964) associated the dissipation of energy with probability, thus giving a statistical interpretation to the principle of entropy. By the Second law, changes in systems imply going from a more to a less ordered state. According to Clausius (1879), the entropy of a physical system is the amount of energy it dissipates.

The entropic change of reversible processes is zero, but in irreversible processes entropy grows with dissipation of heat and reaches it maximum value when the potential for work has been totally consumed. Physical systems reach their equilibrium at their maximum level of entropy—reaching total disorganization (Swanson et al. 1997, p. 46). If entropy is proportional to the disorganization of the system, negentropy is proportional to its order and organization. Boltzmann statistical conception—a populational view of intangible atomic and molecular forces acting stochastically—of thermodynamics that led the role to defining information, in turn leading to the possibility of applying thermodynamics beyond thermal exchanges to complex phenomena such as social systems (Ben-Naim 2007).

An analogy derived from Boltzmann's identification of entropy as molecular (and atomic) disorder—which he made before atoms were commonly accepted by most twentieth century scientists—is to measure entropy in terms of homogeneity (Wagensberg 1985): the degree of order of the system is related to the number of its possible states (homogeneity). In social terms, order and disorder lack moral implications and are free of justice value associations. Contrary to the interpretation of order and disorder of classical Sociology, the concept must be interpreted in thermodynamic terms and not as expressions of sociopolitical order against anarchical chaos. But when material behavior of human beings is studied, there is a connection between order and disorder and between social stability and instability, to which we will return later, as we will regarding how, through this assumption, the unity of society and nature, the social and the biophysical environment, all realms ruled under the same natural laws.

Lets now return to one of the basic features of society as a complex adaptive system: autopoiesis. Working systems generate entropy, thus becoming disorganized, so in order to maintain systems need to regenerate and reorganize continuously, generating order. As observed by Schrodinger (1944), biological systems conserve or increase their order extracting from nature energy, mater, and information and exporting entropy. Thus organization resulting from autopoiesis is possible by an uninterrupted flow of energy, mater, and information operating through exchange with the environment. As stated by Edgar Morin (1977, pp. 156–157), organizational order is built and conquered over disorder.

12.5 The Evolutionary Originality of Human Societies

As we said before, complex adaptive systems are dynamic and non-lineal systems evolving through autopoietic processes of adaptation. According to Lotka (1925, p. 24), evolution is no more than the history of a system experimenting irreversible changes occurring in a world whose entropy constantly increases and is also irreversible. From any perspective, evolution can only occur in a world in which entropy increases. Therefore, the principle of entropy has become one of the main explanatory factors of evolution. As stated by Nicolis and Prigogine (1977, p. 442), evolution is driven by the impulse of energy dissipation. Taking thermodynamics into account, evolution implies complex systems in a constant struggle against disorder—i.e., entropy—by means of the organized dissipation of energy, a process that generates qualitative changes driven by the Second law interplaying with biophysical and socioeconomic processes (Georgescu-Roegen 1975). Natural selection assumed as the main evolutionary mechanism could be seen as a process of *thermodynamic selection* in which systems reducing their entropy and maximizing their flow of consumed energy are favored. In different terms, systems do not evolve for consuming more energy, but for consuming it in a way that its survival capacity is enhanced (Tyrtania 2009, p. 142).

In consequence, evolution is driven by natural selection, a process having a thermodynamic expression. Both Lotka (1925) and Prigogine (1955) showed that evolution follows a shared pattern: maximizing energy flow and minimizing entropy. Therefore the binomial negentropy-entropy can be considered the common denominator of the evolutionary process. Evolution follows a unique course in which evolutionary processes of physical, biological, and social nature interact, each with its own specificity. As expressed by Lovelock (1992, p. 99), organisms evolve in close interaction with the evolution of the environment, both being a part of the same evolutionary process.

Evolution is, thus, a process of formation of dissipative structures resulting in a higher complexity. Complexity is the product of *evolution*, the qualitative change brought about by combinatory innovation and unidirectionality of the Second law (Georgescu-Roegen 1996 ,1971, p. 395). Certainly, biological evolution displays *stationary states*, however, nothing inherent to complex systems compels them to reach or not to reach to such states—i.e., evolution to higher levels of complexity is the product of the evolutionary interaction with the environment and is not predetermined by an unavoidable path. In that sense, evolution has a memory; it generates a sort of *dependence path*, which notwithstanding does not imply linearity. Evolution behaves stochastically (Tyrtania 2008, p. 57) combining a random component with a selective process (Bateson 1993, p. 242).

12.6 Culture as an Evolutionary Innovation

Human societies share with physical and biological systems the same evolutionary precepts, but represent an *innovation* that differentiates and makes its dynamic to be specific, adding complexity and connectivity to the total evolutionary process. Social systems cannot be explained by a simple application of the laws of physics, even though human acts are subject to them.

The reason for this is that despite evolution being a unified process, human society is an evolutionary innovation emerged from the reflective (self-referring) capacity possessed by the human species, more developed than in any other species. The most direct consequence of this human mental feature is the capacity—not exclusive among higher animals, but rare—for building tools and, therefore using energy *outside* the organism, i.e., use of exosomatic energy. For construction and use of tools, the generation and transmission of information and knowledge was needed, i.e., generation of culture was required. Culture involves a symbolic dimension containing, besides knowledge, beliefs, rules and regulations, technologies, etc. Accordingly, the evolutionary innovation is the capability of humans for exosomatic use of information, energy, and mater, in addition giving place to a new type of complex systems: the *reflexive complex systems* (Martínez-Alier et al. 1998, p. 282) or *self-reflexive systems* and *self-aware system* (Kay et al. 1999; Ramos-Martin 2003). This feature will be instrumental, as we will see further on, because it gives social systems a unique *neopoietic* capacity absent from other systems or species, and that confers an essential, creative dimension to human individual and—more so—collective actions.

In fact, the human species was able to construct its own *cognitive orthoses* (language, technology, knowledge) making it capable of gathering, processing, and generating large amounts of information from nature and the social system, thus enabling humans to reach very high levels of complexity and autonomy from the natural environment. Culture is largely the product of the use of complex tools operating not solely as exosomatic heat extractors, but also as generators of information. As is logic to infer, the appearance of language—about 600,000 years ago—was key in the evolution of human societies, an event that occurred in synergy with biological transformationsuch as the increase in brain volume and cooperative behavior turning humans into an *eusocial* species (Wilson 2012).

In analogy with living organisms, culture is the transmission of information by non-genetic means, a metaphor that became popular in the academic world. It has been said that cultural evolution is an extension of biological information *by other means* (Sahlins and Service 1960; Margalef 1980) and the diffusion of genes and of culture has been paralleled. Throughout the expansion of humans to all habitats available in the planet, the human species became differentiated in linguistic groups or cultural species. About 50,000 years ago, the world contained a diverse cultural universe of 12,000 cultures distinguished by language. There is a correspondence between the linguistic and genetic classification trees of the human species (Cavalli-Sforza 1996), and based on this data, it is possible to establish a detailed route and dates of human displacements occurring for thousands of years. The ideas, knowledge, beliefs, laws and regulations, etc. contained in a culture would be the genetic instructions ordering the use of *exosomatic* energy. Sieferle holds that: "In order to understand this we have to comprehend the specific human strategy of 'cultural evolution' as an emergent phenomenon that came into existence historically and whose origin must have been evolutionarily selected for as well as any other organs or traits. In the organic world, programmes leading to the synthesis of replicators are in principle fixed on DNA molecules… The emergence of culture or of cultural evolution proper as our species' basic strategy can be reconstructed as the result of an evolutionary process… The disposition for certain behavior is thus partly inherited, and this genetic basis does not totally vanish even in humans but is transformed by cultural codes. The stage of cultural tradition is reached when information that was individually acquired and stored in a single nervous system can be transmitted over generations without being fixed in the genome (Sieferle 2011, p. 316)."

In sum, the uniqueness of social systems in the evolutionary principle lays in how it processes and transmits information not by means of biological hereditary, but by means of language and symbolic codes. *Culture is then the designer of metabolism fund elements and the combinations of flows of energy and materials that make them function and reproduce. But culture also produces and reproduces the flows of information that order and give structure to energy and materials flows.* This does not exclude the entropic costs—both material as social and regulatory—of the physical consequences of the transmission of information. Culture, in that sense, does not discriminate humans from all other species by a purely symbolic and immaterial flow. The laws of thermodynamics also operate in the realm of information flows, because all information requires of material support.

Culture can then be seen as an innovative manifestation of the adaptive complexity of social systems; it is the name of a new genus of complexity provided by the environment for perpetuating and reorganizing a particular kind of dissipative systems: social systems (Tyrtania 2008, p. 51). However, as we will see below, it is more than a mere adaptive strategy of social systems. As also said by Sieferle, "when cultural evolution started, it continued organic evolution, and its emergence must have been awarded as a successful adaptation since culturally controlled species experience the same selective pressure as species, whose behavior was completely controlled by genetic programmes. Culture is not, however, merely an instrument of adaptation. Culture developed specific system properties that soon gave it characteristics that are not exclusively adaptive (Sieferle 2011, p. 317)."

Culture is but an emergent property of human societies. Its preformative or neopoietic character, its creative nature (Maturana and Varela 1980; Rosen 1985; Pattee 1995; Giampietro et al. 2006) allows for configuring new and more complex dissipative structures at even larger scales by means of technology (Adams 1988). While biological systems have a limited capacity for processing energy—mainly endosomatically—due to availability in the environment as to a genetic load, thank to their mobility, technological capabilities, and their power for expanding the energetic boundaries of their exosomatic metabolism, human societies exhibit a less constrained dissipative capacity that is only limited by the environment. Societies adapt to the environment by changing their structures and frontiers by means of association, integration, or conquest of other societies, something biological organisms cannot do. In other words, differently from biological systems with well-defined boundaries, human societies can organize and reorganize thus acquiring the capability of avoiding or overcoming local limitations from the environment. That explains why societies with industrial metabolism maintain exosomatic consumption levels that are beyond the provision means of their local environments without entering into a steady state.

All this *innovations* confer to the human evolutionary process certain specificity within the normal course of development of complex adaptive systems. Human societies build ever larger and complex dissipative structures with which to compensate for the growing entropy that is transferred to the environment. They are unable to evade the Second law, but can control the rate of the entropic process and even the direction of evolution itself from the standpoint of social objectives (Adams 1988).

Perhaps due to all that, social evolution can be much faster than biological evolution because cultural *mutations* are not only random events (Marten 2001, p. 58) but also a consequence of reflective, intentional actions. What is *specifically human* is *exosomatic consumption of energy*. Since no genetic load regulates such exosomatic consumption, this is made as codified by culture, what involves a faster but less predictable evolutionary rate. Because of that, there is no progress but a self-written process occurring in the present. Evolution does not display a concrete directionality. Human evolution is not progress, it does not respond to a specific purpose. Quoting Tyrtania: "If evolution has no aim, as once said Karl Popper, its advantage over other conceptions of the universe consists in that we can assign one to it. For that, the only thing we need is to have enough time, energy, materials, and information. The evolutionary processes are paradoxical. Marked by uncertainty and risk, they only obey to the law of entropic indetermination (Tyrtania 2008, p. 48]." To that extent, randomness must be accepted as an important component of the evolutionary process that, in addition, forbids the environmental historian from admitting the existence of a preconceived plan or an evolutionary path whose aim is *progress*.

12.7 Evolution, Complexity, and Sustainability

We have arrived to a powerful conclusion, due to its transcendence, novelty and multiple features, and which haves endless consequences: *The human species has the capacity of influencing their own evolution and controlling its future*. That forms part of the evolutionary novelty of human societies. Human beings can build exosomatic dissipative structures by means of artifacts or tools, i.e., through knowledge and technology, and can do it faster and with greater mobility than any other species. Paradoxically, this means that social systems are an exception, but an evolutionary exception within nature. However, many of the theories developed under the luminosity of this feature fall in some sort of automatization in which the behavior of individuals of the species and social group *lack* the power for action or collective activities. Certainly, social systems are dissipative structures capable of perpetuating and reproducing through the exchange with their environment of energy, materials, and information. That means they evolve, contracting or expanding from the energetic perspective, varying their structure and organization. As is known, a complex system has several levels of integration as a product of the battle against entropy: the system seeks for energy from increasingly further environments, being forced to integrate with other dissipative structures, and adopting more and more complex self-regulation and control systems that, in turn, consume more energy (Adams 1975). The entropic deficit becomes a stimulus for interaction, which means that the amount of energy handled by a society is in correspondence with its structural complexity. The evolution of the human species has displayed that same evolutionary pattern, as was explained by Steward (1955), by means of the succession of new types of organization that are increasingly complex. Even Leslie White (1964) suggested measuring the advancement of civilization in terms of the increase of the energy consumed per capita; that would be a measure of the intensity of energy dissipation and, hence, the distance of a society from its state of thermodynamic equilibrium.

But the application of this pattern typical of complex adaptive systems has led to a sort of evolutionary straitjacket that is *counter-historical*. Such is the case of Josep Tainter, for whom complexity is defined as differentiation of structures—i.e., more system components and more types of components—and as variation in organization, defined as constraints on potential ranges of behavior (Tainter 1988). "In human societies, differentiation in structure occurs in such areas as institutions, roles, technologies, and activities. Organization consists of constraints on behavior arising from such things as social norms, peer expectations, and hierarchical direction (….) The development of complexity is thus a paradox of human history. Over the past 12,000 years, we have developed technologies, economies, and social institutions that cost more labor, time, money, energy, and annoyance, and that go against our aversion to such costs. Why, then, did human societies ever become more complex? (Tainter 2011, pp. 89–90)." But such interpretation, which is only possible *ex post facto* and through a very long time period, suggests a process of constant increase of complexity and, consequently, of energy and materials consumption, as an unavoidable trajectory of human evolution. An interpretation of history so lineal that it becomes a straitjacket is inadmissible. The indetermination ruling evolution from the thermodynamic perspective allows for social arrangements at different levels of entropy that are not previously determined and that, therefore, have a variable duration. Societies have existed throughout history whose dissipative structures have remained in a steady state for millennia. In contrast, during the past 250 years the increase in complexity has been accelerated, but not equally throughout the planet. The relative dematerialization currently experienced by the more industrialized countries—i.e., the countries having the highest levels of complexity—can be due simply to a mater of efficiency generating the rebound effect described by Jevons, but contradicts the apparently lineal relation between the increase in complexity and energy dissipation.

In that sense, perhaps the most important thing may be not the trend to increase in complexity, but its connection to the increase in energy level. For Tainter, there are two views of this connection: one called *progressivist* holds that complexity increases because it may do it, i.e., because there is a surplus of energy that allows for it. Thus energy precedes complexity and allows for its emergence. Such event has happened in occasions in which humans adapted energy sources with such potential that the adoption was followed by an increase in the population, the wealth and the complexity of societies. Nevertheless, such events were so rare that they have been assigned significant terms, such as *Agricultural Revolution* or *Industrial Revolution* (Tainter 2011, p. 90).

The second view, the one favored by Tainter, denies that the increase in energy derives from the increase in complexity. If human beings rarely posses surpluses, the availability of extra energy could hardly the main motor of cultural evolution. And it is that complexity has costs. In non-human species this cost it is merely a question of additional calories. But among humans the cost is estimated depending on the amount of resources, time or money, or on more subtle matters such as discomfort. Complexity is a tool for solving basic problems (problems of sustainability, i.e., issues that threaten the continuation of societies). When we such problems are not confronted, we seldom respond by developing more complex technologies, establishing new institutions, adding more specialists or bureaucratic levels to existing institutions, increasing organization and regulation, or gathering and processing more information. In addition, this increment in complexity functions as a spiral. Abundance of energy generates more complexity and, simultaneously, it generates new types of issues, such as wastes or climatic change. Solving these problems requires of complexity for growth, imposing the need for more and more energy. Thus, complexity emerges before there are additional sources of energy available for maintaining it.

This lineal conception of complexity has consequences from the perspective of sustainability. Tainter holds that the more common interpretation of sustainability demands that industrial societies consume fewer resources. This makes that discourse about sustainability are excessively focused on the voluntary or forced reduction of resource consumption and an increased efficiency, perhaps implying lessening complexity. The most frequent conception of sustainability follows a progressivist view when understanding that resources precede and facilitate innovations, which increase complexity: in this way, complexity is seen as voluntary, as a social choice. But the fact that complexity and its costs are incremented as problems are solved suggests the opposite conclusion: by general rule, a society cannot voluntarily reduce its long-term consumption of resources; on the contrary, when problems appear their solution involves the increase of both, complexity and resource consumption. The case of the Roman Empire is a paradigmatic example of increase of complexity leading to civilizatory collapse.

In consequence, for Tainter "complexity is not something that we can ordinarily choose to forego (Tainter 2011, p. 94]." Tainter's conclusions are dismaying and, to a certain extent, legitimize what exists. The first such conclusion is that the solutions commonly recommended for promoting sustainability—i.e., conservation, simplification, valuing of resources, and innovation—can only be applied in the short term. In the long-term, such measures may even be adverse.

The second conclusion is that long-term sustainability depends on solving the great social issues converging during the next decades, which will require more complexity and more energy consumption. Sustainability is not an issue of stasis, but a process of continual adaptation along which new problems are confronted, the goal being to ensure the resources allowing for their solution. "One implication of this discussion is that modern societies will continue to need high-quality energy, and securing this should be the first priority of every nation with a research capability (Tainter 2011, p. 94)."

Evidently, reduction of complexity is always possible by generating the consequent decrease in energy use, as claimed by Marten (2001, p. 149), or vice versa, reducing the use of energy to reduce complexity. Nor evolution necessarily implies material progress—as interpreted by social sciences until the present, nor complexity is a positive effect derived from the former. High-entropy social systems, such as in the industrial metabolic regime, have generated more complexity, but at the same time, a higher level of unsustainability. Any social system aiming towards sustainability must reduce its complexity by reducing at the same time its consumption of energy and materials, or vice versa. This is the only way to avoid the *complexity trap* proposed by Tainter. Sustainability is possible; it is a possible result of evolution. As stated by Leonardo Tyrtania, "sustainability is a possible outcome of the self-organization of an open system. It is a possible result, as others, because a system can either remain in a steady, fluctuating, oscillating, unstable, and even chaotic state. They can remain in any of these states for some time, before definitively being confounded with the environment (Tyrtania 2009, p. 130]." The sustainable society will not be a perfect society, but will necessarily be a low-entropy society and, for sure, with lower levels of complexity, which remains in a steady state with low-entropy dissipative structures.

12.8 Flows of Information, Entropy, and Dissipative Structures

Human societies give priority to performing two basic tasks: on one side, producing goods and services and distributing them among its individual members, and on the other side, reproducing the conditions making production possible in order to gain stability through time. In thermodynamic terms, that implies building dissipative structures and exchanging with the environment energy, materials, and information so that these structures may function. An important number of social relations are oriented to organization and maintenance of such exchange of energy, materials, and information. In fact, the interaction between the components of a system is no more than the exchange of energy, materials, and information. For analytical purpose, les distinguish between two types of exchanges: a purely physical exchange of energy and materials, and a second type of exchange that, despite its physical costs, is more ideal or *immaterial*, the exchange of information. In that sense, the essential distinction introduced by Georgescu-Roegen (1971) between flow-flow and fund-flow is fundamental.

Application of the term *flow* to exchanges of energy, materials, and information makes explicit the dynamic, unidirectional, and irreversible nature of transferences of energy, materials, and information from one point to another within the system, or between the system and its environment (Adams 1975). The function of such flows is to configure and feed the *funds* built by societies for generating goods and services. The configuration and maintenance of such funds require a continuous flow of energy, materials, and information to counterbalance the principle of entropy by generation of order. Such flows, as held by Georgescu-Roegen, maintain an *entropic balance* between the system and the environment that keeps the system away from thermodynamic equilibrium and generating order within chaos.

Prigogine (1947, 1955, 1962), independently, developed a similar conception, distinguishing between *structures of equilibrium* and *dissipative structures*. All complex adaptive systems are kept away from thermodynamic equilibrium by means of a *controlled dissipation* consistent in transferring part of their entropy to the environment. The structures of an open system are maintained thanks to the transfer by the system of a part of the energy being dissipated by its conversion processes; therefore, the name *dissipative systems* (Glandsdorff and Prigogine 1971, p. 288). Such transference is made by means of building dissipative structures using the flows of energy, materials, and information for performing work and dissipating heat, consequently increasing their inner organization. Order emerges from temporal patterns (systems) within a universe that, as a whole, moves slowly towards thermodynamic dissipation (Swanson et al. 1997, p. 47). Prigogine described this configuration of dissipative structures as a process of self-organization of the system. But the *structures of equilibrium* lack their own reproductive dynamic (Adams 2001), i.e., they cannot dissipate energy, hence, neither can they perform work. Crystals are commonly used as physical examples of this type of structures. In the social realm, an example would be ceremonial buildings (e.g., cathedrals) or jewels that do not require consuming energy and materials for their maintenance, which depends on an adequate environment. These are the *sumptuary goods* whose symbolic function is to remark the social differences, for which they do not need to consume energy and materials (Bataille 1989). The use of sumptuary goods is typical of societies with low metabolic entropy.

Certainly, from the biophysical perspective human societies can be considered as dissipative structures, or more precisely, can be considered as made up of dissipative structures exchanging energy, materials, and information with their environment. It is this exchange what originates the metabolic relation and is the foundation of the theoretical proposal of *social metabolism*. Adams (1975)—who calls dissipative energies (combining energy and information) *energetic forms*—considers human societies as a conglomerate of human and non-human forms, of forms in equilibrium and out of equilibrium, of living forms, which we may say constitute the equipment of a society, its material or symbolic fund.

Prigogine also made a relevant distinction between *internal entropy* and *external entropy*, which is also useful as a foundation for our metabolic proposal. He distinguished between the entropy produced inside the system and that imported from the environment into the system. The equation of open systems of Prigogine is: $dS = d_eS + d_iS$, where dS is the total change in entropy of the system, d_eS is the production of external entropy imported by the system, and d_iS is the internal entropy generated by the irreversible processes of the system. While d_iS remains constant or increases, d_eS can be negative if enough energy, materials, and information are imported inside the system. When that happens, the total change in entropy (*dS*) can be negative, such that the order and organization of the system can be increased (Swanson et al. 1997, p. 48). We will insist in this matter later on.

As we have seen, organization is an autopoietic product in which flows of information have a definitive influence. There is no structure without information, as has been demonstrated in the biological world (Margalef 1995). In the social world, systems are also subjected to the laws of thermodynamics, given they occupy time, space, and energetic resources. Application of thermodynamics in the statistical terms of Boltzmann we have already mentioned, provides an explanation of flows as a unidirectional and irreversible process going from its state of order—its more evident manifestation—to a state of disorder, whose organization properties have disappeared. Therefore, the main function of these flows is negentropic: "Information, in this technical sense, is the patterning, order, organization, or non-randomness of a system. Shannon showed that information (*H*) is the negative of entropy (*S*). Consequently, a precise relationship between measures of entropy and information has been identified… Information, however, is more than the physical negentropy in concrete (physical) systems. The field of cybernetics has identified a subjective doubling of the connection between negentropy and information. It permits reciprocal transitions between the two terms (negentropy information) (Beauregard 1961). The meaning of information is different for each transition. The direct transition negentropy information signifies the acquisition of knowledge and the reciprocal transition negentropy information indicates power of organization (Swanson et al. 1997, p. 47)."

Therefore, flows of information are here considered capable of reordering and reorganizing the different components of the physical, biological, and social systems in which they function. That is, they have characteristics the produce action (change). In that sense, the authors distinguish between the information having significance in a system and that reflecting mere observations about a system. Information flows are the basic vital ingredients of the processes of organization of social systems. Information is here defined in a pragmatic or operative way as a codified message, which who makes decisions can use to regulate the levels of entropy.

Some authors made interesting contributions regarding the relation between material and symbolic metabolism—the *hardware* and the *software* (Fischer-Kowalski 1997; Fischer-Kowalski and Weisz 1999). One of them is Echevarria (1998), who proposed the existence of a merely informatics process of communication-interpretation occurring in parallel with the process of production-consumption. The former, essentially cultural process, exists independently of material processes: "The *semiotic*, at the same time it remains within the *practical*, ceases to be confused with it and becomes a special, *purified*, process of production/consumption of meanings…(Echevarria 1998, p. 191)." Its about human as a political animal endowed with a language: "The speaker delivers to who listens a transformation of nature: his voice modifies the acoustic state of the atmosphere and that change, that object, is perceived or consumed as such by the ear of the other (Echevarria 1998, p. 192)." In that way arises the privileged way of communication and interpretation between individuals, the flows of information, a new reality of whose complexity depend the dimensions, rhythms, and transformations of mater and energy.

A paradigmatic case of information flow is money. As suggested by Swanson et al. (1997), money is a commodity, but it is also information: if money is assumed to be a measure of entropy value, its value may be made proportional to its capacity for decreasing the levels of entropy in the social system. Money is thus a good and at the same time, a marker information (exchange marker). As a use value(good to be consumed) it becomes an entropic factor that can efficiently increase the level of internal entropy. In opposition, as an exchange value (information), it can be a dissipative factor increasing the efficiency in the use of mater and energy. During the process of commodification of money the transforming function lies in the autonomy of the flow of information from the regulatory center (the State) to multiple non-state centers (social). Therefore, the flow of information originally aimed to the political reduction of social entropy becomes an incremental factor of social entropy because it looses informational properties and acquires flow functions. Money as a commodity increase flows and decreases organization and order (Swanson et al. 1997).

All physical and biological objects contain information in the manner in which they are structured or organized. Social systems also generate information flows, but differently from the later, they are exosomatic flows generated through communicative processes involving the material or immaterial translocation from one part of the system to the other of signs, symbols, and values.

Culture as an evolutionary innovation is a conglomerate of information flows. "The processing of information by means of symbols is the novel characteristic of the sets evolved as social sets (…) Due to their capacity for symbolization and use of language, humans create systems without precedent in nature. This does not mean that social systems cease to be natural. All systems exchanging energy, materials, and information with their environment are natural. Culture only intensifies such exchanges (Tyrtania 2008, pp. 47–48)." As Gintis (2009, p. 233) has remarked, culture can also be considered as an *epigenetic* mechanism of horizontal, intra-generational transmission of information among humans: i.e., of the system's memory along the evolutionary process. In sum, the design and organization of dissipative structures of social systems corresponds to culture.

We lack of enough space here to develop a theory of information flows and their role in complex adaptive systems. Niklas Luhmann (1998, 1984) developed this theory to a large extent, to whose writing we direct the attention of the interested reader. Luhmann's theory of autopoietic social systems is an instrument of utility for building a theory of information flows and of their role as organizers of the dissipative structures all societies build for compensating for entropy (disorder).

12.9 Physical Entropy: The Thermodynamic Foundation of Social Metabolism

According to the theories of complexity, the way to approach reality that humans have consists in building models of it and to verify their pertinence (Arnold-Cathalifaud 2010; Dockendorff 2012). In the following paragraphs we will attempt to perfect a model of social metabolism that is isomorphic with the physical reality to which we belong, i.e., the material reality of social systems. The model consists of interacting, dissipative structures—or energetic forms—that exchange energy, materials, and information with their environment. Evidently, the model only provides a partial knowledge of the complex social reality. It is a provisional model whose only ambition is being useful for building a more sustainable world in the several dimensions encompassed by the term.

Social metabolism has been defined as the organized exchange of energy, materials, and information between society and the environment (see Chap. 3) with the purpose of producing and reproducing its material means for existence. Since natural processes are irreversible and energy cannot be reused, human societies as open systems must compensate for the entropy they produce through exchange with the environment. In terms of the Second law of thermodynamics, we may say that *social metabolism pertains to the flow of energy, materials, and information that are exchanged by a human society with its environment for forming, maintaining, and reconstructing the dissipative structures allowing it to keep as far away as possible form the state of equilibrium*. In other words, all societies generate order through the importation of energy and materials from the physical environment, and the exportation to the environment of dissipated heat and wastes. We call the organization of this stable exchange of energy, materials, and information *social metabolism.*

From that perspective, the theoretical key is the consideration of human societies, according to their evolutionary innovations they represent, build structures—in the sense of Prigogine—that dissipate heat (entropy) to the environment, obtaining free energy from it. These structures are not only biological (endosomatic) but—thanks to the species' capacity for building tools and mechanical, electronic, and digital artifacts—also technological (exosomatic). The distinction between endosomatic and exosomatic metabolisms was introduced by Lotka (1956) and adopted by Georgescu-Roegen (1971) in his biophysical interpretation of economy. As we have seen, while endosomatic metabolism is genetically determined, exosomatic metabolism is culturally determined and, therefore, subjected to purely social constraints in addition to environmental constraints. Hence, *the metabolism of a society will be the sum of the endosomatic and the exosomatic metabolisms built by society itself through time,* and the makes possible the individual metabolisms of its members.

Thus, human societies create exosomatic dissipative structures of varied functionality that generate goods and services, i.e., social order. *Social order* only refers to a state away from thermodynamic equilibrium and contains no implicit moral valuation regarding being more or less fair or socially admissible. Many situations of social order may exist, some being more morally desirable than others. The flows of energy, materials, and information feed dissipative structures and are thus vital for their maintenance and reproduction. Physical structures that consume resources—both for their building as for their functioning—have been built for providing health, education, security, food, clothing, housing, transportation, etc. For merely analytical purposes we may group all these structures or infrastructures in the five metabolic processes we established in Chap. 5: appropriation, transformation, distribution, consumption, and excretion.

The magnitude of dissipative structures determines the amount of energy and materials consumed by a society, that is, its metabolic profile. Each of the structures needs inputs of energy, materials, and information in a determined amount, and evacuation to the environment of the generated wastes. The differences in installed dissipative structures of countries, explains their differences in terms of resource consumption (Ramos-Martín 2012, p. 73), and therefore, the differences in the size of their metabolisms. As we will see further on, these differences in the capability of generating order also indicate the differences in the levels of economic and social wellbeing.

Georgescu-Roegen (1971) established a distinction that is essential in this context and that was retaken by Giampietro et al. (2008b) as Ramos-Martín (2012) in their metabolic proposal Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). When analyzing the functioning of social metabolism, quantitative analysis should differentiate between flows and funds. Flows involve the energy and materials consumed or dissipated by the metabolic process—e.g., raw materials or fossil fuel. Two types of factors control the rhythm of flows: external factors related to the accessibility of resources available in the environment in which metabolism takes place, and internal factors having to do with the capacity for processing energy and materials during the process of conversion, which itself depends on the technology used and the knowledge for its management. Instead, funds are the entities or structures that transform input flows into output flows at a given time scale, and that, hence, remain constant throughout the dissipative process.

Funds also have two characteristics that are worth remarking: they process energy, materials, and information at a rate determined by their own structure; and that they require being periodically renewed or reproduced. This implies that a part of the input flows need to be devoted to construct, maintain and reproduce the dissipative energies themselves, which, of course, limits their growth rate (Giampietro et al. 2008a). The human population living within the territorial limits of a given society—herein considered as the processor of the energy, materials, and information (mainly endosomatically) to produce work and residual heat—by the society forms part of the fund elements. Other fund elements are agroecosystems (the land), which managed by humans, processes external energy, materials, and information to produce biomass that, in turn, provides a flow that feeds other dissipative structures of social metabolism. Finally, among the fund elements is what economists call *capital*, i.e., the set of artifacts capable of processing energy and materials that are created by humans. Domesticated livestock for producing either food or work must also be considered as fund elements. While fund elements define what the system is, the flows define what the system does (Giampietro et al. 2008b).

Distinguishing between flows and funds is relevant because, according to what Georgescu-Roegen (1977) postulated, the fund elements with which a society counts determines the viability of a given technology, its special scale, and its time span. Technology is only viable if it has an accessible and stable flow of energy and materials in the amount established by the inherent limitations of the fund elements. The above implies the recognition of the limitations to metabolic processes imposed both by the biophysical environment and by the scales of operation (Giampietro et al. 2008b). Another useful distinction rescued and adapted to society by Giampietro et al. (2008b) is that of Ulanowicz (1986), differentiating between two main components of the ecosystems: the hypercycle, i.e., the part providing the gross energy for the whole ecosystem; and the purely dissipative part, devoted to the degradation of the gross energy in the ecosystem. The hypercycle maintains the ecosystem away from thermodynamic equilibrium, while the dissipative part has important functions: "provides a control mechanism over the entire process of energy transformations, explores innovations (guaranteeing adaptability) and stabilizes the evolutionary sustainability of the whole system. In fact, an ecosystem made up of only one hypercycle cannot be stable over time. Without the stabilizing effect of the dissipative part, a positive feedback "will be reflected upon itself without attenuation, and eventually the upward spiral will exceed any conceivable bounds" (Ulanowicz 1986, p. 57). In the analogy with human societies, the hypercycle of the society is made up by the economic sectors generating profit and goods and services and the purely dissipative part the final consumption sector (Giampietro et al. 2008a, p. 3)."

Although the theory of social metabolism has considered and quantified above all the flows of energy and materials, it is essential to take into consideration the fund elements each society has constructed along its evolutionary trajectory. Such elements determine the nature of the flows of energy and materials, and therefore, the metabolic profile of each society. We have seen that human societies also build structures in equilibrium that hence do not dissipate energy, but facilitate the functioning of funds—e.g., communications infrastructure such as highway or railroad networks—that allow dissipative structures—e.g., motor vehicles and trains—to perform their function. These non-dissipative structures also require being maintained and renewed. The sum of non-dissipative and dissipative structures integrates the material fund possessed by a society, and must be approached from the metabolic perspective.

12.10 Internal Entropy and External Entropy

The exchanges of energy, materials, and information are naturally asymmetrical and are always unidirectional; some structures gain order and others loose it, the total amount of entropy always increasing. Open systems can become ordered by means of ensuring a continued flow of energy from its environment, to which the resulting entropy is transferred. Such behavior theorized by Prigogine (1947, 1955, 1962) allows the construction of a theoretical model of social metabolism that can go beyond its mere use as a method for measuring sustainability. Indeed, the proposal of Prigogine can be translated to an equation explaining the material functioning and physical dynamic of human societies. For Prigogine, the total change of entropy of a system is equal to the sum of the external entropy produced that is imported into the society, and the internal entropy due to the irreversibility of the processes occurring inside it.

$$MS_t = MS_{in} + MS_{out} \tag{12.1}$$

where: MS_t = total metabolic entropy; MS_{in} = internal metabolic entropy; and MS_{out} = external metabolic entropy.

The generation of order in a society is achieved by increasing the system's total entropy by the consumption of energy, materials, and information by its dissipative structures or fund elements. The level of order will remain constant or increase if enough amounts of energy, materials, and information are added to the system, creating new dissipative structures. That will, in turn, increase total entropy and, paradoxically, will reduce order or will raise its cost. Complex adaptive structures solved such dilemma by capturing from their environment the flows of energy, materials, and information the need for maintaining and increasing their level of negentropy and transferring to their environment the produced entropy. In other terms, if the external entropy is raised, the total entropy of the system remains constant, at the same time reducing the internal entropy.

Human societies cannot always find in their environment the required amounts of energy, materials, and information they need for increasing their internal order, such that they tend to resort to importations from other societies.

Given that along history no society has been devoid of its own territory for appropriation (even among hunters-gatherers), we will here consider *the internal physical entropy as that produced by metabolic processes occurring within the territorial limits of a society*. Likewise, *external entropy is that generated or transferred to the territory of other society or societies* integrating its surroundings at a higher scale in the system; currently, the nation States. Accordingly, lets assume that the level of negentropy maintained by a society, i.e., its distance from thermodynamic equilibrium, is the sum of the levels of internal and external entropy. Societies reduce their entropy levels by means of the extraction of energy and materials from their internal environments (domestic extraction), or by means of imports from other societies' environment. The degree of complexity (order)—i.e., the magnitude of its metabolic profile—of a society will depend on the magnitude of the flow of energy and materials extracted from their territory, imported from other's territories, or both.

We can translate this to the accountancy language of the methodology of social metabolism (see Schandl et al. 2002), such that assessment of the total level of entropy of a society is made through the proxy of the total energy it dissipates during a given year. The division of the members of the equation makes it easier to make comparisons among societies, and provides their metabolic profile. Hence, the level of entropy will be equal to the annual domestic energy consumption (*DEC* year^{-1}), and the metabolic profile will be equal to the annual domestic energy consumption per capita per year (*DEC* population number^{-1} year^{-1}). Accordingly, Prigogine's equation as formulated in Eq. 12.1 would take the form:

$$DEC = DEI - Ex, \tag{12.2}$$

becoming

$$DEI = DE + Im$$

then

$$DEC = DE + Im - Ex$$

where: *DEC* domestic energy consumption; *DEI* direct energy input; *Ex* exports; *Im* imports; *DE* domestic extraction.

Equation 12.2 focuses on internal and external entropy in human societies seen as thermodynamically open systems exchanging energy, materials, and information in Earth, a planet that although it exchanges energy from the sun and its own surroundings, it can be considered *closed*. Consequently, the level of entropy of a society is always a function of the internal and the external entropies and, thus, an essentially asymmetric function established between societies and their environment or between societies, as we will see next. The above excludes any assumptions about proportionality between the levels of external and internal entropy changes, i.e., if one rises the other must not necessarily need to rise also. This is clarified by the distinction between societies having *high* and *low entropy*. On one side, societies with funds needing for their maintenance of low dissipation of energy and low consumption of materials are low entropy societies that generate low levels of entropy in their environments, i.e., low levels of domestic extraction or imports.

On the other side, societies can only sustain high levels of total entropy if large amounts of energy and materials are appropriated from their domestic environment, and if these were locally insufficient, from large importations of energy and materials. This asymmetric relation between society and the environment is also equivalent in differentials of complexity between the environment and the system. Thus, the system is always less complex than its surroundings. That is the foundation for the strategy of *biomimicry*, intentionally developed by the human and perhaps other higher evolutionary level animal species, and unintentionally by all other living organisms, in the extraction of information from the environment.

12.11 The Thermodynamic Roots of Inequality

With rare exceptions, attempts made to interpret historical transformation from a socioecological perspective have adopted a *neutral* political—ideological—posture, i.e., a sort of aseptic approach is adopted that assigns change to the *structural, systemic factors* as the central and decisive protagonists. Seen like that, humans appear as mere objects devoid of will and moved by the invisible forces of the systemic mechanisms. A precise visualization of the perspective of these approaches is provided by the image of Charles Chaplin forced to be caught by gigantic machinery in his classical film Modern Times. In other words, the approaches we can call socio-cybernetic, the processes of historical transformation appear detached from the economic, social, political, and cultural conflicts, therefore appearing as independent or autonomous relative to human decisions.

This approximation has two main flaws: it ignores first hand the evolutionary function of self-reflection (self-reference) in the adaptive changes of more complex species. Ideas, symbols, ideologies, beliefs, languages are all instruments for self-control and for designing the institutions and the strategies for organization and adaptation to the environment. It also ignores the *interests* as being part of the reproductive drive of individuals or groups that originate complex power (socio-psychological) and control (physical) relations (Adams 1975).

This *structuralist* or cybernetic nature without space for collective action is a weakness shared by most known conceptions of *social metabolism*. The uncoupling in these works—despite the good intentions of their authors—of the purely physical, metabolic dimension of societies and the essentially social dimension is what causes this bias. But this lack of integration also nullifies the interdisciplinarity, holistic character supposed to guide studies of social metabolism. Our goal is to establish links between the physical and sociocultural dimensions; a possibility for whose exploration we believe thermodynamics can provide an appropriate framework.

An aspect little considered when analyzing the factors explaining the dynamics of social metabolism is *social equity*, which depends on the forms of distribution of goods and services produced and wastes generated. Social equity has a major relevance in the functioning of social metabolism. Because of that importance, any approach to the study of the physical, material dimension of each society must account for the causes and levels of inequality and its consequences, especially of the conflicts this causes. We owe to Flannery and Marcus (2012) a detailed and amply documented account of inequality in human societies, its genesis, history and modalities. "By 2500 B.C., virtually every form of inequality known to mankind had been created somewhere in the world, and truly egalitarian societies were gradually being relegated to places no one else wanted (Flannery and Marcus 2012, p. 15)." Social inequality expresses by the unequal assignation of goods and services among social groups or their territories, thus creating a hierarchic societies. A physical interpretation of this social disequilibrium is the unequal distribution of flows of energy and materials, and of recycling of wastes—i.e., the ecosystems' absorption service. As seen above, changes in entropy of a system are always asymmetrical, hence unequal, relative to both terms of the equation: the levels of internal and external entropy. Environment and its resources, either in domestic or in *other* society's territory, take the costs of this asymmetry. Asymmetry is thus at the core of each dissipative process because these operate following two contrary directions: produce work (order), and generate unusable heat (disorder) (Hacyan 2004). Inequality is thus the bucketing of order in one direction, and of disorder in the opposite direction. This dichotomy is also a powerful stimulus for the interaction between individuals and groups in the search of more energy and materials for maintaining order and decreasing disorder. In that context, a most relevant part of social relations is aimed at exchanging energy, materials, information, and wastes. As stated by Tyrtania: "…based on Boltzmann, the struggle for existence is in first stance a dispute for available energy. At an ampler scale, we could agree with Wagensberg (2002) in that progress of a corner of the universe implies the regression of another corner of the universe (Tyrtania 2009, p. 70)."

Therefore, inequality between social groups is a socially established mechanism of transference of entropy, which may generate more entropy if not counterweighed by more energy and materials from the environment or by socially constructed negentropic structures. It also means that a rise of social complexity is frequently the result of social inequity or, said differently, as inequality increased—a process apparently peaking in the present—more energy and materials have been consumed, increasing complexity. Why are capitalism and its industrial metabolic regime based on an increased inequality? Because they require transferring to their social or territorial surroundings the high entropy they generate. The price of the easy and abundant availability of exosomatic energy (fossil fuels) enjoyed by capitalism and industrial systems has been a high degree of social (inequity) and metabolic entropy.

Consequently, asymmetry is applicable to relations between groups or classes within a society and has direct consequences on their environment. For instance, a social group can push to the overexploitation of one or more resources if it accumulates or consumes a growing proportion of the energy and materials available to a society within its territory. In other words, the creation of internal order by a human group can have consequences on the environment of the society as a whole. An example makes this fact more graphical: in feudal or tributary societies based on organic metabolism, the increase in rent forced peasants to offer a portion of their crop, or other natural resource, in detrimental of the amount needed for self-consumption, and could push them to clear new plots, fish or hunt more individuals, and extract or gather a higher volume of products.

The expansion of the agricultural frontier in the absence of enough land forced to break the equilibrium between land uses, creating instability of social metabolism that could lead to overexploitation or to ecological collapse. Something similar happened with the extraction of lumber and firewood from temperate and tropical forests. In societies with organic metabolism, because it is a zero-sum game (Sieferle 2001, p. 27)—i.e., a game I that gains of one party are balanced by the losses of other parties *as exosomatic consumption of the affluent or dominant classes increases, less is the consumption of the remaining of society, even to the point of affecting its endosomatic consumption*. From the environmental perspective, social inequality is thus an *ecosystemic pathology* (Guzmán et al. 2001), a permanent source of metabolic instability and a powerful stimulant of socio-environmental conflict and transformation.

12.12 The Modalities of Social Inequity

In view of the asymmetrical relation, human societies have built dissipative structures of social nature (see below) based on cooperation and equity, without which social life and evolutionary success itself would be impossible, given that maximizing asymmetry would lead to disorder or thermodynamic equilibrium. Nevertheless, *free rider* behaviors are common among human groups that in order to maximize their order they increase entropy in the whole of society, those deprived of enough dissipative structures being the most damaged. This behavior is evident both in the struggle for resources (energy, materials, and information) as in the fight for avoiding the effects of entropic disorder (e.g., pollution). It is then when the conflict rises as a result of power relations (between individuals or groups) and control relations (of individuals or groups over the flows of energy and materials; Adams 1975). The dispute is expressed in three types of behavior shared with other species by humans.

The first of these behaviors is what ecologist call *competitive exclusion*, consistent in the appropriation by a group of humans of a territory, and thus of the use of its resources and services, excluding all other groups. For example, a local community can exclude others from appropriation of a common territory; or a noble arguing territorial right excludes numerous peasant families from the appropriation of a communal asset, a mechanism that was rather common during Feudalism. The situation can originate conflicts and subsequent protests from the excluded. The appropriation by means of legal norms such as property forms part of this type of inequity. A society in which most are excluded from the usufruct of natural resources and services harbors powerful motivations for social and environmental disequilibria.

The second behavior is *parasitism*, occurring when a social group manages to live at the expense of another group or their resources. Such behavior is typical of Neocolonialism that is made possible through unequal exchange (see below). In this form of parasitism the parasite group is interested in maintaining and reproducing such relation, hence the parasitized group. That implies that an essential part of such resources and services goes to the parasitized group for contributing to its sustenance. As we will see further on, this parasitic relation is made possible by the simultaneous exploitation of humans and nature.

The third behavior is *predation*, implying the violent (through conquest or invasion) or pacific (through market or diplomacy) pillage of environmental goods and services and the territory owned by a human group. In predation there is no interest in conserving the environmental resources or services, but simply to appropriate them irrespectively of the effects that has over the predated territory or over the societies settled in it. Examples of predation are slave capture, wood or mineral extraction from colonial forests, and spoils of war.

These three types of inequality have combined in varying intensities in each society along history. That has in turn required the organized and habitual use of violence by the dominant groups, the creation of social consensus regarding the normativity and institutions ensuring the unequal assignment of resources, and the generation of an ideology that dissimulates, justifies or legitimates such unequal assignation. Good examples of these consensuses are the social legitimacy of private property, the international trade agreements, or free commerce among countries. Another excellent example is seen in classical and neoclassical Economy denial of the existence of exploitation mechanisms in economic transactions between sectors or countries, or the assignation of purely monetary value to natural resources, which are usually below their real value.

12.13 Market, Money, and Entropy

Maybe the more generalized form of expression of these asymmetric relations that characterizes inequity within a given social metabolism is parasitism. The ways in which some human groups have created more order around them at the expense of other groups have varied, but can be grouped in two main behaviors: the extraction of economic surplus by coercive or compulsory means, or through mercantile mediations and trade. We are here interested in the biophysical part of this process, which feeds the dissipative structures enjoyed by a society through flows of energy, materials, and information having evident effects on the dynamics of social metabolism.

The extraction of surpluses can be made by means of payment, frequently forced, of a tribute either in money or in commodities, which has been the more generalized historical form of extraction of surplus by privileged or dominant groups. Another way of extraction that was theorized by Ricardo, and above all by Marx, is characteristic of capitalism: the appropriation by the owner of the production means of a part of the value created by human labor. It is the property of the means of production—in our case, the dissipative structures or fund elements—what orients the flows income towards the proprietor. But the extraction of surpluses is also made through the market. The market is an institution reflecting the social relations of power and in charge of exchanging goods and services.

From the biophysical point of view, the market is the institution that makes possible to transfer a given amount of energy, materials, and information from one society or group to another. Paraphrasing Tyrtania (2009, p. 218), the market enables the use of the main advantage derived from transportation possessed by humans: the capacity for putting to work larger amounts of energy and materials.

By this mechanism societies can escape local regulatory circuits, allowing them to raise their metabolic profiles above domestic extraction, thus compensating for resource deficits and waste surpluses. This signifies that the market, a created institution for regulating trade, plays a most relevant role in entropy regulation, thus being the main pacific mechanism for altering the societies' balance between internal and external entropies. A large part of the flows circulating in the market are of energy, materials, and wastes, but also of currency in its different monetary and financial manifestations. The market acts by distributing the access to neg-entropic flows in exchange for money.

Marx described the functioning of markets as the exchange of commodities (C) mediated by money (M): C-M-C. Following the same biophysical reasoning as above, money will then be used for acquiring the flows of energy, materials, and information needed for constructing and reproducing new dissipative structures in the society of destination. Likewise, following the rational of the German philosopher, the mercantile relation should also be: M-C-M'. Swanson et al. (1997) have shown that money is but a marker providing information about the future potential of external and internal entropy and negentropy: "The money-information simultaneously causes and measures fluxes at having economic value and being exchanged, automatically measure, on the attribute-specific exchange value, changes in negentropy and entropy as they control transfers of matter-energy forms [Swanson et al. 1997, p. 64]." In other words, money represents the future possibilities of order and the benefits obtained from trade are only a plus of future negentropy.

But we have already said that the relation between internal and external entropy is always unequal and the market is not free from such a characteristic. In fact, thanks to its inequality the market has historically been one more of the ways for extracting surplus: trade is an exchange of commodities in which one of the parties acquires a plus in future order. Alf Hornborg has explained the intimate mechanisms hiding behind the so called *unequal exchange* and reflecting not only such asymmetric relation among countries, but also the habitual mode of operation of trading relations: "How, then, can we posit the occurrence of 'unequal exchange'? This can be done by analytically demonstrating that there is, in very general terms, a systematic relation between (a) flows of productive potential, (b) flows of 'utility' or exchange value (price), and (c) economic growth and the accumulation of capital. But this relationship is not usefully expressed, as Marx or Odum would have it, that investment of labor or energy somehow translates into exchange value. Rather, there is a kind of *inverse* relation between productive potential and price that follows with logical necessity from the juxtaposition of the Second Law of Thermodynamics and the social institution of market exchange. We know that energy is not so much 'invested' as it is *dissipated* in a production process. Finished products must represent an increase in entropy compared to the resources from which they were produced; yet they must be priced higher. If we consider, longitudinally, the transformationof a given set of natural resources into an industrial product, Odum's measure of 'energy memory' must necessarily correlate positively with 'utility' or price, but objectively speaking, the amount of remaining available energy will be *negatively* correlated with price. As utility or price increases, there will be less of the original, available energy left. This means that industrial centers exporting high-utility commodities will automatically gain access to ever-greater amounts of available energy from their hinterlands. The more energy they have dissipated today, the more 'new' energy they will be able to buy—and dissipate—tomorrow (Hornborg 2011, p. 5)."

But further yet, this same relation can be formulated in opposite terms: *a commodity has a higher price as it accumulates more order or negentropy, and* vice versa. We are then in front of the possibility of coupling an economic and a physical assessment; or facing an innovative connection between economy and thermodynamics, such as visualized by Georgescu-Roegen. Both assumptions are complementary and allow for looking at the same phenomenon from two angles: commodities' higher relative price is the product of the accumulation of order during its fabrication due to lower dissipation of energy, mater, and information. Bot also, it can be seen as a relation of exploitation whenever the surplus entropy is transferred to the environment or territory of another Nation state. The high price obtained by selling commodities allows in turn buying more energy to continue to generate order from more energy, materials, and information. One of the keys of this unequal exchange lays on the investment of large amounts of energy and materials in fund elements and dissipative structures, which is made by the dominant country by means of high quality flows of information that create more order, an so on. In sum, the market has been one of the ways used for extracting the economic surpluses, either as commodities (e.g., the energy contained in agrarian products) or as money: both being flows guaranteeing future order.

In organic metabolic societies in which the transferring of entropy to the environment or to other territories was limited by the scarcity of fuels, the economic surplus (or if preferred, social exploitation) was preferentially concentrated on the appropriation by dominant groups of human labor and animal work through legal or political coercion. However, in societies with industrial metabolism the surplus is being extracted mainly by mercantile mediation (including the labor market, considered by Marx as the foundation of capitalistic exploitation) and, hence, on exchange of manufactures and natural resources. We will return to this in the next chapter.

12.14 Social Entropy

Few academics have applied the principles of thermodynamics to human societies, in particular from social sciences, which has been perceived as a sort of naturalist deviation or as a crude example of a reductionist current that must be avoided at any cost. Among the few exceptions to this rejection is Kenneth Bailey (1990, 1997a, 1997b, 2006a, 2006b), who elaborated a Theory of Social Entropy making attempts for its measurement through an indicator of the internal state of a society: the level of disorder as a temporal variable. Bailey's approach is also based on the statistical interpretation of entropy of Boltzmann (1896/1964). Statistical entropy may refer to the degree of disorder in the interaction and level of communication among social actors (Swanson et al. 1997, p. 61). Again according to Adams (1988), a broad concept of energy is applicable here, such as *capacity for performing work* or its physical equivalent *potential energy*, i.e., the capacity for modifying things. Asides from the physical flows already considered (physical entropy), this faculty is possessed by flows of information capable of creating dissipative structures that revert social entropy, a synonym of disorder (Boulding 1978).

Indeed, for Luhmann (1986, 1995), human beings (psychic systems) do not belong to social systems but to nature as biological entities, an animal species with special characteristics. Social systems are exclusively made up of communication and function by generating knowledge, i.e., symbols. Psychic systems do not communicate directly among them—because their nervous systems cannot interact directly—but through a social system and in doing that, the reproduce that social system. All communicative acts are inherently social and vice versa: there cannot be any communication outside of the social system. The components of the social system are precisely the communicative acts, given that systems are built from communication, which starts: "… by an alteration of the acoustic state of the atmosphere (Echevarria 1998, p. 143)," (language). In that context, entropy is defined as the uncertainty of communication and is in reality an inverse measurement of information. Information is, in turn and according to Shannon, the measure of the reduction in statistical entropy, i.e., of disorder (Mavrofides et al. 2011, p. 360).

Continuing with the analogy and adopting an isomorphic perspective regarding thermodynamic laws, social relations can be understood as *frictions* (a term used in tribology) between social actors, be these individuals or institutions. These frictions are, therefore, uncoordinated and uncooperative interactions having an effect on social organization. Lets keep in mind that entropy is equivalent to the heating or friction between molecules. The social relations established between individuals and between the different social subsystems in order to ensure social production and reproduction generate frictions or interactions that can either increase the level of social entropy or disorder, or on the contrary, generate negentropy or order. Therefore, when behaving as molecules being agitated or fractioned, human beings generate *social heat*, i.e., social entropy.

Morin (1977) said that, under certain circumstances, interactions become interrelations—as associations, unions, combinations, etc—and generate forms of social organization. In contrast, egotistic, *free rider* behaviors are opposite to cooperation and tend to generate conflictive frictions. Individuals, social groups, and Nation states can adopt a competitive behavior. Social disorder must not be identified with anarchy, but with the total absence of cooperation, which makes it very difficult to organize the activities for social and ecological reproduction, i.e., to maintain the flow of social metabolism.

The impossibility of cooperation is what makes societies' survival to be unviable, or in analogy with thermal death, it leads to *social death*. Therefore, societies in thermodynamic equilibrium are societies in which living in coexistence is impossible. Social disorder would result from social friction motivated by divergent interests, or by competition for scarce resources, i.e., from social conflicts. In that sense, the asymmetries in the allotment of goods and services are, and have always been powerful stimulators of conflictive frictions. The social energy that becomes degraded and cannot be reinvested in social work can translate to social protests, violent clashes, criminality, bureaucracy, and above all indicators, to exploitation and lack of cooperation. The structural character of social frictions or conflicts distinguishes this conception from a radical structuralist and functionalist perspective.

In this distinction, our proposal is put away from that of Bailey (1990), in which social entropy is the product of the dysfunction caused by the assignment of *macrosocial* mutable factors (population, territory, information, life standard, technology, and organization) to *microsocial* immutable characteristics of individuals (skin pigmentation, sex, and age). While Bailey characterization of social entropy is far away from functionalism, it shares with it forbiddance of the capacity to perform of individuals and groups, i.e., it omits the capacity for changing of individuals and social groups (neopoiesis). Said in other way, Bailey's conception places human beings in a condition of alienation. In any case, a conception more congruent with socioecological reality must rise from recognizing that human actions, either individual or collective, is capable of increasing total entropy of the social system, or of decreasing it producing order. *Entropy and negentropy are possible results of human actions and practices.*

Information inside systems has the function of establishing coordination and cooperation subsystems that reduce frictions, hence also entropy. Coordination can be achieved by means of multilevel cooperation and collective action, or by means of centralized, coercive, and unequal regulation. Through processing of information flows of exosomatic or cultural nature, societies build social dissipative structures having the function of generating order and avoiding the group entering a state of maximum entropy. There are social relations or interactions that create organizational or institutional forms that become sources of conflicting frictions, and thus of potential disorder, some examples among others are: unequal allotment of goods, services, and wastes; decoupling between population size and resource availability; reproductive failures; the patriarchal system of discrimination by the sex-gender subsystem. *The different forms of social inequity are the main source of conflictive friction and, therefore, of social entropy.*

In consequence, Prigogine's equation (Eq. 12.1) applies also to social systems: the change in social entropy of a given human social group is equal to the sum of its internal and external social entropy:

$$SS_t = SS_{in} + SS_{out} \quad (12.3)$$

where: SS_t = total social entropy; SS_{in} = internal social entropy; and SS_{out} = external social entropy.

For example, the units of social organization with proper coherence and identity (e.g., social classes) can increase their internal order by transferring their social entropy to other social classes or to society as a whole. The extraction by various means of the surplus entropy is but a way of obtaining future order at the expense of others. It is a form of *socio-thermodynamic exploitation*. Such has been the usual behavior of societies, according to Flannery and Marcus (2012) at least since the past 2,500 years, based on competitive social relations and the institutionalization of social inequity. Since then, conflicts and inequality seem to have amplified along history until the present. The same can be said about the asymmetric relation between dominant and dominated kingdoms or states, which becomes evident in industrial metabolism, countries and social classes showing marked differences in level of social inequity. On the contrary, the predominance of cooperative social relations and institutions favoring equity aids to decrease the internal social entropy, and often also the external social entropy. An evident relation can be established between social and physical entropy. Rising physical entropy has been one of the most recurred to ways for compensating the increase of social entropy, as we will see further below.

12.15 Conflict, Protest, and Metabolic Change

The unequal distribution of resources in broad sense, including material and immaterial resources, has historically been a permanent source of conflicts and social protest, and a powerful motor of the historical evolution of societies and their metabolic configuration. With the above statement we do not pretend to reassign social conflict the role of midwife of history. However, in accordance to the status we have seen social inequity has, we must recognize that many impulses of change in metabolic dynamic emerge from conflicts. The social protest emerging from conflicts is one more of the factors thrusting metabolic change and, according to the historical circumstances, even become the most decisive of all. The recognition of such sometimes crucial and always important role of social protest presents a head-on rejection of *cybernetic* currents of social metabolism that deprive socioecological change of any dimension of human collective action. Because of this, our proposal of social metabolism is based on the certainty that social and territorial conflicts are a potential source of socioecological change, and consequently, they must be taken into account when studying the evolutionary dynamics of social metabolism and the socioecological relations between different human groups.

A minimal biophysical approach to functionality of the conflict and the manifestations, particularly collective, emerging from it—going from social protest to war—forces to pay attention to two aspects of conflict: the metabolic impact of conflict, and the implicit or explicit motivations of change present in the metabolic *statu quo* that underlies the part of the protest which we may call to be of environmental nature.

Effectively, all social protests have a contradictory impact on their environment, in this case physical in the form of entropy or negentropy: it may produce order or disorder, increase or decrease social and physical entropy. For example, the Persian Gulf War had negative effects from the burning of oil wells, pollution of oceans, etc., not to mention the effects on civil population. Another example is in the positive conservation effect—despite conservation has not frequently been the explicit objective of protests—of communal defense of forests carried on for a long time by indigenous communities, removing forests from markets and avoiding their clearing. The struggle of peasant laborers in Spain and Italy during the middle twentieth century that, in an uncontested framework of capitalistic competition, caused an increase in labor costs due to a rise in wages, which indirectly and unintentionally favoring the mechanization of most agrarian tasks. This mechanization implied the use by agriculture of massive amounts of fossil fuel. There was, despite the environmental effects, a tangible improvement in the poor life conditions of peasants. Likewise, the protests of many European peasants occurred during the final decades of the twentieth century in demand for more marshland or removal of water from basins, have caused an increase in the expenditures of energy and materials, worsening unsustainability (increasing entropy).

Collective action is a basic component of the autopoietic, and even neopoietic capabilities of social systems. Its origin is frequently from conflicts caused by social entropy and is often guided by common objectives of the individuals participating in the conflict. Thus, from the standpoint of intentionality, collective action can promote the construction of dissipative structures for decreasing the internal entropy (disorder), also reducing or transferring the external entropy to the physical environment. The crucial factor is the character of dissipative structures (high or low entropy) built by the process of self-organization promoted by collective action. In that sense, and differently from conflict, social protest as a collective action cannot be understood as a part of disorder itself, but as a generator of negentropy. Consequently, a protest rising from a social conflict and guided by an agenda of changing the dominant metabolic regime *may* give rise from its initial stages to the gestation of dissipative—negentropic—structures that decrease internal disorder and, simultaneously, also the consumption of energy and materials, so that the transference of entropy to the environment—i.e., the external entropy—is minimized. Disorder through social protest (high quality, low entropy information) can generate a new, self-organized and coherent emergent order.

Of particular importance to the purposes of this book are the conflicts centered in the unequal allotment of entropy in physical-biological or metabolic terms. We already saw the sources and mechanisms by which this asymmetric distribution of entropy operates, and which often give place to conflicts that we may call *environmental conflicts*, and also *metabolic conflicts*. A retrospective view reveals that, indeed, these conflicts had a larger relevance than that usually given by history books, conditioning the relation between societies with their natural environment. The predominance in social sciences of conflicts being interpreted in terms of class or political confrontation has relegated environmental conflicts to oblivion.

Environmental conflicts have their origin in access, management, and distribution of natural resources and services that are perceived as essential for the reproduction of a human group, or in the beneficial or harmful effects these issues produce in human groups. Conflicts, as we have seen, result from the unequal distribution of flows of energy and materials, and the wastes caused by their use. They generate within the five metabolic processes themselves, or as a consequence of the impacts of each one on the social system. Unequal exchange produced not only among nations, regions, territories, but also among social groups (e.g., farmers-agroindustry) is a typical example of the structural foundation of metabolic conflict. What that means is wars as conflicts resulting from the expansion of a given empire, disputes about common resources, the fights of peasants and indigenous communities against the colonial exploitation of certain resources, etc., can have an environmental meaning—although not necessarily so. Environmental conflict is, thus, permanent, structural, and consubstantial with the functioning and evolution of societies.

Thus, environmental protest has effects on the configuration and dynamic of social metabolism, because of which it must be preferentially studied. Conflicts have the capacity for balancing or further unbalancing the internal and external entropies of a social group. Usually, protest arising from an environmental conflict—especially ecologist protests—aid in the internalization of environmental costs and, while they do not achieve an instantaneous change of social metabolism, they ameliorate their negative effects on the environment and widen the road towards the metabolic transformation. They thus function as reducers of internal entropy of the system, i.e., they reduce the amount of entropic flow that is transferred to the physical-biological environment. In that sense, environmental protest can generate social actions promoting a change in the structure and composition of a more sustainable social metabolism. But also they can promote the appropriation and use of more energy and materials, raising the external entropy to the level of total entropy, as is the case in most modern armed conflicts between Nation states or their coalitions.

This contradictory result of environmental protest advises us to discern between its implicit or explicit objectives to determine if they promote sustainability or the opposite. In that context, reproductive and distributive environmental protests must be distinguished based on if the configuration of social metabolism is or is not compromised. Those conflicts centered in the dispute for resources, the ways in which these are managed, or the externalities produced by their use, must be considered as environmental conflicts, despite that none of the involved social stakeholders manifest an explicit intention of sustainability, or even if the explicit goal differs widely from sustainability. In a similar direction, the North American specialized literature has introduced the term *environmental justice* (see Dorsey 1997; Faber 1988).

Nonetheless, in some of these environmental conflicts there is an explicit intentionality for conserving resources, cases in which they become *environmentalist* conflicts (Table 12.1). Environmentalist conflicts are a specific *variety* of environmental conflicts in which one of the parties has the intention of conserving

Table 12.1 Typology of environmental conflicts

Denomination	Type of conflict	Social metabolism	Logic/Discourse
Environmental	Distributive	Intrametabolic	Not claiming for sustainability/Multiple languages
Environmentalist	Reproductive	Intermetabolic	Claiming sustainability/Multiple languages
Ecologist	Reproductive	Intermetabolic	Claiming sustainability/Explicit ecologist discourse

Source Soto Fernández et al. (2007)

resources in a sustainable way, which is an expression of a conscious decision, despite the language used is different from that used by current the ecologist movement.

According to Guha and Martínez-Alier (1997), there are ecologist protests, both present and past, in communities that, independently of possessing or not an explicit ecologist ideology, involve in a defense of environmental conditions or of the egalitarian access and distribution of the natural resources to which their existence is linked to. These authors have called these protests the *environmentalism of the poor* in opposition to Inglehart's (1977) interpretation, according to which environmentalism is proper of societies that have reached a certain degree of wellbeing and that can thus afford to worry about post-materialistic values such as those regarding the environment.

In that sense, the distinction made by Guha and Gadgil (1993) between *intramodal* and *intermodal* conflicts may be useful. The example of peasant protest can make this distinction clearer. When the organic metabolic regime makes contact with the industrial metabolic regime, which is organized around very different economic, ecological, and social principles, which they attempt to impose, intermodal conflicts rise between both regimes.

In these conditions, for example, the objective of peasant protest is defending their mode of metabolic organization with nature, confronting the attempts of subordination or transformationpromoted by the industrial mode of using nature. A paradigmatic example is the defense of communal assets as a vindication played a protagonist role in most peasant protests during the nineteenth and twentieth centuries. Since what is questioned is the mode of use of resources, these conflicts are essentially reproductive, regardless that distributive dimensions may also occur. Because of that, these conflicts are of environmentalist nature.

Contrariwise, when peasants and household farmers dispute against other social groups or among themselves for the allotment of natural resources, transformed goods, or services within the same metabolic regime, the protest can be considered to be the product of an intramodal conflict. A typical example of this is the dispute for the volume and distribution of water among a community of irrigation farmers. Also within this type of conflicts are the frictions among peasant communities during the eighteenth and nineteenth centuries for the assignation of a communal territory in dispute, for establishing boundaries, or for appropriation quotas in common grassland. In these cases the mode of use of resources is not the main question. In this tenor, many territorial conflicts among countries, regions and even communities happened during the past centuries.

Nevertheless, some believe that disputes between peasants and feudal lords for appropriation of communal forests in the Modern Age Europe were only another manifestation of class struggle. Typifying these conflicts as environmental would simply be shift of terms amidst the heat of historiographical fad. However, the nature of environmental and class conflicts has been and continues to be different, although in certain circumstances and moments in the past many environmental and even environmentalist conflicts were indeed conflicts between classes as conventionally understood.

Indeed, in some societies the conflicts for resources become the main protagonist of social conflict and the fundamental reason for confrontation between social groups. Social conflicts occurring on agrarian societies frequently are expressed as disputes for resources or environment in general (land, water, forests, hunting preys, etc.), among other things, because subsistence and the amount of surpluses are directly linked to appropriation of natural resources. We may thus say that class conflicts in societies with organic metabolism are frequently also environmental conflicts, in as much as subsistence is linked to appropriation, and even the possibility of using human labor depends on the access to natural resources.

To the contrary, in industrial societies in which fossil fuel have made subsistence to cease depending on local natural resources, or uses these in a limited amount, class conflicts have expressed through vindication of salary or improvement of laboring conditions. In industrial societies the material part of social functioning has been veiled by money and hidden behind technology such that environmental conflicts seem to loose their relevance. It was the ecological crisis and the growing difficulty of current societies for concealing their modes of life what has made environmental conflicts to resurge at the center of the social scene.

Translated to the thermodynamic reasoning we have adopted, we can say that environmental protests focus in the distribution of flows of energy, materials, and information, thus being distributive protests. For example, disputes about access to natural resources between social groups (lords and serfs or peasants for communal appropriation), between communities (disputes for boundaries between villages), and between States (conflicts, including war, among States for access and usufruct of one or more resources; or protest rising from so called *not in my backyard* (*nimby*) conflicts caused by social consequences of relocation of wastes). On the contrary, environmentalist protests are reproductive in as much as they question the configuration of dissipative structures that, as we saw, determine the flows of energy, materials, and information, and in last instance, the magnitude of social metabolism.

The distinction between environmental and environmentalist protests does not I any way imply a rigid differentiation, but a merely analytical distinction. Social protest is necessarily autopoietic, i.e., it can or not increase its social relevance, and even alter the arrangement of the components that drive metabolism as a whole, producing changes and generating evolutionary processes. It is not rare that a social conflict (apparently unlinked from environmental issues or having a low significance to them) may originate an environmental or environmentalist protest, i.e., that an environmental protest ends up becoming an environmentalist protest, or vice versa.

12.16 Political Entropy

We have defined society as a self-organized system based on the assemblage of biophysical, and communicational or symbolic structures (Fischer-Kowalski et al. 1999, 2007). Social metabolism serves to "maintain and reproduce these biophysical compartments within a certain territory and is organized by society through its communication systems such as the economy (Wiedenhofer et al. 2013, p. 183)."

The effects generated by social and metabolic entropy, i.e., the type of disorder they trigger, differentiate them. Metabolic entropy is expressed as the ecological crisis and its effects are of physical nature. However, social entropy expresses as social conflict and destructuration (confrontations, inequity, competition, absence of cooperation, criminality, poverty). But there is an evident trade off between social and metabolic entropies that, from our standpoint, are useful for explaining the evolutionary dynamic of social systems, and in particular of its metabolism with nature. Social entropy translates (or rather *transduces*, a term from neurology for defining communication mechanisms that convert environmental signals into neurophysiological states) the level of metabolic entropy, and in turn, social entropy produces a certain level of metabolic entropy. Thus, there is a bidirectional correlation between both types of entropy, which can be formalized by using the same Eq. 12.1 from Prigogine used above:

$$SEE_t = (SE_in + ME_in) + (SE_out + ME_out) \tag{12.4}$$

where: SEE_t = total Socio-ecological Entropy, SE_{in} = internal Social Entropy, ME_{in} = internal Metabolic Entropy, SE_{out} = external Social Entropy, and ME_{out} = external Metabolic Entropy.

Inequity caused by situations that tend to increase social entropy, e.g., generating poverty or a sense of scarcity. Usually, societies compensate such increment by importing a certain amount of energy and materials from the environment for generating order. For example, the increase during the past two centuries of exosomatic consumption has been the answer of the system to the growing inequalities threatening to rise social entropy to unsustainable levels, thus generating metabolic energy and, eventually, ecological crisis itself. In this interpretation of social entropy, exosomatic consumption turns into an instrument compensating the maintenance of an unfair social system through the construction and installation of new, more costly dissipative structures, reducing internal entropy and in parallel rising external entropy, i.e., transferring entropy to the environment.

But this bidirectional correlation is indirect and mediated by regulatory and institutional mechanisms, which are also subject to the principle of entropy (political or institutional entropy). The inefficiency in social allotment of resources generates a reaction of tension (conflict) and the associated information generates negentropic structures (institutions), which are but filters, sensors, or institutional programmers responsible for detecting and readapting metabolic entropy by means of social entropy, or vice versa. In the socioecological theory we propose, dissipative structures are therefore a product of self-reflexive regulation of social entropy through institutional regulators. In this way, entropy would explain the causes, functions, and mechanisms that give origin and meaning to the existence of forms of power (regulation) from the micro to the macro (State) level political power. Family, community, State, are examples of negentropic structures as any efficient form of social regulation. In consequence, social institutions in the broadest sense—we understand institutions as any stable social practice or relation subjected to rules, although these may be informal—and also in the narrowest sense of state public institutions, must be seen as social socioecological relations having the task of regulating both social and metabolic entropies. In other terms, political power manages socioenvironmental entropy by means of generating dissipative structures in three realms: metabolic, political, and social.

An entropic theory of regulatory institutions claims that there is an isomorphism between these three dimensions of entropy (metabolic, political, and social; Fig. 12.1), such that more social entropy (inequity) is corresponded by more metabolic entropy. Therefore, the function of political regulators is to synchronize social metabolism at its two extremes (biosphere and society) knowing that the same regulatory function implies an entropic cost that is inherent to regulation, hence regulating the entropy generated by regulation itself. This confers a high degree of complexity and self-reflexivity to political institutions that cannot be substituted by simple self-management mechanisms.

Political power, regulator and producer of information and coordination, has then a negentropic function. The paradox lies in that this negentropic function generates its own entropy. The positive equilibrium between negentropy and entropy mark the limits of validity and success of a determined form of political power. Political power reduces entropy by means of fomenting coordination between the different stakeholders (individuals and institutions) involved in social metabolism. Cooperation is in itself the less entropic forms coordination (Axelrod 1984). The democratic State and society represents a form of cooperative coordination that can occur in societies with high demographic and technological complexities.

Until the appearance of the first symptoms of the ecological crisis, society decreased the levels of both types of entropy—social and political—by transferring it to the biophysical environment: hence increasing metabolic entropy:

$$\Delta \mathrm{PS} + \Delta \mathrm{SS} \rightarrow \Delta \mathrm{MS} \tag{12.5}$$

where: ΔPE = increase in political entropy, ΔSE = increase in social entropy, and ΔME = increase in metabolic entropy.

But the environment of all societies, i.e., the natural part formed by the biosphere, atmosphere, hydrosphere, etc., is a closed system receiving energy only

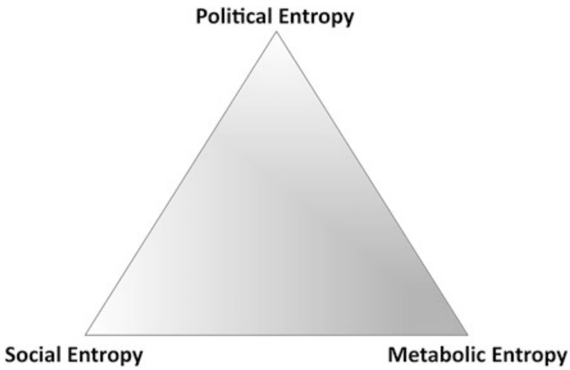

Fig. 12.1 The triangle of entropy. See text

from the outside, not an open system exchanging energy and material with its surroundings. If human society were an isolated system it would have long ago perished with the current growth model; but if it were an open system (hence ME were nearly infinite), there would be a reasonable hope of Eq. 12.5 being still valid ($\Delta PS + \Delta SS \rightarrow \Delta MS \leftrightarrow MS = \infty$). Even so, in an open system the binomial ΔPE and ΔSE could collapse by the increase of PS (conflicts, violence, war) and of SS (disorganization and non-cooperation). Therefore, political power has to manage political entropy (distribution of power and status), social entropy (distribution of resources), and metabolic entropy (exchange between society and nature), and at the same time, the interactions between all three entropies. From the latter perspective, the liberal myth of the radical separation between political society and civil society is further unjustifiable.

The function of political institutions is to control and minimize metabolic and social entropies by means of flows of information, but also by means of managing its own internal entropy (transaction costs, bureaucracy, political oligarchies, centralized decisions, war, etc.). The entropic propensity of political institutions (Niskanen theorem) is an unavoidable fare institutions need to pay due to its nature of negentropic institutions in the metabolic and social realms. In that sense, it is important to distinguish between the operative entropy of political regulators (the highly entropic institutional designs such as, for example, neoclassical macroeconomic indicators as GDP or the use of market prices as a unique indicator of value) and the internal, functional entropy of the political regulator that is translated in centralization of decisions, high cost of transactions, bureaucracy, etc. The political institutions reduce social and metabolic entropy by increasing their internal entropy. That makes political proposals of *minimal statism* or deregulation to be dangerous (entropic). Apparently, these proposals can have certain popular or intuitive success because they alleviate us from the strong entropic propensity of the State and regulation institutions, but the risk is still greater: increasing social and metabolic entropy.

In the thermodynamic sense of the human species, social energy being but its work potential is based on our *eusocial* evolutionary nature (in Wilson's (1971) terms). This characteristic is not exclusively human but common to all species capable of forming societies, representing a qualitative leap in the evolution of life in the planet. Cooperation is thus a structural constant of our evolutionary history. A different mater is analyzing how cooperative strategies turn out being iteratively the most efficient, as demonstrated by evolutionary game theory.

Regulators (institutional designs) favoring cooperation are much more efficient than those favoring non-cooperation. In terms of tribology cooperation decrease the ware caused by increased frictions (inherent to complexity) by means of the design of such frictions (institutional relations) and of their lubrication (motivation) in stimuli and penalizations. Friction is the result of a conflict, or better, friction is conflict: a relation of competition and confrontation between two individuals or groups. Frictions (conflicts) can be regulated cooperatively or be deregulated non-cooperatively. The underlying wear in non-cooperative deregulation is much more sever and the motivation much less than in cooperative regulation. Observe the difference between the ordered evacuation of a multitude from inside a stadium guided by rules, signals, and counting with accessible exit spaces, and the same multitude evacuating the stadium by means of chaotic movements of one against the other. The amount of frictions (physical contacts) and the amount of wear decrease in an ordered versus a chaotic evacuation.

An example of misunderstanding of how incoordination leads to high levels of metabolic entropy is in the so-called *tragedy of the commons* (Hardin 1968), in which the responsibility of grassland is assigned to the community owning it. Certainly, an aggregated set of individual, non-coordinated behaviors leads to an unsustainable level of exploitation of any resource, but as shown by Ostrom (2011), what leads to overexploitation is the lack of communal management and not vice versa. Individual, non-coordinated action is an example of maximum friction generating an increase of metabolic entropy, but also, in also in the long-term to scarcity and inequity, to the increase of social entropy. The granting of property rights (an alternative for market proposed by Hardin) or the centralized management of an external, coercive regulator (statification alternative) are possible answers to the problem of individual incoordination, but as shown by Ostrom (2011), they carry their own dose of entropy from incentivizing competition and inequity. Communal, cooperative management of resources is the form of coordination that generates less social, political, and metabolic entropy because it minimizes social frictions, and with that, disincentives non-cooperative behaviors.

References

Adams RN (1975) Energy and structure. a theory of social power. University of Texas Press, Austin

Adams RN (1988) The eight day: social evolution as the self-organization of energy. University of Texas Press, Austin

Adams RN (2001) El octavo día. Universidad Autónoma Metropolitana, México

Arnold-Cathalifaud M (2010) Constructivismo Sociopoiético. Revista del Magíster en Análisis Sistémico Aplicado a la Sociedad 23:1–8

Axelrod R (1984) The Evolution of Cooperation. Basic Books, USA
Bailey K (2006a) Living systems theory and social entropy theory. Systems Research and Behavioral Science 23:291–300
Bailey KD (1990) Theory of Social Entropy. SUNNY Press, USA
Bailey KD (1997a) The autopiesis of social systems: Assessing Lymahnn's Theory of self reference. Systems Research and Behavioral Science14:83–100
Bailey KD (1997b) System entropy analysis. Kybernetes 26(6/7):674–688
Bailey KD (2006a) Sociocybernetics and social entropy theory. Kybernetes 35(3/4):375–384
Bataille G (1989) The Accursed Share: An Essay on General Economy. Zone Books, New York
Bateson G (1993) Espíritu y naturaleza. Amorrortu, Buenos Aires
Beauregard OC (1961) Sur l'equivalence Entre Information et Entropie. Sciences 11:51–58
Ben-Naim A (2007) Entropy Demystified. World Scientific Publishing Co. Pte. Led., London
Boltzmann L (1896/1964). Lectures on gas theory. University of California Press, Berkeley
Boulding KE (1978) Ecodynamics: A New Theory of Societal Evolution. Sage Publications, Beverley Hills
Cavalli-Sforza LL (1996) Genes, Peoples, and Languages. University of California Press, USA
Clausius R (1879) The Mechanical Theory of Heat. Macmillan and Co., London
Dockendorff C (2012) Veinticinco años en pos de un nuevo paradigma social: lecciones aprendidas. Polis 33:2–20
Dorsey M (1997) Environmental justice: issues of racism, poverty and the environment. Capital. Nat Social 8(3):139–146
Echevarria C (1998) A three-factor agricultural production function: the case of Canada. Int Econ J 2:63–76
Faber D (1988) The Struggle for Ecological Democracy: Environmental Justice Movements in the United States. Guilford Press, New York
Fischer-Kowalski M (1997) Society's Metabolism. On the Childhood and Adolescence of a Rising Conceptual Star. In: Redclift M, Woodgate G (eds), The International Handbook of Environmental Sociology. Cheltenham: Edward Elga, London, pp 119–137
Fischer-Kowalski M, Haberl H (2007) Socioecological transitions and global change: trajectories of social metabolism and land use. Edward Elgar, Cheltenham
Fischer-Kowalski M, Weisz H (1999) Society as a hybrid between material and symbolic realms. toward a theoretical framework of society-nature interaction. Adv Hum Ecol 8:215–251
Flannery K, Marcus J (2012) The Creation of Inequality: How Our Prehistoric Ancestors Set the Stage for Monarchy, Slavery, and Empire. Harvard University Press, USA
Georgescu-Roegen N (1971) The entropy law and the economic process. Harvard University Press, Cambridge
Georgescu-Roegen N (1977) Matter matters, too. In: Wilson KD (ed) Prospects for growth: expectations for the future. Praeger, New York, pp 203–313
Georgescu-Roegen N (1975) Energy and the economic myths. South Econ J 41(3):347–368
Georgescu-Roegen N (1996) La ley de la entropía y el proceso económico. Fundación Argentaria, Madrid
Giampietro M, Allen TFH, Mayumi K (2006) The epistemological predicament associated with purposive quantitative analysis. Ecol Complex 3:307–327
Giampietro M, Mayumi K, Ramos-Martin J (2008a) Multi-scale integrated analysis of societal and ecosystem metabolism (MUSIASEM). An outline of rationale and theory. Document de Treball. Departament d'Economia Aplicada
Giampietro M, Mayumi K, Ramos-Martin J (2008b) Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): theoretical concepts and basic rationale. Energy 34:313–322
Giampietro M, Mayumi K, Sorman AH (2011) The metabolic pattern of societies: where economists fall short. Routledge, London
Gintis H (2009) The bounds of reason: game theory and the unification of the behavioral sciences. Princeton University Press, Princeton

Glansdorff P, Prigogine I (1971) Thermodinamic theory of structure, stability and fluctuations. Wiley Interscience, New York

Guha R, Martínez-Alier J (1997) Varieties of environmentalism: essays North and South. Earthscan, London

Guha R, Gadgil M (1993) Los hábitats en la historia de la humanidad. Ayer 43:49–110

Guzmán Casado G, González de Molina M, Sevilla Guzmán E (2001) Introducción a la agroecología como desarrollo rural sostenible. Mundiprensa, Madrid

Hacyan S (2004) Física y metafísica del espacio y el tiempo: la filosofía en el laboratorio. FCE, México

Haimovici A, Tagliazucchi E, Balenzuela P, Chialvo DR (2013) Brain organization into resting state networks emerges at criticality on a model of the human connectome. Phys Rev Lett 110:178101

Hardin G (1968) The tragedy of the commons. Science 162(3859):1243–1248

Hornborg A (2011) A lucid assessment of uneven development as a result of the unequal exchange of time and space. USA: Lund University centre of excellence for integration of social and natural dimensions of sustainability

Inglehart R (1977) The Silent revolution: Changing Values and Political Styles among Western Publics. Princeton University Press, New Jersey

Kay JJ, Regier AH, Boyle M, Francis G (1999) An ecosystem approach for sustainability: addressing the challenge for complexity. Futures 31:721–742

Lotka A (1956) Elements of mathematical biology. Dover Publication, New York

Lotka Alfred (1925) Elements of physical biology. Dover, Nueva York

Lovelock J, Bateson G, Margulis L et al (1992) Gaia. Implicaciones de la nueva biología. Kairós, Barcelona

Luhmann N (1984) Soziale Systeme: Grundriss einer allgemeine theorie. Suhrkamp, Frankfurt

Luhmann N (1986) The Autopoiesis of Social Systems. In Geyer F, Zeuwen JV (eds), Sociocybernetic Paradoxes: Observation, Control and Evolution of Self-Steering Systems. Sage, London, 172–192

Luhmann N (1995) Social Systems. Stanford University Press, Stanford

Luhmann N (1998) Complejidad y modernidad. De la unidad a la diferencia. Editorial Trotta, España

Margalef R (1980) La biosfera. Entre la termodinámica y el juego. Kairós, Barcelona

Margalef R (1995) Aplicacions del caos determinsita en ecologia In: Flos J (ed), Ordre i caos en ecologia. Publicacions Universitat de Barcelona, Barcelona, pp 171–184

Marten GG (2001) Human ecology: basic concepts for sustainable development. Earthscan Publications, London

Martínez-Alier J, Munda G, O'Neill J (1998) Weak comparability of values as a foundation for ecological economics. Ecol Econ 26:277–286

Maturana HR, Varela FJ (1980) Autopoiesis and cognition. the realization of the living. Boston studies in the philosophy and history of science. Reidel Publishing Company, Boston

Mavrofides T, Kameas A, Papageorgiou D, Los A (2011) On the entropy of social systems: a revision of the concepts of entropy and energy in the social context systems research and behavioral. Science 28:353–368

Morin E (1977) El método, I: La naturaleza de la naturaleza. Cátedra, Madrid

Nicolis G, Prigogine I (1977) Self-organization in nonequilibrium systems. Wiley, New York

Ostrom E (2011) El gobierno de los bienes comunes. FCE, México

Pattee HH (1995) Evolving self-reference: matter, symbols, and semantic closure. Commun Cogn Artif Intell 12:9–28

Prigogine I (1947) Etude Thermodynamique des Phenomenes Irreversibles. Liège, Paris

Prigogine I (1955) Thermodynamics of irreversible processes and fluctuations. Temperature 2:215–232

Prigogine I (1962) Non-equilibrium statistical mechanics. Interscience, New York

Prigogine I (1987) Exploring complexity. Eur J Oper Res 30:97–103

Prigogine I (1983) Tan sólo una ilusión? Una exploración del caos al orden. Tusquets, Barcelona

Prigogine Y, Stengers I (1979) La nueva alianza. Metamorfosis de la ciencia. Alianza Editorial, Madrid
Ramos-Martin J (2003) Empiricism in ecological economics: a perspective from complex systems theory. Ecol Econ 46:387–398
Ramos-Martin J (2012) Economía Biofísica. Investigación y Ciencia, pp 68–75
Rosen R (1985) Anticipatory systems: philosophical, mathematical and methodological foundations. Pergamon Press, New York
Ruiz Ballesteros E (2013) Socioecosistemas y resiliencia socio-ecológica. Una aproximación Compleja al medio ambiente. In: Ruiz Ballesteros E, Solana Ruiz JL (eds) Complejidad y Ciencias Sociales. Sevilla, UNIA, pp 295–331
Sahlins M (1960) Evolution and culture. University of Michigan, Michigan
Schandl H, Grünbühel CM, Haberl H, Weisz H (2002) Handbook of physical accounting. measuring bio-physical dimensions of socio-economic activities MFA—EFA—HANPP. Social Ecology Working Paper 73, Vienna
Schrodinger E (1944) What is Life? The Physical Aspect of the Living Cell. Cambride University Press, USA
Sieferle RP (2001) The Subterranean Forest. Energy Systems and the Industrial Revolution. The White Horse Press, Cambridge
Sieferle RP (2011) Cultural evolution and social metabolism. Hum Geogr 93(4):315–324
Slesser M (1978) Energy in the economy. Macmillan, London
Steward JH (1955) Theory of culture change: the methodology of multilinear evolution. Illinois University Press, Urbana
Soto Fernández D, Herrera, González de Molina A, González de Molina M, Ortega Santos A (2007) La protesta campesina como protestaambiental, Siglos XVIII-XX. Historia Agraria 42:277–301
Swanson GA, Bailey KD, Miller JG (1997) Entropy, social entropy and money: a living systems theory perspective. Syst Res Behav Sci 14(1):45–65
Tainter JA (2011) Energy, complexity, and sustainability: a historical perspective. Environ Innovation Societal Trans 1:89–95
Tainter JA (1988) The collapse of complex societies. Cambridge University Press, Cambridge
Tyrtania L (2008) La indeterminación entrópica Notas sobre disipación de energía, evolución y complejidad. Desacatos 28:41–68
Tyrtania L (2009) Evolución y sociedad. Termodinámica de la supervivencia para una sociedad a escala humana. Universidad Autónoma Metropolitana, México
Ulanowicz RE (1986) Growth and development: ecosystem phenomenology. Springer, New York
Wagensberg J (1985) Ideas sobre la complejidad del mundo. Tusquets, Barcelona
Wagensberg J (2002) Si la naturaleza es la respuesta, ¿cuál era la pregunta?. Tusquets, Barcelona
White L (1964) La ciencia de la cultura. Paidós, Buenos Aires
Wiedenhofer D, Rovenskaya E, Haas W et al. (2013) Is there a 1970s syndrome? Analyzing structural breaks in the metabolism of industrialeconomies. Energy Procedia 40:182–191
Wilson EO (1971) The insect societies. Belknap Press of Harvard University Press, Cambridge
Wilson EO (2012) The Social Conquest of the Earth. Liverigth Publishing Co., New York

Chapter 13
Metabolic Transitions: A Theory of Socioecological Transformation

13.1 Introduction

In the preceding chapters we made a detailed description of the concept of social metabolism which we synthesized in a basic model, we distinguished three main types of social metabolism along history, and we visualized a conceptual framework having as theoretical axis the concepts of entropy, evolution, sustainability, and cooperation (Chap. 12). What follows is to build a theory of transformations, which based on what we have said, should be classified as socioecological, given that the transformations derive from the interplay of social and natural mutations. The task is quite ambitious and even premature because, until the present, and due to the novelty of the approach, there is no full depth analysis of the empirical data available, nor enough field studies of metabolic transformations have been made—either for time periods or eras, or for regions and countries—to be compared in order to discover patterns or regularities.

But despite these limitations, some useful provisional working hypotheses, clues, and orientations can be advanced to serve as the foundations of a theory as that we anticipated. The following sections offer a general panoramic bird's view of the main trends and patterns of change through history. With comparative purposes, other approaches prior to that of social metabolism are also reviewed.

13.2 Societary Configurations

One of the central tasks of history is to identify societary archetypes (or prototypes) throughout the dilated historical process, i.e., to define the major social systems by a number of features. Among the wide spectrum of available interpretations of the historical transformation of human societies, two of them built from different intellectual traditions are noteworthy: (i) those developed by archaeologists and anthropologist through the confluence of interpretation of cultural ecology and systems theory; and (ii) those of historians, anthropologists,

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political scientists, and economists deriving from the theoretical and empirical development of the concept of mode of production proposed by K. Marx in the nineteenth century. The concept of mode of production has in a way acted as the fundamental theoretical assumption of the present center-periphery model (Frank 1967), the World-Systems theory (Wallerstein 1974–1980), and the theory named second contradiction of capitalism by O'Connor (1988; Benton 1996).

Flannery (1972), in what is considered as a seminal contribution, made a typology of the different states along history of human society containing four basic societarian configurations to which all forms adopted through time by human societies belong: the **band**, the **tribe**, the **chiefdom**, and the **state**. Each one of these types appeared in different historical moments, have well defined cultural characteristics, and have particular systems for social control and decision-making.

Flannery's highly coherent typology—its recognition confronting little or no mayor disagreement—defines four clearly distinct stages in the sequence of the increasingly complex civilizing process embodied by human history. But also we must arrive to an admissible explanation of the mechanisms governing such qualitative leaps. Flannery (1972) attempts to understand the main observed trends for complexity by adoption of the principles of complex systems theory (i.e. cybernetics): segregation (the level of diversification and specialization of component systems), centralization (the level of interactions occurring between subsystems and of feedback connections with superior social decision-making levels), evolutionary mechanisms (promotion, and linearization), and systemic pathologies. Based on these principles applied by several classes of social institutions, Flannery (1972, p. 409) provides 15 rules explaining the rise, growth, maturation, and collapse of states, assuming that: "*…the mechanisms and processes are universal, not merely in human society but in the evolution of complex systems in general*".

In a like tone, Adams (1975) dedicated a whole book (Energy and Structure: a theory of social power) to explain history of human societies from the concepts of control—over nature and more specifically, over energy flows—and power—of some social sectors over other social sectors—exerted through technology and labor organization. Inspired by previous works of the anthropologist Leslie White and of the ecologist Howard T. Odum, Adam tried to explain the growing complexity of human societies by reconfiguring Flannery's (1972) civilization types, assuming as a central thesis that all increment or transformation of energy flows implies a greater control over environment, and a further exercise of social power.

A similar idea, but with lower theoretical pretensions, was retaken and developed one and two decades later in the books of Debeir et al. (1986)—Les servitudes de la puissance—and of Smil (1994)—Energy in World History. Both works make a fascinating and detailed review of human use of energy through history revealing in detail the role of technological innovations as propellants of qualitative leaps in sociopolitical structures. Both books also explicitly recognize the complex interaction occurring between nature and the social and economic (or productive) dimensions. Particularly relevant in these accounts is the relevance of the increased energetic capacity of devices created along the past 300 years, and how this radically modified the offer of energy sources. The invention of the first hydraulic wheels driven by water and of windmills impelled by the wind, was overpowered by steam turbines, initially powered by combustion of firewood and later of coal, which eventually were displaced by internal combustion engines: each of these modalities modified to a certain extent the metabolic processes of appropriation, transformation, and transport of goods extracted from nature.

The second trend of interpretations of human society transformations vortexes around the concept of mode of production, a concept defined by Marx (1867) as the confluence of relations between the production agents themselves and with nature: such relations define society seen as its economic structure. Marx (1971) adds that this confluence appears as a particular form of property, it actually is due to a particular mode of production, which appears both as relations between individuals and as their daily behavior towards nature.

It was precisely the science of modes of production, as Dowidar (1978) called political economy, which assumed the task of developing—not without difficulty—the concept of mode of production introduced by Marx in the nineteenth century in his analysis of capitalism. The concept allows for recognizing the forms adopted by the economic structures along history, which through their confrontation, combination, and articulation give place to a series of social structures. Fossaert (1977, p. 45) characterizes modes of production in general as:

> …a dual relation between the owners of the means of production and the laborers that drive those means. Dual relation, that is unfolded in two dialectically linked aspects: on one part, a relation of property determining both the modalities according to which the means of production can be put in action and the fate of what is produced; on the other, a relation of real appropriation, that is, a relation of production that ensures the transformationof natural objects to satisfy the needs of humans grouped in society. In sum: a relation of property and a relation of production. Relations which connect two generally different categories of actors: the laborer, that is, the general category of human beings providing the work force by which the means of production are activated; and the non-laborers, that is, the general category of those who appropriate the surplus and that, in order to do so, have to either be the owners of the means of production, or must be positioned as beneficiaries of the redistribution of the social product. Finally, in the center of the system, natural objects more or less transformed by previous labor, objects that are commonly identified with the means of production despite they are no more than material cover.

The concept of mode of production produced a debate of such magnitude that it became buried under an avalanche of divergent interpretations, nevertheless the concept continues to be highly valuable for its visible closeness to the concept of social metabolism. Consequently, a careful and in depth demarcation must be established between both concepts For that, the original spirit of the concept of mode of production that was gradually modified until becoming mostly an economic concept, and in which nature is a ghostly entity—thus betraying its original interdisciplinary character—must be rescued. Fossaert (1977) was a key writer in this duty of rescue and revaluation, achieving the construction of a general theory of modes of production (Fig. 13.1) founded upon a precise definition of the variables involved in the concept and their possible combinations, which allowed him for recognizing fifteen different modalities occurring throughout history.

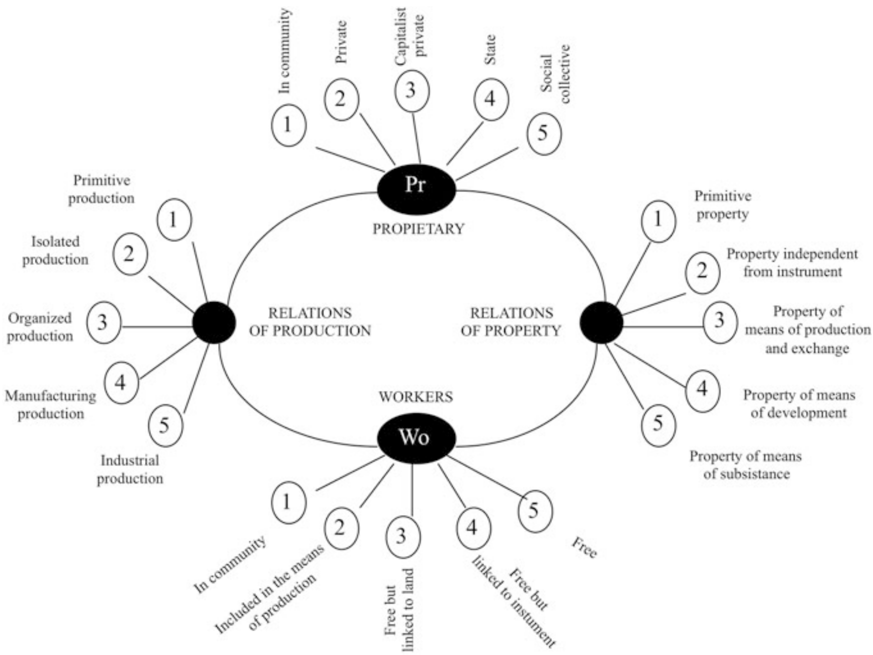

Fig. 13.1 Variables considered by Fossaert (1977) during the reconstruction of the different modes of production occurred throughout history

The reformulation of the concept of mode of production made by Wolf (1982) is also useful for our objectives. Wolf (1982) believes that three large groups of modes of production can be differentiated along history: (a) based on kinship systems, (b) derived from tribute, and (c) consequent of the industrial revolution and the development of capitalism. From the correlation of the societary types of Flannery (1972) and the groups of modes of production established by Wolf (1982) 10 years later, some general patterns can be derived regarding the forms of organization adopted by human societies throughout history, which are decisive from a socioenvironmental perspective (Fig. 13.2).

The first important discrimination is that made between egalitarian and non-egalitarian societies, in both typologies the former being equivalent to bands and tribes that are based on kinship (Flannery 1972; Wolf 1982), the latter correspondent to Flannery's (1972) chiefdoms and stratified societies. In the socio-cultural evolutionary stage of egalitarian society, the role within the general metabolic process of humans is socially undifferentiated. There is no unequal sharing of negentropy and, except for infants and elders that depend on their relatives, all members of society function as primary appropriators for most of their life, and metabolism is limited to appropriation, production, consumption, and excretion.

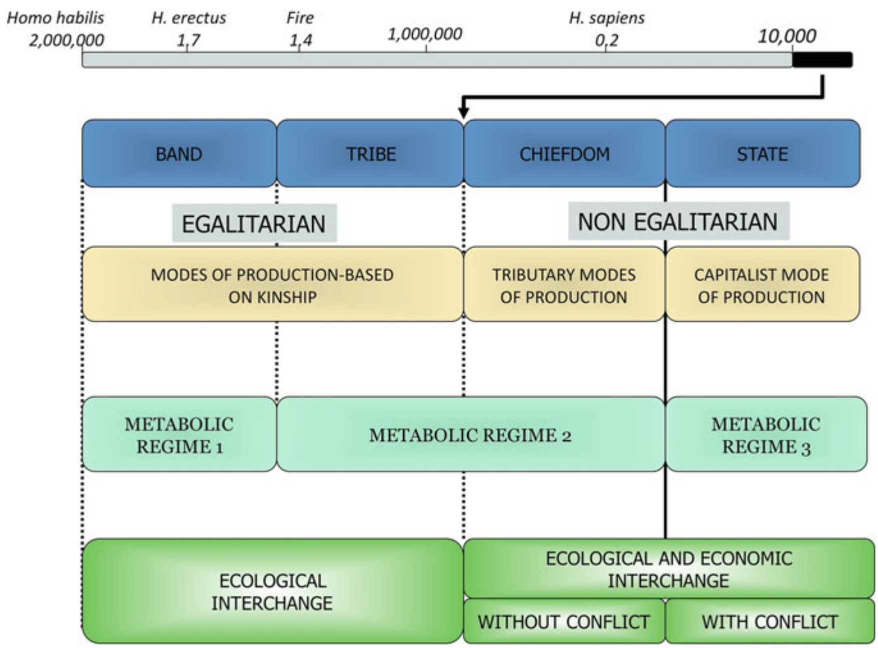

Fig. 13.2 Diagram showing the correlation between the societary types (Flannery 1972), the mode of production (Wolf 1982), and the three types of social metabolism

In fact, in egalitarian society circulation of what is produced is yet not present, or in other terms, the phenomenon of economic exchange between members of other production units is absent. This means that at this stage of social development humans only realize ecological exchange with nature, given that, as we have seen, exchanges made inside society are of social or cultural nature (gifts, dowry, donations, etc.), and simply consume and excrete all what is produced (Fig. 13.2).

Non-egalitarian societies are the product of the appearance of the phenomena of economic exchange, including circulation of what is produced or appropriated, transformation of what is put in circulation, and division of society in two well-defined social segments: a sector of surplus producers, and a sector of surplus takers (Wolf 1982, p. 99), or if preferred, a sector of laborers and a sector of owners (Fossaert 1977). This social differentiation created a sector of non-rural producers to be released from the chores of direct appropriation of nature, a sector that after expanding and becoming consolidated gave place to new spatial assemblies: urban settlements.

However, in order for this novel urban sector to survive as non-rural producers, it required of the surplus produced by the rural sector. Noticeably, and pending of explanation, is the fact that social differentiation occurred concomitantly with inequity. Flannery (1972, pp. 402–403) considers kinship and the associated land-tenure of lineages as explanatory factors: "*One of the thorniest problems in cultural evolution is the origins of hereditary inequality—the leap to a stage where* *lineages are 'ranked' with regard to each other, and men from birth are of 'chiefly' or 'commoner' descent, regardless of their own individual capabilities. Since lineages are also property-holding units, it is not surprising to find that in some chiefdoms the best agricultural and or the best fishing localities are 'owned' by the highest-ranking lineages*". The differentiation of human societies, beginning some 5,000 years ago, that ended up creating rural and urban inhabitants was at the same time a process of social disparity: humans divided in extractors of surplus free of productive obligations, and producers of surplus forced to produce them. It seems as if coercion and exploitation was a requirement for advancing to more complex states, a phenomenon continuing at present.

In this way, human beings now differentiated in their roles in metabolism, also divided in two different segments, thus ceasing to be what they used to be at the same time: laboring owners and owning laborers. Since that moment and until the present, history of humanity becomes the history of conflicts between a sector of humans obligated to produce surplus (the peasants or laborers), and a sector obligated to produce surplus in order to appropriate it (the landlords or employers). This phenomenon acquires a substantial meaning because it expresses an asymmetric relation within society, which is at the same time a relation of power, a form of exploitation and the evidence of unequal exchange in the material sphere.

The different relationships adopted by these two socially differentiated sectors of individuals will determine the configurations of non-egalitarian societies. In societies with tributary modes of production, beginning in chiefdoms and culminating in states, the sector of producers—first rural and later urban as crafters and merchants—is forced to produce a surplus for the elite through some form of political, religious or military coercion mechanism that is never exclusively economic. Thus, regardless of the name being invoked—chief, divinity, god, king, the crown, pharaoh, lord, noble or the monarch—laborers are always forced to generate surplus that is extracted as tax, rent, forced labor, or goods by a central authority that profits from the effort.

In historical terms, this situation persisted among human societies since the first chiefdoms appeared—as archeologists has been able to record from 5500 in the Middle East and 1000–800 B.C. and Mesoamerica and the Andes (Flannery 1972, p. 403)—and until the beginning of the Industrial Revolution around 1750–1800, considered as the birth of capitalism (Cipolla 1983). It is with the advent of the capitalist mode of production that the transfer of surplus takes place without any apparent coercion, but through simple and material (although invisible) mechanisms of economic exchange. That is, surplus is transmitted by means of a free relation between surplus producers (laborers) and surplus takers (possessors).

Regardless the above, the wide variety of societary configurations emerging from historical development were all based on an interface with nature that remained nearly static, an ecological-social interaction of mega-historical character as described by Flannery (1972, p. 412): "*Looked at in this way, the most striking differences between states and simpler societies lie in the realm of decision-making and its hierarchical organization, rather than in matter and energy exchanges*".

13.3 Human Webs: The Kinetics of Historical Change

Lets now look at the third approach, which not only represents a fresh look, but also is useful for the concrete analysis of social metabolisms. Rather than being based on searching social models through history in order to develop a societary typology from these models, this approach focuses on analyzing historical events in specific, concrete scenarios, as revealed by empirical evidence based on interpretation of the construction of evermore extensive and dense webs of communications, technologies, and products (McNeill and McNeill 2004).

From a deep-time perspective, history of human societies reveals two main mega-trends: (a) a general increase in human population, and (b) the expansion in distance and density of webs of communication and information exchange (including knowledge and beliefs), technologies, products, and genes. Both processes run in parallel although not always in synchrony. The analysis of these human webs made by McNeill and McNeill (2004) has discovered highly interesting patterns, offering a method for studying history having an encompassing, or species, view present in every stage and segment of human and social history, which we consider highly useful for the perspective adopted in this book.

As essentially social beings, individuals belonging to the human species have always formed organizations, articulated groups, of different sizes and extensions. The initial organization was the band containing groups of families dedicated to performing collective activities, having a certain degree of self coordination, and related by kinship. The first webs, simple and elementary, appeared when a number of bands established links mostly of cultural nature, united by common language and history, thus generating the first tribes. With that, humans extended their interpersonal relations, shared experiences, and expanded their known territory.

After the agricultural or Neolithic revolution enabled sedentarism, tribes were formed by a number of villages or communities having higher population than bands, thus giving birth to the next level of organization. Webs extended further and became denser as interchanges of information, products, technologies, and genes—exchange of women (exogamy) was common—became more numerous. To this point human webs remained limited in number of participants and territorial extension, and were exclusively formed by individuals involved in the appropriation of nature.

As a result of the advances in management of the resources present in the natural environment, which allowed for incrementing production and led to surplus generation, it was to be expected that for the first time a sector of non-appropriators would appear, and which the remaining members of the village would sustain. By that means, human webs expanded in chiefdoms, this time coordinated by a chief that could agglutinate and command members of more than one village.

Human webs took a qualitative leap with the advent of an increasing number of individuals devoted to activities other than appropriation, such as circulation (merchants) or transformation(craftsmen) of products. With time, this non-appropriator sector of the population became so important that the need emerged for creating a new sector dedicated to govern, usually by divine mandate. That gave birth to the state and, intimately related to it and as its spatial expression, to cities. The augmented power of states allowed them for increasing their capacity for controlling the territory, thus enabling the extension of exchange webs. States gave place to empires when one or more states proclaimed themselves as the dominant power of many other societies.

As shown by McNeill and McNeill (2004, pp. 2–3), webs at different scales can be identified throughout history and in the different regions of the world: local, regional, metropolitan, cosmopolitan, and global. Each scale represents a hierarchical level in a larger web formed by smaller webs. In fact, webs are the expression of the couplings and configurations of the different social metabolisms present in a territory, and their fine analysis reveals the links between the different metabolic processes.

While the cinegetic metabolism only allowed for limited webs of bands integrated in tribes, the agrarian or organic-based metabolism allowed for the existence of metropolitan and cosmopolitan webs that operated in the ancient world. Finally, industrial metabolism gave place to the first global web in history. McNeill and McNeill (2004, p. 3) describe the formation of an Antique World web that covered most of Eurasia and Northern Africa established nearly 2,000 years ago from gradual agglutination of smaller regional and local webs. In the past 500 years oceanic navigation made this web cosmopolitan by linking metropolitan webs. The current global web in which we are all immersed involves cooperation as much as competition (McNeill and McNeill 2004, p. 3).

13.4 Reading the Past in a Metabolic Key

Currently, audacious, sophisticated and comprehensive analyses are made from within and outside the field of environmental science aiming at responding to an intellectual challenge: arriving to a socioecological interpretation of history (e.g., Costanza et al. 2007). These studies make attempts for finding attributes of social systems that allow for understanding their capacity of responding to natural changes such as climatic perturbations. In order to arrive to socioecological explanations of historical transformations, use is made of conceptualizations such as complexity, adaptation, vulnerability, flexibility, resilience, hypercoherence, control, and connectivity (e.g., Flannery 1972; Adams 1975; Tainter 1988; Giampietro 1997; Redman and King 2003; Redman et al. 2007). All these studies have a predominant systemic, and even cybernetic, approach that seeks in societies structural mechanisms having some heuristic value. However, with few exceptions (e.g., Giampietro 1997) these studies are lacking of a conceptual framework in which to contextualize and locate the principles and mechanisms used for analysis, and of a precise methodology for studying societies. In other words, these analyses fail to provide a systematized and coherent panorama of the interplay through time of human societies and nature.

Contrastingly, reading history in a metabolic key provides advantages: (i) the five metabolic processes provide a conceptual framework that differentiates and clearly defines between the external relations between society and nature and the internal relations between human individuals; (ii) two dimensions in constant interaction are recognized, a material dimension in the form of processes and patterns of internal and external exchanges of goods and services (mater and energy), and an immaterial or intangible dimension formed by institutions, knowledge, cosmovisions, and rules (information); (iii) allows for systematic and coherent observation of historical transformations deriving from the changes at several scales of forms of articulation with nature, and of the different societary configurations emerging from the interplay between the tangible–the hardware formed by dissipative structures processing flows of mater and energy—and the intangible–the software formed by dissipative structures processing flows of information—dimensions of all human societies; and (iv) recognition of metabolisms occurring within a concrete space boundaries (national, regional, communitarian, etc.) and of multiscalar webs resulting from the metabolic processes of different social sectors.

13.5 Main Metabolic Transformations

Along the recognized time period of 200,000 years of existence of the human species the main societary configurations have materialized in increasingly complex ramifications that are rooted in the three assumed main metabolic regimes (cinegetic or extractive, agrarian or organic, and industrial or fossil-fuel-based), and have defined levels of energy consumption (GJ inhab-1 y-1) and excretion (t inhab-1 y-1).

As represented in Fig. 13.3, the main societary configurations recognized along history form a sequence of evermore-complex social designs interweaved with natural ecosystems and landscapes under the three modalities of social metabolism. A panorama clearly emerges formed by a sequence of socioecological stages including the different historical periods, population sizes, impacts upon and transformations of the biophysical environment, and the degrees of complexity recognized by Flannery (1972). The challenge thus is to decipher these and other general trends, discover casual factors or sets of factors of changes, and to identify the patterns occurring along time.

We thus arrive to a provisional an unfinished first general view that offers several important elements in the identification of metabolic states throughout history. After defining the three main moments of interrelation of societies and nature from the analysis of the modalities adopted by appropriation, it is deemed necessary to unveil the intricate relations between appropriation and the remaining metabolic processes of circulation, transformation, consumption, and excretion, and between this material real and the intangible dimension: i.e., between the hardware and the software of social metabolism.

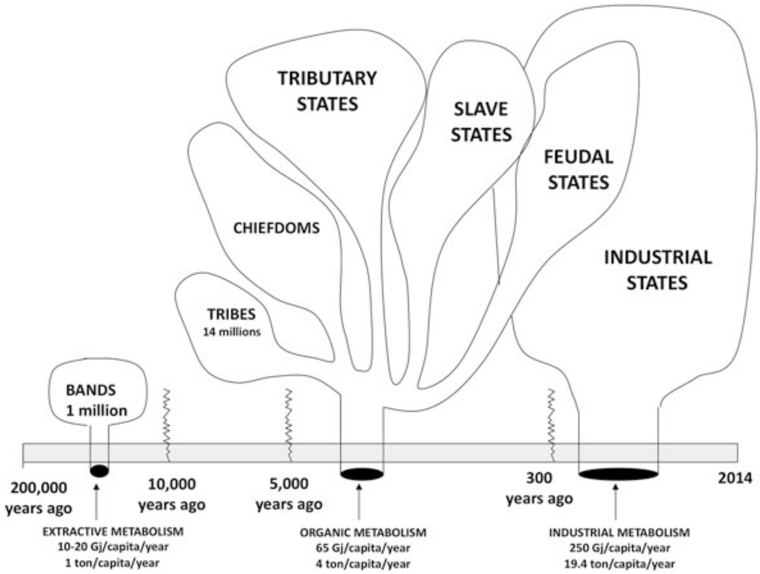

Fig. 13.3 Diagrammatic representation of the three types of social metabolism and the main societary configurations suggested by Flannery (1972). The amount of energy and wastes are indicated for each metabolism

The clues for this second task seem to be found, on one side, in the variation and modalities of technology that are mainly marked by a continued innovation derived from the advancement of knowledge and leading to an increasingly more efficient use of energy. On the other side, apparent clues can be found in two equally important phenomena: the relations of power, which are most clearly expressed in economic exchange; and the generation of administrative, political, productive, religious, juridical, and cultural institutions, which operate as stages for economic and ecologic material transactions.

Whatever approach is assumed and followed, it seems clear that the use of the concept of social metabolism as defined in Chap. 3 forces to analyze the adopted hypotheses within the framework of the sociometabolic process itself in its different scales and in different time periods. The above implies evaluating in concrete territories and epochs the reciprocity of effects established between the processes of appropriation, circulation, transformation, consumption, and excretion.

Overall, the objective is to unveil the ways in which human beings and their intangible symbolic structures are configured in regard of the five processes of social metabolism occurring in a given environment, and reciprocally, the ways in which the social relations with nature—mostly expressed as appropriation and excretion processes—become impacted or transformed by the modalities of appropriation, circulation, transformation, consumption, and excretion of materials and energy adopted by particular societies.

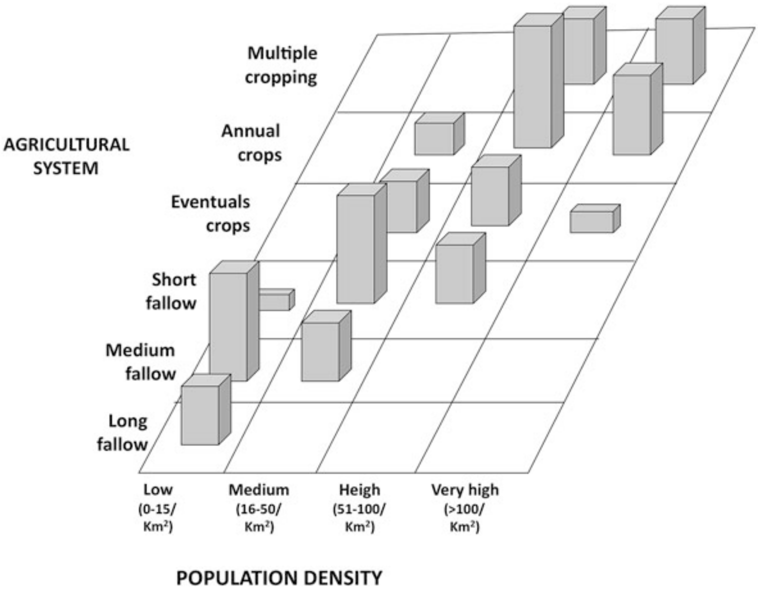

Fig. 13.4 Correlation between population density and level of agricultural intensification in nine African countries. *Source* Pingali et al. 1987

The most noticeable fact emerging from reading history in the metabolic key is the wide societary variation rooted upon only three modalities of relation with nature. From a deep-time perspective, the three modes of social metabolism are continuums interrupted by leaps allowing for qualitatively increase the return flows during the process of appropriation of nature. These discontinuities were caused by transformations not only of the sources of energy, but also by changes in the capability of humans for managing the components and processes of ecosystems and landscapes (Fig. 13.4).

The first consequence of the increased efficiency in energy, material, and services flows was the growth of human population. The transition between the extractive and the organic modes—taking 5,000 years—multiplied the original global human population by 14, also increasing both the annual per capita consumption of energy and volume of wastes excreted. But this scenario is lessened by the demographic expansion from the leap between the organic to the industrial metabolism: between 1820 and 2011 the global population multiplied by seven (rom 1–7 billion inhabitants, and the same can be said of the annual per capita consumption of energy and waste generation).

The 10,000 years in which social metabolism was exclusively organic have a special relevance, given that it was in that period when the more significant social transformations took place. Human society changed its organization from tribal to chiefdom, finally becoming state societies. Cities appeared together with states, because the process of urbanization expresses in the territory the centralizing, hierarchical, and asymmetric character of these societies, afterwards metropolitan webs appeared, the first cosmopolitan web finally making its appearance towards the fifteenth century (McNeill and McNeill 2004).

All these increments in social complexity were propped by the advances made in the forms of organic appropriation of nature. If the Neolithic Revolution (that allowed for the transformation from the extractive to the organic mode) was essentially an advance in human capacity for managing nature in the form of the manipulation of populations of plant and animal species (originating thousands of races and varieties from hundreds of domesticated species), this newly conquered capability would continue its perfection and innovation during the following 7,000 years.

The available archaeological and historical analyses demonstrate such advancements. For example, the productivity in Egypt is estimated to have increased from 1.3 to 1.8 inhab ha-1 of arable land between 2500 and 1250 B.C., and during the Roman empire, when Egypt became the breadbasket of Rome, it raised to 2.4 inhab ha-1 of arable land (Butzer 1976). In China these figures are more striking, productivity of organic base agriculture going from sustaining 1–2 persons per hectare during its early stages, 2.8 in 1400, 4.8 in 1600, 5 towards 1900, and 5.5 during the 1930s (Smil 1994, p. 63). In Mesoamerica, the lacustrine system in the Valley of Mexico sustained 4 persons per hectare of arable land, including the chinampas—strips of land surrounded by water and fertilized by lacustrine sediments—that can sustain 13–16 persons per hectare. The Inca civilization achieved similar productivity levels in elevated fields along the coastlines of Lake Titicaca known as guaru-guaru (Denevan 1982).

In Europe, the more intensively cultivated regions of the Netherlands, Germany, France, and England productivity was of between 7 and 10 people per hectare of arable land (Smil 1994).

The organic mode of appropriation achieved other advances with the creation and perfection of two devices: ships and mills moved by wind, and the water wheel. The water wheel reached its maximum expression in Europe during Medieval times when thousands of them were found throughout its territory (Basalla 1988), becoming the leading technology for several uses including irrigation, corn milling, hide and paper presses, mining, and metallurgy, and in a way preceding the steam engine. The organic or agrarian mode as provider of food reached its limits and began to be transformed by the appearances of new engines moved by fossil energy (coal, oil, and gas), which were the product of the invention in the nineteenth century of the internal combustion engine. The advances of agrochemistry added to the transformation and genetic science gave place to new varieties of plants and animals.

Despite its productive limitations, the organic or agrarian metabolism is still put in practice by an ample sector of the human species (Fig. 13.5) and is the most successful and extensively used form of interplay with nature. Seen in wide perspective, organic metabolism is placed between the extractive metabolism, which along 95 % of historical time maintained humans in a state of nearly total stagnation, and the industrial metabolism, which despite its short existence for the past

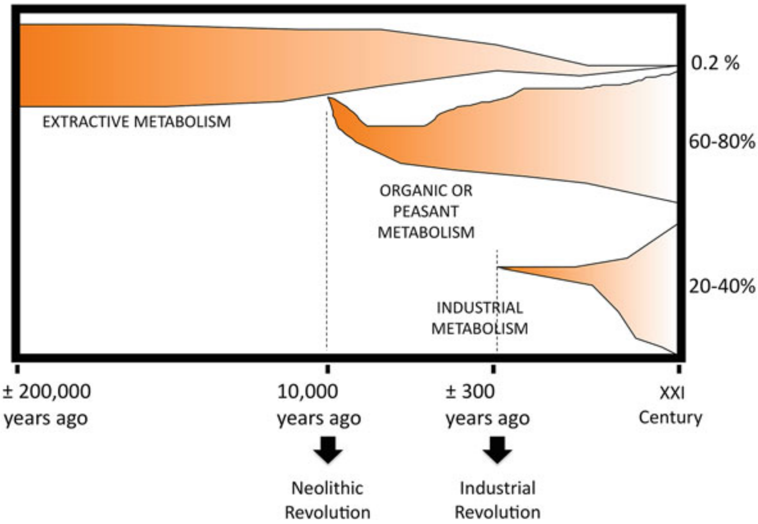

Fig. 13.5 The three main modes of social metabolism along time, and the estimated percentage of the present population living under each one of these metabolic regimes

100–150 years, is currently endangering not only the existence of the human species, but that of life and of the equilibrium of the planetary ecosystem.

The social and ecological situation prevailing in the contemporaneous world—the World-System (Wallerstein 1974–1980)—is the result of the complex interactions taking place between the metabolisms of societies, having unequal socio-political complexities and historical origins, arranged as metabolic constellations in the form of networks and systems of webs of increasing complexity. Seen as generally as is possible, the social historical process has involved clear trends for the increase in human population, higher energy flows, higher population density (sedentarism followed by urbanization), more extensive human settlements, social stratification and inequality, labor division, productive specialization, processing, storage and consumption of goods (materials and energy), technologies, knowledges, and information.

13.6 The Modern World Crisis and Industrial Metabolism

The word modern was used for the first time in English by the end of the sixteenth century to denote present time, its meaning slowly changing to a future totally different from the past, and further yet, a better world as never existed before. Four centuries later, the idea of modernity as a synonym of progress, wellbeing, security, and peace, cannot at present be sustained, as the main supports of modern world are similarly being questioned: dominant science and technology, profane and rational life, and the assumed superiority of individualism. Also debatable are many of the values promoted by industrial civilization, among which are: the obsessive mania for dominating nature, and its reproduction by accumulation of capital based on a dogmatic belief in the mechanisms of technology and the market.

The modern world crisis derives from the additive accumulation of the processes of industrial metabolism. The key factor is, without doubt, a change of energy source that induced the accelerated creation of new technologies, mechanization of countless processes, and caused the change from organic appropriation to one based on fossil fuels, including uranium-based nuclear energy. This shift in energy source radically transformed the practices of use of nature, allowed for a noticeable increment of surplus, and, as a consequence of the increasing volumes of foodstuffs and raw materials made available, also resulted in population and industrial growth. The outcome of all this was an extraordinary intensification of the exosomatic energy.

The transformation began by the seventeenth century and its key moments were the invention of the steam engine and its continued perfection during the nineteenth century, the invention of the internal combustion engine around 1900, and the extensive use of coal, and more relevantly, of oil and gas. This new form of energetic conversion transformed chemical energy into mechanical energy, potentiating human power to unbelievable levels. Until then, mechanical energy derived from human and animal muscle power, and on mills or ships moved by the force of wind or water. Thus, industrial metabolism became determined by the use of oil, a new era started in 1859 when the first oil well began operating in the east coast of the U.S., and consolidated by the use of electricity and nuclear power.

Equally important was the appearance of official science certified by the first scientific societies like the Royal Society founded in London in 1662—and renamed in 1664 as the Royal Society of London for Improving Natural Knowledge—and the Académie Royal des Sciences of France first born in 1666. The advances made in scientific research in fields such as genetics, and agrochemistry decidedly transformed the agricultural and livestock sectors by introduction of new varieties of plants and animals and new chemical fertilizers. This new inputs were accompanied of the use of newly created machines associated to appropriation tasks as to transformation of raw materials.

The result of the interplay of all these processes was the unleashing of what John McNeill (2000, p. 4) has called "…*a giant, uncontrolled experiment on earth*" made evident in the progressive acceleration of numerous environmental and social phenomena during the past 100 years, and in particular during the past five decades (see MEA 2005). This qualitative leap in human transformation power first had impressive effects on the forms of appropriation of nature—agriculture, livestock breeding, fishing, management of water, forestry, and mining, among other sectors—that, in turn, potentiated the accelerated growth of human population, cities, and industry.

From the metabolic standpoint, the industrial civilization revolutionized as never before in history the act of appropriation, which propelled circulation and transformation of products, rising consumption, but above all, increased excretion to unprecedented levels. Industrial metabolism has indeed not only substantially amplified appropriation, circulation and transformation, but has also exacerbated the excretion processes to unbelievable levels, placing it as the process with most impact by the incapacity for controlling the evermore growing volumes of generated wastes including materials, substances, gases, refuses, radiation, electromagnetic waves, and new genomes. Such incapacity is mainly derived from the amount and contents of excreted wastes that exceed the capacity of natural systems for assimilating and recycling them, or are intrinsically unrecyclable.

The human species has been present in the planet for 200,000 years, a mere blink in the dilated and quasi-eternal Earth's history. Along most of that period of human existence, the planetary habitat has suffered a growing pressure from the species. However, nothing is comparable to what has occurred during the past 100 years, a time lapse of 0.05 % of human history. At present, a series of phenomena having no precedents in history can be identified (McNeill 2000, 2007; Mantua 2007; Hibbard et al. 2007; MEA 2005). For example, the global human population over quadruplicated from 1.6 to 6 billions between 1900 and 2000. This implies the birth in the planet of 77 millions human beings each year. At this rate, the demographic clock is, and will remain to be, a time bomb leaving in the twentieth century one fifth of all living or death persons ever been born. But demographic facts are left behind by data about the world's economy. Assessed in 1990 U.S. dollars, the global economy multiplied by 14 between 1900 and 2000, so that the global economy of 1950 has been surpassed by the current economy of the U.S., and the global economy of 1900 is equivalent to the present Japanese economy (McNeill 2000).

The use of energy measured in metric tons of oil is the third indicator to have been greatly accelerated during the past century: it increased 16 times. The energy used during the twentieth century was greater than that used by the human species throughout its history, and ten times larger than the total energy used in the previous one thousand years (McNeill 2000). In comparison with the former data, the use of water increased nine times, the amount of carbon dioxide (CO_2) emissions incremented by 13 times, and industrial total atmospheric pollutant emissions, by 40 times!

Likewise, the extraction and consumption of metals (copper, zinc, manganese, chrome, nickel, magnesium, tin, molybdenum, and mercury) had a spectacular increment during the past 100 years. Between 1900 and 2009 the consumption of resources went from 7 to nearly 70 billion tons (7–70 Gt). All types of products show a high increment: biomass, from 5 to 20 Gt; fossil fuels, 1–13 Gt; metals, 0.2–6 Gt; and building materials, 0.7–28 Gt. Despite the mass of biomass was quadrupled; its growth is the lowest in relative terms. In fact, the annual per capita consumption of biomass remained somewhat stable during the twentieth century, the consumption of inorganic resources went from 1 to 7 t inhab-1 y-1. This means that the consumption of materials grew during the past century at a higher rate than population. In fact, the population multiplied by 4.4, while consumption of resources by 9.6. Each current earth's inhabitant needs 2.2 times more materials than inhabitants at the beginning of the past century, or what is the same, the strong pressure exerted over resources during recent history cannot be explained by demographic causes alone because the growth of consumption has been much higher than population growth.

Automobiles and cattle may be considered as icons of the twentieth century. Each year one car is produced for every two human beings being born so that by 2010 the global vehicle fleet reached one billion. Cars produce 15 % of atmospheric polluting gases, its building generates between 15 and 20 tons of wastes, and each year car accidents kill one million and injure between 25 and 35 million people (Toledo 2002). The car has killed more U.S. citizens than the First and Second World Wars, the Korean War and the Vietnam War together. On the other side, all the cattle in the planet weight more than all human beings, in some countries as in Uruguay, Costa Rica, and Australia there are more cattle than people. By 2001 the cattle population reached to 1.53 billions, each of its members eructing methane and nitrous oxide, gases that contribute to global warming. The expansion of cattle has been the main cause for destruction of millions of hectares of tropical forests.

With populations close to those of humans, cars and cattle—two engendered inventions of human creativity during the past century—are already competing with its creators for food. In countries as Brasil or the U.S., each agricultural parcel can be either devoted to feeding cars with biofuels, cattle with grasses, or human beings with cereals, vegetables, and fruits.

The final event that accompanied the above processes is generation of excreted materials, substances, sewage water, radiation, altered genomes, and solid wastes. The volumes of waste generated have exceeded al predictions. It can be said that the present time planet is evermore becoming a space that is irremediably polluted with a nearly endless number of wastes and byproducts. Only in Europe—maybe the strictest regulated territory in the world—there are over 30,000 uncontrolled chemicals, i.e., of which little can be said about their effect on environment and human health (El País 9/25/2005, 21). The noticeable increase in allergies, asthma, cancer, hormonal dysfunctions, and infertility is possibly linked with the uncontrolled use of these chemicals.

In an unprecedented event, the U.S. journalist D.E. Duncan had himself analyzed for the presence in his organism of several chemical substances including pesticides, dioxins, phthalates, heavy metals, bisphenols, and other toxic agents. The results of the analyses showed that 165 of the 320 substances tested for were present in some dose in Duncan's body (Duncan 2006). Otherwise, the World Health Organization estimated in 3 million the number of cases of severe intoxication with pesticides during 1990.

Within the scenario herein described, mention must be made of useless electronic devices. For example, there are currently nearly 2.1 billions of mobile phones in the world, nearly one for every three persons, which given that the device's average useful life is of 14 months, the number of mobile phones disposed as electronic waste is fantastic: in the U.S. alone, 500 million mobile phones are disposed.

13.7 A Conclusion

Considering the reviewed facts, postulates made and analyzed in this book, it may be concluded that the historical processes must forcedly be approached within the framework of social metabolism at its different scales and moments. That implies evaluating the reciprocal effects and synergies established between all parts of the metabolic process (appropriation, circulation, transformation, consumption, and excretion) within a given territory and time period, among the different societary configurations, and considering the mechanisms in which the immaterial dimensions condition such metabolic processes.

Thus, on one side the mode of appropriation must be determined, and on the other side, the modes of circulation—intimately related to transporting capacity, modes of transformation–substantially determined by the technological devices for energy conversion, modes of consumption—determined socially, economically, and culturally, and modes of excretion—closely associated to technology and the nature of the wastes being generated, given that it is not the same to excrete organic mater than heavy metals or radioactive residues—must be known.

In the case of circulation it is possible to distinguish different modalities based on the capacity of transportation in terms of potency, speed, and the payload size. One thing is to transport materials by human energy alone—as occurred in Mesoamerican societies, another thing is to use animal power—several variants existing: oxen, mules, donkeys, horses, elephants, camels, llamas, and guanacos, ships—in continental and oceanic waters—moved by the combination of wind and human power, and finally, or transportation by engine power—steam engines, railroads, motor vehicles.

To the visible moiety of metabolism, expressing as an eternally continued and unidirectional flow of materials and energies that are appropriated, transported, transformed, consumed, and returned to nature as wastes, the invisible complement must be added, be it as mercantile transactions—either equivalent or unequal, institutions of several sorts, world visions, knowledge systems, and technological designs. The large socioecological interrogations and research challenges are in discovering how these interplays transform through time, and what weight these material and immaterial dimension have on the transformations (Fig. 13.6).

From the above it is deduced that, unlike other previously postulated forms of interpreting history, the study of metabolic constellations demands of multi-criteria analysis, because the subject of study is polyhedral and polyvalent, and because in each particular case each factor becomes more or less important. This suggests a non-ontological theory that considers social systems as a posteriori abstractions of regularities observed along history. Such a theory should only have an instrumental, methodological meaning—as the concept of social metabolism itself—with no regulatory goal and that is only useful to see how each society relates with nature, and how it acquires certain configuration through that relation. Hence, the theory would have no power for structuring societies and lack an integrative successional or evolutionary scheme leading to a determined state of

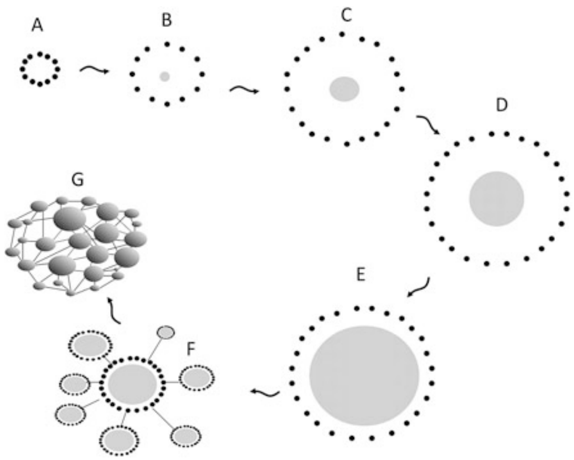

Fig. 13.6 Historical development seen from an ample perspective is expressed in several general processes such as the growth of urban population (center) at expenses of rural population (periphery) and the integration of evermore-complex networks (webs), which leads to the present global world-system. **a** Tribal societies (agricultural and pre-agricultural) in which all the population is strictly agrarian; **b** Chiefdoms, in which for the first time a family of non-appropriators/producers appears: the chief's or patriarch's family; **c** Pre-urban states in which the agrarian population is noticeable higher than the urban population, real cities being absent; **d** Urban state societies with equivalent agrarian and urban populations; **e** State societies dominated by urban population; **f** Imperial societies integrated in networks of societies having unequal complexity and metabolisms; **g** World-systems including cosmopolitan networks

society, because each social system has put into play diverse forms of production within an interlinked, but dynamic whole, establishing its metabolism with nature.

As it has also been stressed in this book, the multicriteria nature of metabolic analysis does not oversee nor hide the importance of social inequity or the different forms of exploitation and social mobilization as agents of historical transformation. This approach differs from and is critical to cybernetic—structural-functionalistic—formulations and currents, which undervalue or even ignore the relevance of human action in change. However, human action does not contain all of the power for metabolic transformation, despite being an important vector of change. Other factors of human action such as technological innovation, institutional actions, and public or state regulation must also be pondered. Human agents may act consciously or unconsciously, individually or collectively, directly or indirectly, immediately or not, from within society and social activism or from the laboratory, the office, the workshop or the State.

Reiterating, what this book offers is a fundamentally novel way of visualizing historical processes based on the comprehensive analysis of natural and social processes through a version of the concept of social metabolism—herein postulated and described in detail—which is not limited to analysis of mere interchanges of energy and mater between society and nature, as do most users of the concept, but that also recognizes the existence of another dimension that is immaterial, symbolic or cultural, and which expresses as flows of information. It is in the mutations suffered along time by this material and immaterial structure, occurring in response to changes or oscillations of nature, where to attempt to identify the gradual or sudden, expected or surprising transformations derived from the historical analysis. Of course these transformations will have a dual social and ecological character, because they rise from the encounter of phenomena occurring within society and in the external natural realm. In this way, the door is open for the construction of a single history: that of human beings, their societies, and of nature and its processes.

13.8 Metabolic Change: Metamorphosis and Socioecological Transitions

Describing the course followed by humanity and distinguishing changes, multiple lines of changes, and even linear sequences of change is, as we have suggested, a task made for historians. Transformation has been neither lineal nor forced by a predetermined law beyond the will of human beings, but multi-lineal and largely random (Prigogine 1996). The transformation has trended towards an increase in complexity, yet complexity has not been a guarantee of stability, but all to the contrary. Humanity has spent 99 % of its existence under more or less simple forms of social organization and only 1 % of the time has the complexity of its societies spectacularly increased, thus becoming unstable, as proved by the occurrence in the modern era of the most atrocious genocides, the most severe and fast social destabilizations, and the most concerning threats of climatic change and the still latent nuclear destruction. The fate of humanity was not predetermined or prescribed. It is the historians' mission—in our case, the environmental historian—to explain why human societies made decisions that caused them to evolve in a non-linear direction until their present state.

Indeed, societies mutate according not to written precepts dependent upon a number of factors and circumstances that historians struggle to understand. Also a duty of environmental history is to provide theoretical constructs that make understandable the complexity of any mutation from one form of metabolism to another. History of past societies in their environments could in general be seen as the description of all its different social metabolisms, their magnitude, the impact they had on the natural environment, and of how these societies transited between states. Opposite to what occurs in natural evolutionary processes or developmental stages—birth, development, maturity, and death—in which more energy is consumed during the stage of development than at maturity, when energy expenditures are less, the increase in complexity of societies has been achieved by consuming increasing amounts of energy and materials. If consumption of resources has been the main cause—but not the only one—of the transformation of some societies to a higher level of complexity, we must find which types of factors motivated a larger consumption of energy and materials, mostly for exosomatic consumption of given societies throughout their transformation along time.

In the social sciences, the theories explaining long-term changes of human societies from the concept of transition have gained increasing relevance, given that the civilizatory crisis pushes towards a better understanding of historical change, in this case towards sustainability. Reviews of transition theories can be seen in Olsthoorn and Wieczorek (2006), Geels (2005), Markard et al. (2012), Grin et al. (2010), and Lachman (2013). In the post war Marxist literature the concept of transition between modes of production gained a special relevance, having a clearly political rather than academic orientation. These studies lost currency after the crisis of Marxism, but regained emergence when the environmental crisis restated the problem of how to make the transition towards a more sustainable world. The result was a new wave of transition studies, this time focused on sustainability transition, most of them centering on the technological aspect of change, giving technological innovation the protagonist role (Bergh and Bruinsma 2008).

For transition current advocates, transition is defined as *"a fundamental change in structure (e.g. organizations, institutions), culture (e.g. norms, behavior) and practices (e.g. routines, skills)* [Loorbach and Rotmans 2010 *quoted in* Lachman 2013]". Transitions change the predominant ways in which social needs such as transportation, energy, or agriculture are satisfied (Kemp and Loorbach 2003; Alkemade et al. 2011). Due to the large number of factors and participating actors, transitions are characterized by their complexity and uncertainty, and usually occur as lengthy processes (Rotmans et al. 2001).

Therefore, transition cannot be predesigned, copied or imposed from the outside, it cannot be managed or controlled, but only guided, provoked or stimulated in terms of rate, magnitude, and duration (Kemp and Loorbach 2003), which implies that transition can only be studied in retrospection. At any rate, the main weakness of transition theories is their lack of a political or institutional dimension of transition that cannot be attributed only to technological innovation without accounting for institutional frameworks favoring and developing such transitions.

In the past decade another current has developed that analyzes the process of transition to sustainability from the metabolic perspective. The Viennese school developed a proposal defining socioecological transitions as processes in which social metabolic configuration suffer structural changes. The Viennese school emphasizes qualitative changes occurring along decades or centuries and affecting the configuration of energy, mater, and information flows between societies and their environments (Fischer-Kowalski and Rotmans 2009; Fischer-Kowalski 2011).

Following the approach of Fischer-Kowalski and Haberl (2007, p. 3), socio-ecological transition is understood as a process of change from one state to another qualitatively different state, a process that is not linear and that may be chaotic. Transition does not travel along previously stepped paths, and its change or direction cannot be entirely controlled, along the way being space for spontaneity or appearance of unpredictable phenomena (Holling 2001).

The concept of transition cannot thus inform about the path followed along a previously traced route nor it cancels the spontaneous emergence of unpredicted events. The transition from one state to another cannot be wholly controlled nor is it possible to deliberately transit between states, especially if the complex systems theory is applied given its autopoyetic nature.

Transition implies major changes and not simple readjustments or improvements, it means arriving to a new, qualitatively different state of the system. In this sense, we agree with Fischer-Kowalski and Haberl (2007, p. 7) when stating that the socioecological transition is the product of a deliberative change. Against the nineteenth century predictions of a scenario of progress going from a less to a more mature state—from feudalism to capitalism, and from the latter to socialism—we claim that the future is not predetermined, which gives agents of the process the relevant capacity of deciding, and hence, introduces uncertainty regarding the future. This claim is supported by the transition to a more sustainable world: it seems logic, but it is far from being inevitable.

Yet, Lachman (2013, p. 274) appropriately criticized this socioecological transition approach claiming that the proposal of the Viennese school of a sociometabolic transition is placed at the level of an exceedingly abstract system (social metabolism) in which social actors are excluded. Factors such as beliefs, political, economical or cultural interests are not accounted for, which makes unlikely that this general and abstract model can provide its users any advice regarding the design of policies appropriate for making the transition to advance. Our proposal agrees with this criticism, and based on what was seen in Chap. 16, it considers social actors are unquestionable protagonists. With the latter assumption in mind, collective action is assigned a major role in the process of transition.

In any case, analyzing social systems from the past by applying the theories and methods of social metabolism is particularly useful for our purposes. The use of this conceptual tool provides information about their physical functioning over time and about their spatial differences, facilitates a more clear understanding of the structural and physical-biological functional differences between hunter-gatherer, organic based, and industrialized societies, the way in which these societies were transformed, and informs about which are the explanatory factors of such changes. As was seen in Chap. 12, human societies evolve side by side with nature, however by its own factors and mechanisms. This recognition of the essential unity of the evolutionary process implies conceiving social change as that in which the new emerges from the old, innovation elaborates on preexisting material. It was Edgar Morin (2010) who suggested that the necessary change towards a more sustainable world is a process of metamorphosis, a new qualitatively different socio-ecological order that must be built, however, on the existing foundations. By doing so, it distances itself from the eternal contradiction between reform and revolution, between evolution and rupture. Metamorphosis is thus an appropriate metaphor for understanding the enormous complexity of socioecological change.

Despite all, the succession of socioecological regimes having different complexity levels and between which transitions can take place, is quite similar to the classical view of historical evolution of societies that lead to the Marxist theory of modes of production. After all, the recognition by most theoreticians in the field of the value of the contributions made by Marxist thinkers such as Maurice Godelier is not given for free. The proposals of Fischer-Kowalski and Haberl (2007) is not exactly equal to that of Godelier, it admits uncertainty and lack of defined directions of change, but is strongly reminiscent of former constructs in which the socioecological regime derives from an ontological structure that suggests immobility or, at least, equilibrium, and a dynamic of mere adjustments, the real changes exclusively occurring during periods of transition.

We are considering social metabolism in an instrumental and contingent way, thus lessening its normative load, not only because it is an ex post facto crated tool for understanding historical processes, but also because socioecological change is a constitutive property of social systems. The three described metabolic regimes—ideal types in Max Weber's sense—are conceptual constructs elaborated from the observed regularities of the socioecological organizations of the different societies exiting in the past. From our perspective, the process of socioecological change is continuous and leads to emergent structures of social metabolism that will not remain equal until a new period of transition begins. As we saw in Chap. 12, complex systems—alike human societies experimenting a continued process of transformation—do not evolve following the dynamics envisioned by the theory of modes of production.

However, it remains to debate if human societies traverse through phases of growth, development, and reach stationary states as complex systems do. Three phases have been discerned by socioecological transition studies: a phase of take-off in which the configuration of the system is unstable, and significant changes begin to merge announcing more radical future changes; a phase of acceleration characterized by swift and increasingly profound changes; and a phase of stabilization in which changes slow down. The steady state is the socioecological status that most resembles the stability showed by the modes of production from the perspective of identity. But nothing prescribes that human society must by fate experience such a steady state, or that this state be the final one before beginning the transition to a different metabolic regime. Social systems do not evolve linearly but in unexpected, random directions, among other things, because being entropically undetermined. Definitively, we understand socioecological transitional as the temporal process in which take place the most relevant changes leading to one of the isomorphic models of the metabolic regime we are considering. The socioecological transition is also a conceptual tool lacking ontological pretensions that seeks for making the socioenvironmental understandable by means of reducing its complexity. In that sense, the concepts of socioecological change and metamorphosis complement each other well, allowing transition to be understood as a process by which the social metabolism changes, for example, from the organic to the industrial modes. Metamorphosis admits variably lasting hybrid forms in which metabolism is neither entirely organic nor industrial.

13.9 The Main Driving Forces of Change

The analysis of the driving forces of socioenvironmental change is also a complex task consisting in exploring how the material processes of social metabolism (appropriation, circulation, transformation, consumption, and excretion) function mediated by the intangible factors (beliefs, knowledge, technology, institutions, etc.) in a combined way, and how that function changes as a consequence of the differential role played by components of the system through time. This process occurs directly linked to the complex, intricate, and reciprocal interrelations with the dynamics of ecosystems and landscapes being appropriated, or in of those in which the wastes are disposed off. The goal then is to find the rules of metabolic mutation based on a polyhedral or polyvalent system that is modified both in response to external factors on which it materially depends, and in response of the relative weight adopted by the inner, immaterial and material factors.

The metabolic change, or the metabolic dynamics, stems from the biophysical interaction between society and environment, having at its center the resource-population binomial. This demographic and resources binomial must not be seen blindly, as in the conventional simplified and reductionist approaches of human ecologies contemplating societies as one more biological population within the ecosystem. Instead, population change must be understood like the demographic expression of the synthesis of other factors, and resources must be seen as the limit and potency of the natural conditions that contain, sustain, and make possible any society. As we have seen, human societies attempt to remain as far from thermal equilibrium as it is possible, and they do that by using dissipative structures having a certain amount of energy, mater, and information. Flows of energy, materials, and the information circulating with them, are extracted by means of physical and biological environmental technologies. While through its mechanisms of information society determines which natural resources to appropriate, their amount is determined by environment itself so that the first factor to account for is the stock of resources available to a given society. The quantity and quality of natural resources and environmental services will limit the capacity of a society for depending on domestic extraction of energy and material flows, and for creating favorable environmental conditions for dissipative structures to do their work.

The changes in quantity and quality of the offer from ecosystems of natural resources and services are determined by two groups of factors: the dynamics of nature itself, and the effects societies exert on nature. On one side, natural dynamics have long-term time dimensions, but sudden changes do occur, which through environmental fluctuations or perturbations can alter the demographic processes of societies. Examples of this are the direct incidence of climatic fluctuations and other unpredictable or surprising events in the demographic and economic dynamics of organic metabolism by creating more or less favorable conditions for agriculture, livestock breeding, and forestry, therefore increasing or decreasing the surface of land required to supply social needs. Likewise, in the fourteenth century in Europe the Little Ice Age and volcanic eruptions generated climatic changes that caused rainy falls, cold springs, wet summers, and floods. During that period, locust plagues, earthquakes, and the Black Death epidemic also occurred. The consequences on societies of these perturbations were high rises of basic grain prices, famine, higher mortality, and a decrease in population, which caused a prolonged economic decline (Pfister 1988; Reilly and Anderson 1992). Something similar happened during the long crisis of the seventeenth century (Dearing et al. 2007, p. 242), originated by climatic perturbations accumulated between 1470 and 1630, and between 1688 and 1720. Climatic anomalies caused by El Niño in Australia, India, the Caribbean, Northern Africa, Western Europe, and the U.S. had dramatic social and economic consequences as documented by Richard Grove (2007).

On the other side, examples of social effects on resource quantity and quality are found in the depletion of guano reservoirs in Peru during the twentieth century, and the deforestation and scarcity of firewood in eighteenth century England. Social responses can be adaptation or surpassing of such limitations by means of technology or of new territorial arrangements.

The quantity and quality of wastes from metabolic processes must be also considered from the perspective of natural resources. While before the industrial revolution wastes had a low explanatory value of social dynamics and resource supply, since the nineteenth century, waste generation has gained in explanatory value until becoming one of the most relevant factors of change and environmental protests against pollution—for example, against pollution with nitrates and pesticides of groundwater and surface water consumed by people. The greenhouse effect and its foreseen consequences as climatic change and natural catastrophes is a good example of the importance that waste generation can have in technological change, adjustment of population, and finally on the design of social metabolism.

Population—the group of human individuals socially organized and receiving flows of energy and materials—is the opposite pole of resources. Human populations as dissipative structures can be dually considered: as processors of energy and mater by means of endosomatic consumption that generates work, wastes, and residual heat, and as a consumer of energy and materials through exosomatic dissipative structures processing energy and mater. Consequently, the metabolic profile of a society (the size of its metabolism either total or per capita) will be the result of the amount of energy and mater the society can extract from the environment for constructing and maintain dissipative structures that generate order, i.e., the sum of the endosomatic and exosomatic consumption,

$$\mathrm{MS} = \Sigma \mathrm{P}_n{}^{*}\,(\mathrm{endc} + \mathrm{exoc}) \tag{13.1}$$

where MS = Metabolic Size, P_n = Population size, endc = level of endosomatic consumption, and exoc = level of exosomatic consumption.

Seen from this perspective, the metabolic size is the product of the increase or decrease of the population, which has a dual effect: changing the amount of work force available, or changing the levels of consumption. Since the average endosomatic requirement of humans is little variable, the levels of exosomatic consumption are decisive for promoting change. Consumption may exceed or not the carrying capacity of the environment and cause adjustments in the organization of metabolism and of the environmental impacts generated.

The importance of population as working force varies among metabolic regimes, as exemplified by agriculture. Until mechanization had advanced late in the twentieth century, a strong link existed—and continues to exist in certain regions—between the size of the population and the intensity of cultivation. Demographic fluctuations had a direct incidence on the offer of labor for labor-intensive agrarian systems. The orientation and size of migratory flows and the rate of intensification of cultivation—besides technological innovation—is explained by the variations in the capability of the population of agrarian communities to satisfy such demand for work force. But as mechanization replaced work force, labor offer ceased to be the main condition for production. The decoupling of productive dynamic and demography had begun in the first decades of the twentieth century with the transition between the old and the new demographic regime, and the appearance of new irrigation and fertilization technologies.

There is nevertheless a controversial and mutable relation between economic and demographic growth, but it seems clear that the expansion of the human species over the surface of the earth, and its growing capacity for intervening in physical and biological processes, are related to the metabolism with nature of industrial civilization. Without the sustained expansion of the economy, monetary income, and social division and demand of labor, the current population densities would have never been reached to. It has been industrial metabolism what has created conditions for demographic growth, and not the reverse, as can be verified by examining the different population growth rates experienced by the human species. Between the beginning of our era and until 1750 the world population grew at a cumulative annual rate of 0.06 %, of 0.48 % from 1750 to 1850, 0.71 % between 1850 and 1950, and of 1.76 % from 1950 to the present (Tello et al. 2012). If in organic societies the structural scarcity of foodstuffs limited the proliferation of the species, counting with large amounts of fossil energy from the subsoil made industrial societies capable of overcoming the territorial limitations to production of energy, thus releasing the Malthusian brakes of demographic growth.

When considering that demography is the main explanatory variable of metabolic dynamic, other relevant varieties must also be taken into account: population size and its associated demographic dynamic, the level of endosomatic consumption and its changes along time, the level of exosomatic consumption and its changes, the size and structure of the population determining the installed potency or maximum labor capacity, etc.

The pressure on resources will increase, together with the internal metabolic entropy, if social entropy is compensated by increasing metabolic entropy, for example by building new more complex dissipative structures. One of the mechanisms generating more social entropy is the unequal assignation of goods and services, both material and immaterial. For example, it is very probable that metabolic entropy increases if part of the population is deprived of the social wealth generated in the appropriation and transformation of natural resources. The above statement can be represented by:

$$\begin{aligned} P_s &= \Sigma Sg_1\,(\blacktriangle\,\text{exoc}),\ Sg_2\,(\text{exoc}),\ Sg_3\,(\text{exoc}) = \blacktriangle\,\text{ME} \\ P_s &= \Sigma Sg_1\,(\blacktriangle\,\text{exoc}),\ Sg_2\,(\text{exoc}),\ Sg_3\,(\blacktriangledown\,\text{exoc}) = \text{ME} \\ P_s &= \Sigma Sg_1\,(\text{exoc}),\ Sg_2\,(\text{exoc}), Sg_3\,(\blacktriangledown\,\text{exoc}) = \blacktriangledown\,\text{ME} \end{aligned} \tag{13.2}$$

where P_s = Metabolic Profile of society, Sg_n = social group of society, exoc = level of exosomatic consumption, and ME = Metabolic Entropy.

Indeed, the forms of access and distribution of natural resources and services, and access to the satisfiers created for meeting the historically transforming needs of the individuals conforming each society has an influence, sometimes decisive, on the size and dimensions of social metabolism. Access to these satisfiers has been conditioned by the forms of appropriation of flows of energy and materials, or of their abstract expression in the form of money. An unequal distribution of access and enjoyment of satisfiers creates pressure towards a higher metabolic effort than that created by a more egalitarian distribution. The relations between appropriation, transformation, distribution, consumption, and excretion are conditioned by the symmetrical assignment of resources and satisfiers. The unequal distribution of resources has historically been a permanent source of conflicts that have become a powerful driver of the historical evolution of societies beyond environmental issues.

We saw in Chap. 12 that the behavior of the human species had an evident impact in metabolic dynamics. For example, a society in which the majority is competitively excluded from the usufruct of natural resources and services has powerful impulse towards social or environmental disequilibrium; exemplified by the usurpation of communal assets that was frequent in Feudal Europe. Deprival of forest products including firewood, lumber, hunting preys, gathered products, foraging land and others was one of the causes of increased pressure over the remaining communal forests. The exploitation of agrarian labor by dominant classes is a paradigmatic case of parasitism. The increment of the royalty income in Modern Europe, correlated with the increase of the exosomatic consumption of the dominant classes (Pomerantz 2000) has been singled as one of the causes of discontent that eventually lead to the French Revolution (see Aston and Philpin 1988). The colonized territories can be a good example of a predatory behavior by capture of slaves, lumber and mineral extraction, spoils of war, etc. (Guha 1989; Peluso 1992; Grove 1993).

The mechanisms of social exploitation or forced transference of income that we have seen can reduce the amount of available resources for satisfying both endosomatic and exosomatic consumption, or said differently, increase the aggregate consumption of the population and increase beyond the size of its population the demands made from the territory. From a socioecological perspective, social equity is not only an ethical imperative that condemns inequality, but also an ecosystemic pathology leading as we have seen to environmental degradation. This latter perspective is fundamental for our analysis because it takes the concept of equity to the grounds of its effects on sustainability (Guzmán Casado et al. 2000, p. 102). There are numerous cases, both past and present, in which poverty and inaccessibility to resources lead to environmental degradation from forest degradation and clearing, cultivation of slopes, overgrazing, use of agrochemicals, or other causes.

13.10 The Secondary Drivers

But the relation between demography and resource availability can also be altered by a series of factors of technological, economic, political, and even ideological nature. In that sense, technological change becomes a first order variable that rises or lowers the terms of the relation. According to its physical and biological characteristics, one or more ecosystems can sustain a given number of individuals at a certain level of endo and exosomatic consumption, thus determining the size of their metabolism. However, technological solutions may increase the carrying capacity beyond its possibilities by increasing the metabolic efficiency of the utilization of the available energy and materials. Usually, technological innovation has favored productivity increase, because of which it becomes relevant also for understanding the transformations in metabolic regimes—particularly the industrial one—and has been intimately associated to economic growth. Translated into physical terms, technological innovation has incorporated to the economic process large amounts of energy and materials, consequently generating increasingly widespread and deep environmental impacts. From the physical perspective, the historical trend has been towards the building of artifacts or technological processes that process growing amounts of energy, materials, and information. Stated in other terms, despite that the efficiency in the use of resources—measured for example as energetic intensity per monetary unit—has been incremented, through technological transformation societies have acquired increasingly complex and energy demanding dissipative structures.

$$\mathrm{MS} = \Sigma \mathrm{P}_n * (\mathrm{endc} + \mathrm{exoc})/\mathrm{Tech} \tag{13.3}$$

where MS = Metabolic size, P_n = Population size, endc = level of endosomatic consumption, exoc = level of exosomatic consumption, and Tech = Technological efficiency.

These social and physical dissipative structures required for their design and construction of flows of information. In that sense, sources of information must be considered as the forms of generation of knowledge through experience or other forms of generation and transmission of knowledge, such as science. The capacity for technological innovation, and therefore to a certain extent also of the conformation of the metabolic processes itself, has during the past two centuries depended on the development of scientific knowledge. The ways of generation and transmission of knowledge have adopted many modes, as for example the knowledge stored in the biocultural memory of many agrarian and indigenous communities throughout the world (Toledo and Barrera-Bassols 2008). Together with knowledge, the dominant cosmovision from each historical period has had a direct impact on the environment. The ideas about nature, and the human perception deriving from them have a definite influence on the conformation of metabolism and in trends of change. The present ecological crisis would be incomprehensible without the change in ideas occurring since the late eighteenth century, which opened the way to a biocentric anthropocentrism self-referenced in human beings themselves.

13.11 Ecological and Economic Exchange

The interchange between societies of energy, materials, and information and their respective metabolisms are among the most important variables for explaining their size and their economic and political capacities through time. A given social metabolism can grow beyond its supply of resources if it is capable of obtaining from outside its immediate surroundings the necessary resources for functioning. In that sense, economic exchange is relevant in environmental history for explaining socioenvironmental change. Economic exchange is actually an instrument of transference of energy and materials between societies that consumes energy and generates wastes. A society can increase the sustentation capacity of its territory by importing resources from other societies through economic exchange. The intensity and amplitude of communications has made the exchange of energy and materials between metabolisms, and have turned unequal exchange into a first order explanatory variable for understanding the global socioecological configuration, in particular during the past two centuries.

In fact, a theory of socioecological transformations cannot be built ignoring the characteristics of the material interchanges taking place between human beings (economic exchange) and between these and nature (ecological exchange), and forming part of the general process of social metabolism. Defining ecological exchange is easy, but the economic exchange of materials, energies, water, services, or commodities is problematic because it is mediated by a debatable mechanism of value assignment according to culture, context, and subjective reasons (Martínez-Alier 1987; Hornborg 1998, 2003). In this latter case, there is a theoretical tangle in the field of economy, having immediate political implications, but not yet unraveled.

The degree of equality of ecological exchanges is determined by human appropriation of energy and materials not surpassing the ecosystem's reproductive capacity, and social excretion being under the environment's absorption capacity limits. The character of ecological exchange can be quantified in terms of these two indicators and human impact on ecosystems can thus be evaluated. Human exploitation of nature will appear when humans, by diverse types and intensities of activities, attempt against the existence of the ecosystems they use, as in exploited fish populations, forest products, soils, and water sources.

It is not the same with economic exchanges because there are several approaches to quantify the value of what is exchanged, each one reaching to different conclusions and having different implications. For the neo-classical economists it is the market what fixes the price of commodities through offer and demand, and since unequal exchange is inexistent, trade cannot generate social inequity or exploitation. But for Marx there are forms of exploitation in the exchange because a part of the work force given by the laborer (rural, urban or industrial) is not recognized nor paid by the market. A third position is that of Odum (1985) who has attempted to build an energetic theory of value of commodities based on the amount of energy incorporated into a product, economic value of merchandises being proportional to the input of energy required for their production. Marx and Odum (1985) identify a sub-payment, be it of labor or energy input, which immediately uncovers the mechanism of exploitation by means of transference of value.

More recently, Hornborg (1998, 2003) has introduced a new idea based on the principles of thermodynamics: given that there is dissipation of energy in every transformation of a raw material, the more a product is transformed, the more energy will be dissipated, the amount of available energy is inversely proportional to the price of the product. This can be translated as that the sum of the products exported from an industrial center contain less available energy than the sum of the imported components, which from a strictly thermodynamic perspective corroborates unequal exchange between the center and the periphery of countries, regions or sectors.

Whichever interpretation is accurate, and this mater should be solved in the future, the fact is that in transactions between humans there are and have been throughout history many instances of unequal, or non equivalent exchange. These instances place unequal economic exchanges as a force triggering similarly asymmetric ecological exchanges, leading to a fundamental hypothesis: societies can only persist and avoid their collapse by inactivating the effects of unequal economic exchange over exchanges with nature. Said in other way: when exploitation inside society is not transferred to and turned into exploitation of nature.

These importations of resources can be made pacifically through economic exchange, or be enforced through political and military subjugation of one State by another. The decisions made from power and, in general, from the social institutions in charge of regulating social relations, use of resources, and environmental functions, have an unquestionable relevance. We are referring to the stable (regulations and juridical norms) or punctual (decisions) power relations having the goal of reproduction both of the metabolism between society and nature, as the forms in which society organizes and therefore, the forms in which energy and materials flow inside it. Influenced by the remaining factors, regulation has a definitive influence on these other factors and the dynamics of social metabolism. We saw in Chap. 12 the definitive function of institutions for controlling—in the cybernetic sense of organizing—and regulate social and metabolic entropy, either reproducing or changing the biophysical and social structures.

As seen in Chap. 12, unequal distribution of material or immaterial resources has historically been a permanent source of conflicts and a powerful motor for the historical evolution of societies and their corresponding metabolic configurations. For example, current environmental protests, in particular from ecologists, help to internalize the environmental costs and to reduce the entropy in the internal or external environment, and while they cannot make social metabolism to change suddenly, they diminish its negative impacts on natural environment and widen the road towards metabolic change. We can thus say that conflict, especially environmental conflict, can increase or decrease the size and intensity of metabolism, i.e., the flow of energy, materials, and information. Therefore conflicts can contribute to increase or decrease the levels of sustainability. In consequence, both social conflicts and purely environmental conflicts are a potential source of socioecological change and should be taken into account when studying the evolutionary dynamic of social metabolism, and of the socioecological relations between societies.

13.12 Uncertainty as a Factor of Change

Finally, environmental historians should pay attention to randomness, or more precisely, to uncertainty, a factor that is usually ignored by social sciences. As suggested by several authors, uncertainty or surprise is an unavoidable factor in any socioecological analysis (Holling et al. 1998; Funtowicz and Ravetz 1993). Uncertainty characterizes events having unknown means, unclear causes, and their casual factors being interrelated in ways not completely understood. Because of that the operations governing their predictability occur in strange or undescribed manner. Uncertainty can be interpreted as a phenomenon occurring at random—without an apparent logical casualty—and thus being erratic. But uncertainty can also be interpreted as the logical—although unpredictable—result of interaction between the many factors of social metabolism we have seen. To make uncertain phenomena more complicated and unpredictable, natural resources represent an enormously complex factor combining physical, chemical, geological, and biological environmental components that are expressed in ecosystems and landscapes. An example can be seen in the close relation during recent times between the growth and intensification of social metabolism and the frequency of apparently hazardous catastrophic events.

In coherence to what we have said, the analysis of mutations of social metabolism finds its meaning in the combination of the stated factors, either externally or inside society, and in the former case, both tangible and intangible, whose forms of interplay and specific hierarchy will be privative of each place and historical circumstances. Seen in this way, the course followed by humanity resembles the growth of branches of different thickness expressing the level of appropriation of sap—resources—and whose geometrical representation is that of a fractal.

13.13 The Industrialization Process: An Example of Metabolic Change Induced by Inequality

The correlation between inequality, social and metabolic entropy can be explained by what happened with the expansion of industrial metabolism during the past two centuries, an analysis that is essential when examining the forces of socioecological change. The process of industrialization has been identified with continued increase of the productivity of labor and energetic efficiency of the industrial output, which causes a continued economic growth. That is what is known as expanded or enlarged reproduction of capital. Translated to thermodynamic terms, the industrial metabolic regime has been founded on the continued assemblage of dissipative structures that have progressively raised the requirements of energy, materials, and information.

Inequality is by nature the result of continued economic growth. It has been the result of the habitual functioning of market or capitalistic economies since its success in eighteenth century England. As demonstrated by Marx, inequality is inscribed in the most intimate mechanisms of the capitalist productive system and the social predominance of the market. As stated before, market involves a relation of power, which due to its nature assigns goods and services in an unequal way according to the amount of tangible or intangible resources with which individuals, social groups, or corporations enter the market.

As industrialization progresses and economic growth have become established, inequalities have increased in parallel. In the year 2000, according to the World Bank global inequality among world inhabitants was considerable: the most affluent 20 % of the global population accumulated 86 % of the total global income, while the poorest 20 % had access to only 1.3 % of the global income (Worldwatch Institute 2005). Inequality is also apparent between countries: in 2005, the annual per capita GDP (estimated in international dollars adjusted by the purchasing power parity) was of around $42,000 in the U.S.; of $30,000 in the U.K., Germany, Spain, and France; of $10,500 in Mexico; and in China it was under $6,500. The GDP in Sub-Saharan Africa was more modest, being of $2,000 in Nigeria, and of $360 in Liberia, the poorest country in the world.

Although unequal distribution of income is an antique phenomenon, it abruptly peaked after the industrial revolution (Acemoglu 2009). Before that date, the income of agrarian economies grew at a slow rate and only during episodes of economic growth, but it was neither cumulative nor continued through time. Modern economic growth has contributed to the rise of the living standards of countries that became industrialized, but in exchange for unprecedented high levels of inequality between social groups and territories. Based on the Theil index measuring inequality, some studies have shown that inequality among individuals increased during the nineteenth century, stabilized between the First and Second World Wars, and increased once more during the second half of the twentieth century (Bourguignon and Morrison 2002).

The value of the Theil index went from 0.52 in 1820 to 0.80 in 1910, remaining nearly unchanged until the 1950s, again rising to 0.86 in the late 1990s. This behavior of inequality largely agrees with the evolution of consumption of energies and materials. From the thermodynamic perspective, economic growth, i.e., the growth of consumption of energy and materials creating order (material wellbeing), has been possible by transferring, first to the working class—rising social entropy above metabolic entropy, increasingly more to the environment of industrialized countries—increasing metabolic entropy to lower social entropy, and finally to poor countries—transferring to these countries the social and metabolic entropies.

During the first stages of the birth and expansion of industrialization through Europe, the U.S., and Japan, the opportunity to enter this new regime was to a large extend determined by the availability of fossil fuel reservoirs, in particular of coal, and meeting a number of institutional requirements to promote energetic transition and the expansion of industrialism, but also to have abundant and low cost work force. As we have seen, industrial processes required large amounts of work force. During that time period, a large part of the internal entropy generated by the process of industrialization was shared between the domestic environment (internal physical entropy) and the working class (internal social entropy). In that sense, the social costs of industrialization experienced by England are a good example of this correlation between social and metabolic entropies. In abstract terms, the correlation is expressed as:

$$E_t = (SE_{in} > ME_{in}) > E_{out} \tag{13.4}$$

where E_t = total Entropy, SE_{in} = internal Social Entropy, ME_{in} = internal Metabolic Entropy, and E_{out} = external Entropy.

Nevertheless, the expansion of industrialization would not have been possible in some countries without the supply by their agrarian sectors of enough foodstuffs to satisfy the needs of the increasingly large population beginning to be settled in cities. That task was achieved by the agrarian sector because cropland for more and more intense cultivation was still available, but in other countries the solution was to import from third party countries large amounts of food, and to a lesser extent of fertilizers. In these latter countries where the internal entropy was still low, exports of agrarian products and other raw materials frequently generated exploitation of workers—slavery, plantations, destruction of peasant economies, etc., resource depletion—guano in Peru, nitrates in Chile, etc., pest dissemination—coffee rust, prickly pears, etc. This meant that the external entropy of affluent countries began to grow.

Social distress accompanied the development of capitalism until labor organizations through mutualistic societies, trade unions, and finally, labor parties, confronted the worst laboring conditions and pauper living conditions of the working class. A transition from the predominance of social entropy to metabolic entropy began between the end of the nineteenth century and the Second World War, which would end in the great acceleration of the 1950s. Keynesian policies and the impulse of the labor movement collided in an agreement in which collective negotiation, and the rising trend of direct and indirect salaries became institutionalized through the establishment of welfare state policies. The increase of labor and social costs was compensated by new and more numerous dissipative structures that altered the former relation between social and metabolic entropies. The continued growth of exosomatic consumption, i.e., the growth of the metabolic profile of citizens, became the privileged way to make bearable the growing levels of social inequality in industrialized countries, and a mechanism for expanding the domestic market.

$$E_t = (SE_{in} < ME_{in}) > E_{out} \tag{13.5}$$

where E_t = total Entropy, SE_{in} = internal Social Entropy, ME_{in} = internal Metabolic Entropy, and E_{out} = external Entropy.

While towards 1820 the main component of inequality can be explained by differences between social groups inside countries, gradually the inequality between territories gained terrain and went from 11 % in 1820 to 58 % in 1992. The industrial metabolism with a capacity for expansion inserted at its core did not expand uniformly throughout the planet creating the conditions we know from developed countries: industrial predominance, decreased agrarian sector, rise of income per capita, material wellbeing, etc. This means industrialization has expanded by creating order, but at the same time, the progress of the industrial metabolic regime needed to transfer to nature or to other social groups the energy being dissipated in the process, which is achieved by international trade based on unequal exchange. Asymmetric trade became the most sophisticated exploitation technique of history requiring only punctual use of violence, not involving a complete control neither of the territory in which sources of resources exist, nor of the work force as it used to be in slavery or servitude. As economic growth became accelerated during the postwar period, the dependency of potencies on sources of materials and energy from peripheral countries became decisive for sustaining economic growth and wellbeing in the West, i.e., for building and maintaining their increasingly numerous dissipative structures in the form of economic and social infrastructures. The growth of the metabolic profile of the affluent countries was now only possible by the costs paid by the peripheral countries.

$$E_t = (SE_{in} < ME_{in}) < E_{out} \tag{13.6}$$

where E_t = total Entropy, SE_{in} = internal Social Entropy, ME_{in} = internal Metabolic Entropy, and E_{out} = external Entropy.

The relative dematerialization of industrialized societies beginning in the 1970s with the transfer to poor countries of most entropic processes is a clear manifestation of the need of capitalistic systems for exporting their growing entropy. Industrialized developed countries do not reach to a steady state, but their highly entropic processes take place outside their territory, while the services these processes provide are recovered. This fact is further demonstrated by the continued growth in industrialized countries of the income per capita in parallel with that of exosomatic consumption. It is for a reason that development and underdevelopment—order and disorder—are said to be two faces of the same phenomenon: economic growth or capitalistic development is always unequal. This is but an economic metaphor of the principle of entropy. The fact is that the dissimilarities in rates of economic growth in the different regions of the planet during the past 200 years have accentuated the economic divergence between rich and poor countries in terms of income per capita (Acemoglu 2009). According to data from the Angus Maddison, between 1820 and 2008 the real income of the population multiplied by 25 in the New Europe (former colonies populated by Europeans as the U.S., Canada, Australia, and New Zealand), by 18 in Western Europe, by 10 in Latin America, and by a little over 4 in Africa. A direct link is found between industrialization, economic growth, and inequality in the world (Tello et al. 2012, p. 10), i.e., between the increase of inequality and the highly entropic character of the industrial metabolic regime.

References

Acemoglu D (2009) Introduction to modern economic growth. Princeton University Press, Princeton

Adams RN (1975) Energy and structure. A theory of social power. University of Texas Press, Austin

Alkemade F, Hekkert MP, Negro SO (2011) Transition policy and innovation policy: friends or foes? Environ Innov Soc Transitions 1(1):125–129

Aston TH, Philpin CH (eds) (1988) El debate Brenner: estructura de clases agrarias y desarrollo económico en la Europa preindustrial. Editorial Crítica, Barcelona

Basalla G (1988) The evolution of technology. Cambridge University Press, New York

Benton T (ed) (1996) Greening marxism. Guilford Press, New York

van der Bergh JC, Bruinsma FR (eds) (2008) Managing the transition to renewable energy. Edward Elgar, Cheltenham

Bourguignon F, Morrison C (2002) Inequality among world citizens: 1820-1992. Am Econ Rev 92(4):727–744

Butzer K (1976) Early hydraulic civilization in Egypt. University of Chicago Press, Chicago

Cipolla C (1983) Historia económica de Europa: la revolución industrial. Ariel, Barcelona

Costanza R, Graumclih LJ, Steffen W (eds) (2007) Sustainability or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts

Dearing JA et al (2007) Group report: integrating socioenvironmental interactions over centennial timescales. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 243–274

Debier JC, Déleage JP, Hémery D (1986) Les Servitudes de la Puissance: une Histoire de L'Energie. Flammarion, Paris

Denevan WM (1982) Hydraulic agriculture in the American tropics: forms, measures and recent research. In: Flannery KV (ed) Maya subsistence. Academic Press, New York, pp 181–204
Dowidar MH (1978) Le Economie Politique, Une Science Sociale. F. Masper, Paris
Duncan DE (2006) The pollution within. National Geographic, Oct 2006
Fischer-Kowalski M (2011) Analyzing sustainability transitions as a shift between socio-metabolic regimes. Environ Innov Soc Transitions 1(1):152–159
Fischer-Kowalski M, Haberl H (eds) (2007) Socioecological transitions and global change. trajectories of social metabolism and land use. Edward Elgar, Cheltenham
Fischer-Kowalski M, Rotmans J (2009) Conceptualizing, observing, and influencing social-ecological transitions. Ecol Soc 14(2):3
Flannery KV (1972) The cultural evolution of civilizations. Annu Rev Ecol Syst 3:399–426
Fossaert R (1977) La Société, Tome 2, Les Structures Économiques. Éditions du Seuil, París
Frank AG (1967) Capitalism and underdevelopment in Latin America. Monthly Review Press, Nueva York
Funtowicz S, Ravetz JR (1993) Science for the post-normal age. Futures 25(7):35–38
Geels FW (2005) Co-evolution of technology and society: the transition in water supply and personal hygiene in the Netherlands (1850–1930): a case study in multi-level perspective. Technol Soc 27:363–397
Giampietro M (1997) Linking technology, natural resources and the socioeconomic structure: a theoretical model. Adv Hum Ecol 6:75–130
Grin J, Rotmans J, Schot J, Geels FW, Loorbach D (2010) Transitions to sustainable development. New directions in the study of long term transformative change. Routhledge, New York
Grove R (1993) Conserving the Eden: The (European) East Indian Companies and their environmental policies on St Helena, Mauritius and in Western India, 1660 to 1854. Comp Stud Soc Hist 35(2):318–351
Grove R (2007) Revolutionary weather. The climate and economic crisis of 1788–1795 and the discovery of El Niño. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 152–167
Guha R (1989) The unquiet woods: ecological change and peasant resistance in the Himalaya. Oxford University Press, New Delhi
Guzmán Casado G, González de Molina M, Sevilla Guzmán E (2000) Introducción a la Agroecología como desarrollo rural sostenible. Editorial Mundiprensa, Madrid
Hibbard KA et al (2007) Decadal-scale interactions of humans and the environment. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 341–377
Holling CS (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4:390–405
Holling CS, Berkes F, Folke C (1998) Science, sustainability and resource management. In: Berkes F, Folke C (eds) Linking social and ecological systems. Cambridge University Press, Cambridge, pp 342–362
Hornborg A (2003) The unequal exchange of time and space: toward a non-normative ecological theory of exploitation. J Ecol Anthropol 7:4–9
Hornborg A (1998) Towards an ecological theory of unequal exchange. Ecol Econ 25:127–136
Kemp R, Loorbach D (2003) Governance for sustainability through transition management. In: Paper for EAEPE 2003 Conference, Maastricht
Lachman DA (2013) A survey and review of approaches to study transitions. Energy Policy 58:269–276
Loorbach D, Rotmans J (2010) Transition management and strategic niche management. Dutch Res Inst Transitions, Rotterdam
Mantua NJ (2007) A decadal chronology of 20th century changes in earth natural systems. In: Costanza R et al. (eds), Sustainability or collapse? an integrated history and future of people on earth. The MIT Press, Cambridge

Markard J, Raven R, Truffer B (2012) Sustainability transitions: an emerging field of research and its prospects. Res Policy 41(6):955–967

Martínez-Alier J (1987) Economía Ecológica. Fondo de Cultura Económica, México

Marx K 1867 (1975) El Capital. Siglo XXI Editores, México

Marx K (1971) Formas que Preceden o la Producción Capitalista. Cuadernos del Pasado y Presente, Córdoba

McNeill JR (2000) Something new under the Sun: An environmental history of the twentieth century world. Penguin Books, USA

McNeill JR (2007) Social, economic and political forces in environmental change: decadal scale (1900–2000). In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 301–330

McNeill JR, McNeill WH (2004) Las Redes Humanas: una historia global del mundo. Crítica, Barcelona

MEA (Millenium Ecosystem Assessment) (2005) Synthesis report. Island Press, Washington. www.milleniumassesssment.org/ Accessed 18 Oct 2013

Morin E (2010) Elogio de la metamorfosis. El País, Madrid

O'Connor J (1988) Capitalism, nature, socialism: a theoretical introduction. Capitalism Nat Soc 1(1):11–38

Odum EP (1985) Fundamentos de Ecología. Interamericana, México

Olsthoorn X, Wieczorek AJ (eds) (2006) Understanding industrial transformation: views from different disciplines. Springer, USA

Peluso N (1992) Rich forest; poor people. Resources control and resistance in Java. University of California Press, Los Angeles

Pfister C (1988) Fluctuations climatiques et prix céréaliers en Europe du XVIe. au XXe siècle. Annales ESC 41(1):25–53

Pingali P, Bigot I, Binswanger HP (1987) Agricultural mechanization and the evolution of farming systems in sub-Saharan Africa. John Hopkins University Press, USA

Pomerantz K (2000) The great divergence: China, Europe, and the making of the modern world economy, 2000. Princeton University Press, Princeton

Prigogine I (1996) The end of certainty: time, chaos, and the new laws of nature. Simon Schuster Ed, USA

Redman L Ch et al (2007) Group report: millenial persepctive on the dynamic interaction of climate, people and resources. In: Costanza R, Graumclih L, Steffen W (eds) Sustainabiliy or collapse? An integrated history and future of people on earth. The MIT Press, Massachusetts, pp 116–148

Redman L Ch, Kinzig AP (2003) Resilience of past landscapes: resilience theory, society, and the long durée. Conserv Ecol 7:457–471

Reilly JM, Anderson M (1992) Economic issues in global climate change. Agriculture, forestry and natural resources. Westview Press, USA

Rotmans J, Kemp R, van Asselt M (2001) More evolution than revolution: transition management in public policy. Foresight 3:15–31

Smil V (1994) Energy in world history. Westview Press, Denver

Tainter JA (1988) The collapse of complex societies. Cambridge University Press, Cambridge

Tello E, Martínez J, Ramón R, Garay L, Badía M, Carreras A (2012) Cómo hemos llegado hasta aquí. Una introducción a la historia económica global. Universtiat Oberta de Catalunya, Barcelona

Toledo VM (2002) La religión del automóvil: crónica de una tragedia. Ecología Política 23:9–12

Toledo VM, Barrera-Bassols N (2008) La Memoria Biocultural. La importancia agroecológica de las sabidurías tradicionales. Icaria, Barcelona

Wallerstein I (1974–1980) The modern world system. Capitalist agriculture and the origins of the european world-economy in the sixteenth century. Academic Press, London

Wolf E (1982) Europe and the people without history. University of California Press, California

Worldwatch Institute (2005) La situación del mundo, 2005. Icaria, Barcelona

Chapter 14
Epilogue: Metabolisms, Entropy and Sustainable Society

Any epilogue is the cherry on the cake.

Anonymous

14.1 Introduction

In December 2012, a pink-haired complex systems researcher named Brad Werner made his way through the throng of 24,000 earth and space scientists at the Fall Meeting of the American Geophysical Union, held annually in San Francisco… it was Werner's own session that was attracting much of the buzz. It was titled "Is Earth F**ked?"… Standing at the front of the conference room, the geophysicist from the University of California, San Diego walked the crowd through the advanced computer model he was using to answer that question. He talked about system boundaries, perturbations, dissipation, attractors, bifurcations and a whole bunch of other stuff largely incomprehensible to those of us uninitiated in complex systems theory. But the bottom line was clear enough: global capitalism has made the depletion of resources so rapid, convenient and barrier-free that "earth-human systems" are becoming dangerously unstable in response… There was one dynamic in the model, however, that offered some hope. Werner termed it "resistance"—movements of "people or groups of people" who "adopt a certain set of dynamics that does not fit within the capitalist culture". According to the abstract for his presentation, this includes "environmental direct action, resistance taken from outside the dominant culture, as in protests, blockades and sabotage by indigenous peoples, workers, anarchists and other activist groups"… We know that past social movements have "had tremendous influence on… how the dominant culture evolved", he pointed out. So it stands to reason that, "if we're thinking about the future of the earth, and the future of our coupling to the environment, we have to include resistance as part of that dynamics. And that, Werner argued, is not a matter of opinion, but "really a geophysics problem (Klein 2013)".

The event that motivated this reaction is significant in more than one way. Maybe it was the first time that in a high rank, sober, rigorous, and solemn scientific congress, a researcher included *civil protest* and *resistance* as a factor—not only essential but paying a key role—in a predictive model constructed from the perspective of complex systems theory. Calls for civil rebellion had until then

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raised from political rallies and congresses, street barricades, angry demonstrations, and social networks, but not from decent and ordered congresses of a science as hard and rigorous as Geochemistry. This occurrence is also noticeable because it expresses the feeling of despair of researchers in charge of studying the global ecological crisis, and climatic change in particular. While evidence from numerous interdisciplinary, international research teams about the precarious condition of the planet continues to accumulate, neither governments, nor enterprises, nor international organizations appear to be moved to make the corresponding urgent decisions. The voices, increasingly loud, coming from scientific circles are not listened by the world sectors that are supposed to make required decisions, and their warnings and recommendations are nearly always ignored. The above statements can be confirmed by the sequel of international meetings about the Kyoto Protocol that took place between 1997 and 2013, all ending up in a series of failures.

The above said, in a fine context interpretation characterizing an institutional crisis, must be glossed as evidence by the choir denouncing the unvaibility of the main institutions of the modern age—the State, democracy, the market, industry and a long list of others—and the reciprocal widening of the breach of insecurity and uncertainty within what the German sociologist Beck (1986) called a *risk society*.

14.2 The Multiple Calls of Critical Thinkers

As we stated in the introduction to this book, what we are really experiencing is the increasingly urgent and desperate calls warning about the process of slipping to collapse of the world. These claims coming from the most lucid sector of humanity have been emitted from several fields of knowledge by thinkers having different backgrounds, formations, and nationalities. The so-called scientific cries, as that of geophysicist Brad Werner, and the claims and demands of an ample sector of society expressed by multiple means, have been preceded and anticipated by the reflections of numerous authors. We have made a selection of which we consider to be crucial critical thinkers with the intention of illustrating the widening of the rupture that we may call the *supreme concern*, and which is the ultimate and profound motive of this book.

One decade after the end of the Second World War, Erich Fromm (1900–1980) published in 1955 one more of his numerous books with the title *The Sane Society*, in which he presents a vision that became more and more evident as modern, industrial civilization became consolidated (Fromm 1955). *The Sane Society*—a monumental book as most of Fromm's writings—includes theses he previously formulated in his books *Psychoanalyse and Ethik* Fromm (1946) and *The fear of Freedom* (1941), thus being the third part of a trilogy. In this book Fromm makes a profound radiography of modern society based on the explanation of human beings not as entities moved exclusively by irrational impulses, but as the product of a lengthy process of biological and social evolution. Are we sane? Fromm asks, concluding that the pathological psychology of society needs to be overcome by a new relation of human beings with nature, themselves, and other human beings.

In the following decade, another giant of critical thought, Arthur Koestler (1905–1983), a writer of novels, essays, and scientific works, published the book *The Ghost in the Machine* (Koestler 1967) with a subtitle that summarizes its content: *The urge to self-destruction: a psychological and evolutionary study of modern man's predicament*. As Fromm, Koestler records the danger of modern times: "So one ought to be cautious with pronouncements about the uniqueness of one's own time. Nevertheless there are at least two good reasons, which justify the view that humanity is going through a crisis unprecedented in its nature and magnitude in the whole of its past history. The first is quantitative, the second qualitative (Koestler 1967, p. 313)." The first cause of this human crisis is identified by Koestler as the rupture of ecological balance due to the demographic explosion, and the huge power for transformation, communication, and knowledge achieved by humanity. The second cause is the capacity for self-destruction derived from the invention of thermonuclear bombs. He then warns us: "…before the thermonuclear bomb, man had to live with the idea of his death as an individual; from now onward mankind has to live with the idea of its death as a species (Koestler 1967, p. 322)." Consequently, he establishes that: "The human race is facing a challenge unprecedented in its history—which can only be met by taking action of an equally unprecedented nature (Koestler 1967, p. 323)."

At the end of the twentieth century, after the work of these two pioneers, we have seen the appearance of noticeable contributions of authors as the Austrian philosopher Ivan Illich, the Brazilian theologist Leonardo Boff, and the immense writings of the French philosopher Edgar Morin. Of great interest are also the contributions of the Austrian physicist Frijot Capra (1982), whose book *The Turning Point, Science, Society and the Rising Culture* reviews the history and weaknesses and reductionism of Cartesian and Newtonian science. Capra claims that science has become outdated in terms of modern ecological issues, requiring the adoption of complex systems theory. Also noteworthy are the writings of the U.S. historian Morris Berman, among which his book *The Reenchantment of the World* (Berman 1981) represents a breaking point achieving to reveal in detail and in depth the mutation that caused the advent of modernity in the conception of the natural world. Other thinkers needing mention are Ulrich Beck and his *Risk Society* (Beck 1992) in Germany, Vandana Shiva in India, Serge Latouche and André Gorz in France, and Ramón Fernández-Duran (1947–2011) in Spain, in particular his book *El Antropoceno. La expansión del capitalismo global choca con la Biosfera* (Fernández-Durán 2011). Within the political realm, the reflections emitted from opposite angles of Fidel Castro and by Al Gore are obligate references.

The theses, warnings, fears, and predictions of these authors and other more contributed to create a new critical culture questioning industrial modernity and thrusting a new utopia in which re-harmonization among society and nature occupies the stellar role. As reputedly stated in this book, the main big task has been to re-calibrate the instruments of knowledge about current reality, given that they have lost their usefulness for achieving an adequate perception of the unexpected and surprising phenomena modeling the history of the planet Earth.

14.3 The Limited Capacities of Contemporaneous Science

Contrary to the dominant claims everywhere being diffused regarding the power and effectiveness of science, the manifest limitations of contemporaneous scientific research for understanding, and most important, for solving the major current issues must be humbly admitted. The velocities in which changes occur and the new synergies these trigger are being amplified faster than the rhythm with which knowledge advances. And advancing does not mean increasing the number of participants or intellectual products generated (papers, patents, technologies), but to increase the capacity for understanding of the phenomena that surge, mutate, and multiply vertiginously. It is thus a matter of quality rather than quantity. Currently, science is realized by thousands of human beings in an unconnected, specialized, and fragmented way and distanced from real world issues. Corporative and governmental interests, responding to mercantile, political, and military needs, constrain today's science before facing the primary and essential needs of society—and even more worrisome, of the human species, the planetary equilibrium, and life itself. The latter problems, of high complexity, are the ones that must be attacked first, which requires of a series of scientific institutions compromised with society and nature, and of a new social agreement.

For instance, current science has resigned to elaborate a theory allowing for the proper understanding and consequent analysis of contemporaneous reality, which as we have seen, requires more than a trans-scalar perspective, but also of a diachronic or historical view. The question that must be first sown in every woman or man devoted to science is: What happened, what is happening, and what will happen with the planet Earth that serves as the habitat of the human species? The lack of holistic perspectives and the marked bias towards the compartmentalized observation of minute phenomena of specialized science explains why, unlike to the nineteenth century, few efforts are made for arriving to an integrated, holistic knowledge.

A good part of the mess in which the human species is found at the present is the absence of new *navigation instruments* than those provided by the 300 years of experience, the antiquity of the form of knowledge known as science. For a time dimension of 200,000 years, approximately the time of existence of the human species, the accumulated experience of scientific thinking is not only minimal, but perhaps also negligible. We should question ourselves if we should turn to pre-scientific or pre-modern knowledge—the set of wisdom still persisting—and that form a sort of biocultural memory of the species (Toledo and Barrera-Bassols 2008).

As we have seen throughout this book—attempting to overcome such limitations, the serious, rigorous, and deep efforts made from different fields of knowledge under holistic criteria, represent a counter-current struggle. However, all these efforts have not yet led to an integrative framework. Such is the case of what we have called *hybrid disciplines* (see Chap. 2 and Fig. 2.1), which are new fields of study originated within consolidated fields of knowledge about society, humanities, and technology. These hybrid disciplines have attempted to establish links with ecology, seen as a science of synthesis of nature, agglutinating the analysis of physical, chemical, geological, and biological processes. Appearing in different times and from different fields of study, hybrid disciplines have had a noticeable, and some times explosive progress along the past two or three decades, to the point that in some cases they have surpassed their own *mother fields*, as perhaps are the cases of agroecology or environmental history. However, given that each of these hybrid disciplines was born from well-delimited fields of study, none of them offers a general theoretical framework regarding the relations between society and nature. Instead, each hybrid disciplines self-proclaim themselves as chosen for accomplishing such a task, but always carrying their own epistemological limits marked by their central object of study (economy, history, agroecosystems, culture, politics, etc.). Their sin is to have been born from a specific, specialized field of study.

14.4 A Synthesis of Syntheses

The visualization and construction of an appropriate theoretical framework about current reality requires to *orchestrate* the today dispersed vast knowledges about the multiple dimensions of such reality. The challenge proposed by this book was to make a coherent integration, that is theoretically robust, offers means for its application, and encompass reality (Chap. 2). In the second half of the twentieth century several currents were born, developed, and expanded which assumed that same challenge as their central goal. These currents form the background for this book. Among others, the complex systems theory of L. Von Bertalanffy leads the list, together with the so-called theory of complexity and its different ramifications (E. Morin and many other authors). Other less ambitious, but not less relevant attempts surged from Sociobiology founded by E. O. Wilson, whose main proposals served as foundation for establishing a connection between biological and cultural evolution, i.e., for integrating the research of geneticists, ethologists, paleontologists, archaeologists, psychobiologists, and linguists. Also of key importance were authors working for applying complex systems theory, first to living organisms and later to human societies, in particular regarding the laws of thermodynamics and the principle of entropy. The central proposal of such new currents was recovering the holistic, integrative, and interdisciplinary perspective (Koestler and Smythies 1971).

But during the construction of a new scientific paradigm a simple rule must be contemplated without which the effort is far from being guaranteed: how to sum the knowledge accumulated under the questioned paradigms? This question leads to solving the dilemma between what Holling (1998) called the *science of parts* and the *science of integration of parts*, i.e., between the conventional way of making science and another opposite way (Table 14.1). It is about the analytical and the integrating approaches. The question is, are these two ways excluding or complementary? Holling provided an answer for this question: "Both the science of parts and the science of the integration of parts are essential for understanding and action. Those more comfortable in exercising only one of these, have the responsibility to understand the other. Otherwise the science of parts can fall into the trap of providing precise answers to the wrong question and the science of the integration of parts into providing useless answers to the right question (Holling 1998, p. 4)."

In our effort for building a theory of social metabolism we have perused these valuable currents that preceded us and from which we have elaborated a synthesis of several previous or partial syntheses. With that, we attempt to give birth to a theoretical and methodological instrument of utility for understanding the contemporary world. We believe that this synthesis, concretized in the basic model we propose and use (Chap. 4), has made at least five innovations: (a) a socioecological approach contemplating society and nature as two inseparable entities, i.e., incomprehensible if analyzed separately; (b) a novel diachronic focus placing and examining this social and natural complex through time and forming part of *environmental history*, a hybrid discipline that relocated history as a part of a sustainable science and turned it into an essentially practical *salvage science*, an idea that was amply discussed in Chap. 2; (c) the analysis of the *soft component* of the metabolic phenomenon, the properly social dimension which will reveal the properly sociological inspection of the study object, and that centers in information flows, which in turn allow for communication among individuals of the human species converted into societies, fundamentally but not exclusively based on language or symbols that induce the creation of diverse institutions and degrees of complexity; (d) the visualization, an ambitious attempt, of metabolic transformations as one more case of the general evolutionary process (of matter, life, and human intelligence), and hence, as a metamorphosis within the general laws of thermodynamics that generates equilibrium or disequilibrium, chaos or order.

The above culminated in the definition of three types of entropy: *metabolic*, *social*, and *institutional* or *political* (Chaps. 12 and 13); and as a consequence of the above, (e) the discovery of the existence of a new relation having enormous ethical, political, and civilizatory value: the apparently indissoluble link between the mechanisms of *exploitation of nature* (the environment or external universe of society) and of *social exploitation*, revealed not only by the revision of human historical evolution, but also by the evolutionary flow of life and the cosmos. All this provides numerous significations to this new interpretation of reality (past, present, and future), one of which stands out for its great relevance given the current crisis: *to the double exploitation there should be a corresponding double emancipation: ecological and social*. The following sections are dedicated to make a brief reflection about these five innovations.

Table 14.1 Comparison of the two cultures of biological ecology. After Holling (1998)

Attribute	Analytical	Integrative
Philosophy	• Narrow and targeted • Disproof by experiment • Parsimony the rule	• Broad and exploratory • Multiple lines of converging evidence • Requisite simplicity the goal
Perceived organization	• Biotic interactions • Fixed environment • Single scale	• Biophysical interactions • Self-organization • Multiple scales with cross scale interactions
Causation	• Single and separable	• Multiple and only partially separable
Hypotheses	• Single hypotheses and nulls rejection of false hypotheses	• Multiple, competing hypotheses • Separation among competing hypotheses
Uncertainty	• Eliminate uncertainty	• Incorporate uncertainty
Statistics	• Standard statistics • Experimental • Concern with Type I error	• Non-standard statistics • Concern with Type II error
Evaluation goal	• Peer assessment to reach ultimate unanimous agreement	• Peer assessment, judgment to reach a partial consensus
The danger	• Exactly right answer for the wrong question	• Exactly right question but useless answer

14.5 The Reappearance of Nature

One among the prevailing false ideas fed by the impressive expansion of cities and industry is supposing that nature is currently inexistent or radically diminished. Nothing more to the contrary of what is really happening. Given the present over presence of human beings and their structures, apparatuses, and paraphernalia, and given the new mechanism and processes unleashed by them, nature and society are as never before in permanent reciprocity. Also, like never before the natural phenomena on which human life is dependent are *reacting* with such force and unpredictability. In a world in which risks are increasing rather than decreasing, as the processes of modernity become consolidated, ecological issues are increasingly the most dangerous for *all* of humanity, to the point that at present, academic, political, and international diplomacy circles are speaking about an imminent collapse.

This is due to the integration of natural processes to modern social processes of industrialization and mercantilization. "…Nature is subjected and depleted in the late twentieth century, and has thus passed from being an exterior phenomenon to being an *interior* phenomenon; from a given phenomenon to a *produced* phenomenon. As a consequence of its technical-industrial transformation and its global commercialization, nature has been included in the industrial system (Beck 1992, p. 18). And it is this socio-ecological or ecological-social transformation what turns the world into a new scenario: "Risks show in their diffusion a *boomerang social effect*: neither the rich and powerful are sure in front of them. The secondary effects formerly latent strike also the centers of production. The same promoters of modernization, fall in an emphatic and concrete way in the turmoil of the dangers they unleash and from which they benefit (Beck 1992, p. 54)." In other terms, "… misery is hierarchical, smog is democratic (Beck 1992, p. 53). The events of the past decade confirm the above-said: the inhabitants of the main European countries suffered the impacts of the extreme rise in temperature during the midsummer heat of august, 2003 causing tens of thousands of deaths. Hurricane Katrina went directly over the oil wells in the U.S. Gulf of Mexico coasts (Fig. 14.1). Valued in U.S. dollars, the effects of climatic change expressed in extreme phenomena and natural catastrophes turn nature into a new and almighty economic force (see Fig. 14.2). All this gives social metabolism significance as a theoretical and methodological platform useful for analyzing the new and complex planetary processes.

14.6 Human Beings Are Tangible, Society Is Ethereal

The coupled approach to society and nature automatically leads us to the question of if what happens inside society is only material or there is an *invisible* dimension in biophysical terms. This question brings us back to the antique dilemma between matter and spirit or between materialism and idealism, i.e., it places us in the dual dimension of any society: the symbolic and the material. We have already pointed out in several sections of Chaps. 4, 12 and 13 that a first obligate step was to recognize the difference between the tangible and the intangible parts of socio-natural metabolisms. That is because what is being exchanged are not only flows of energy and materials, but also of information. While this dual character is highly relevant, it is not exclusive of human societies but exists in other biological systems.

We owe to Marina Fischer-Kowalski the computational metaphor, increasingly diffused and that has also been adopted by us in this book, for distinguishing between the tangible and the intangible parts of social metabolism: "Hardware is a structure that is made to function by means of software, given a free flow of energy. Hardware and software can be handled independently, but one without the other does not work… Neither can be said to 'rule' or to 'dominate' the other: they have to fit together, to understand each other, to communicate well, to be compatible… Fischer-Kowalski (1997, pp. 128–129)."

This is closely related to Luhman's (1984) developments about communication in his general theory of social systems. At the moment that a member of this new *gregarious animal* species modified the acoustic state of the atmosphere with his voice, and that modification was perceived by the ear of another similar, communication flow was established (Echeverría 1998) together with the supra-individual assembly that gave place to societies. Consequently, society is essentially

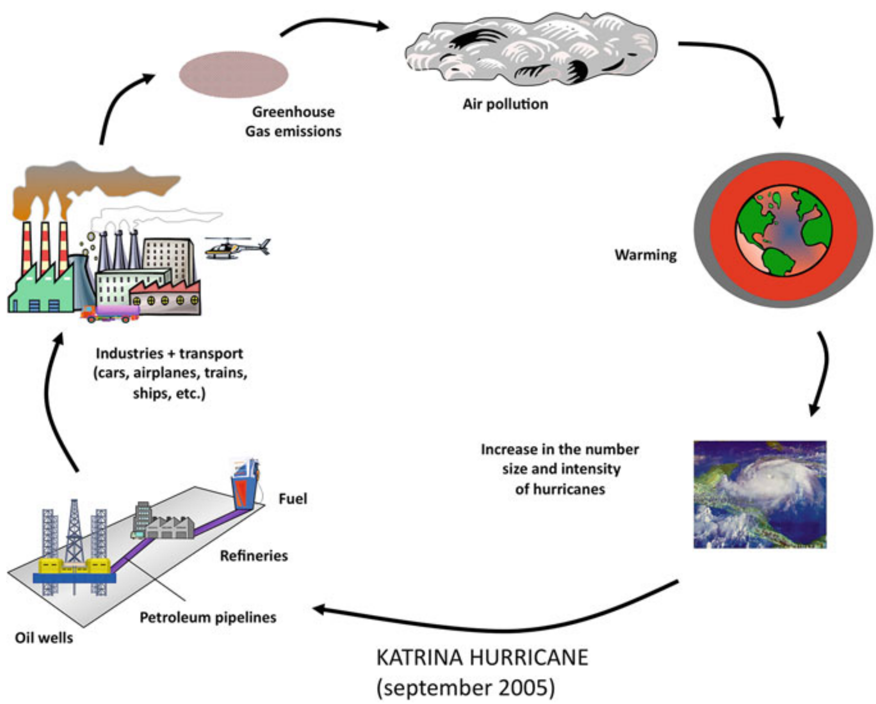

Fig. 14.1 The *boomerang effect* is plenty illustrated by the destructive impacts of Hurricane Katrina on the United States oil installations on the coasts of Gulf of México

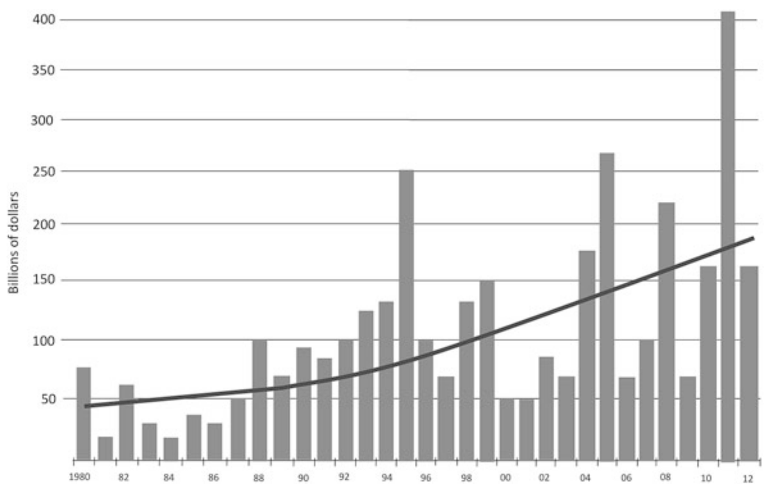

Fig. 14.2 Economic losses in, billions of dollars, caused by natural disasters between 1980 and 2012. *Source* World Bank

communication, exchange of symbols, cultural expression that, as we saw in Chap. 4, generate new emergent properties (knowledges, beliefs, rules, institutions) that become linked to the tangible realm represented by the five metabolic processes we have defined (Fig. 14.3). The emergence of language providing a better communication between members of a species, has been decidedly relevant for creating the cultural sphere, which in turn has been crucial for growth, expansion, and complexity of the social system.

14.7 The Social Phenomenon Is Not a Human Creation

Without disrespect for the valuable efforts made by sociologists, their main mistake has been to assume that social coexistence is a human invention. Doing that is one more act of anthropocentric arrogance. Contrary to what is thought, society as a system or structure is a biological creation, as shown by the thousands of social animal species defined as conspecific individuals assembled together for collaborating in common objectives providing evolutionary advantages. This sole fact would suffice for suffocating the paradigm of exceptionality claimed by the leading authors in sociology, who sustain that social phenomena can only be explained by *social* factors. This flawed reasoning also speaks for the fragmented advance of current science, in which fields of knowledge develop without acknowledging the results from other fields; as if reality could be explained only through the analysis of its particularities.

The arrival of a wider, more comprehensive perspective of animal societies, including human, is to be acknowledged to Wilson's (1975) book *The New Synthesis*. Sociobiology expands the concept of natural selection to social systems including human. Sociobiologists think that innate behavior patterns are modified or disappear during a process of natural selection. For sociobiology behavior results from an intricate interrelation between genes and the environment.

Based on a synthesis of sociability throughout the animal realm, Wilson (1975) distinguishes four social evolutionary peaks: (a) colonial invertebrates forming corals, jellyfish, syphonophores, and bryozoans; (b) social insects: ants, termites, bees, and wasps; (c) vertebrates, with multiple examples in fish, amphibia, reptiles, birds, mammals, and non-human primates; and (d) the human species and its ancestors in the genera *Ardipithecus*, *Kenyanthropus*, *Australopithecus*, and *Homo*.

14.8 And Neither Is Politics…

If society is not a human invention, neither is politics. All societies persisting during a period of time function as a system in which mechanisms for organization, control, and decision-making can vary widely. Social assemblies—be these animal or human—can be hierarchical or egalitarian, in which cases authoritarian

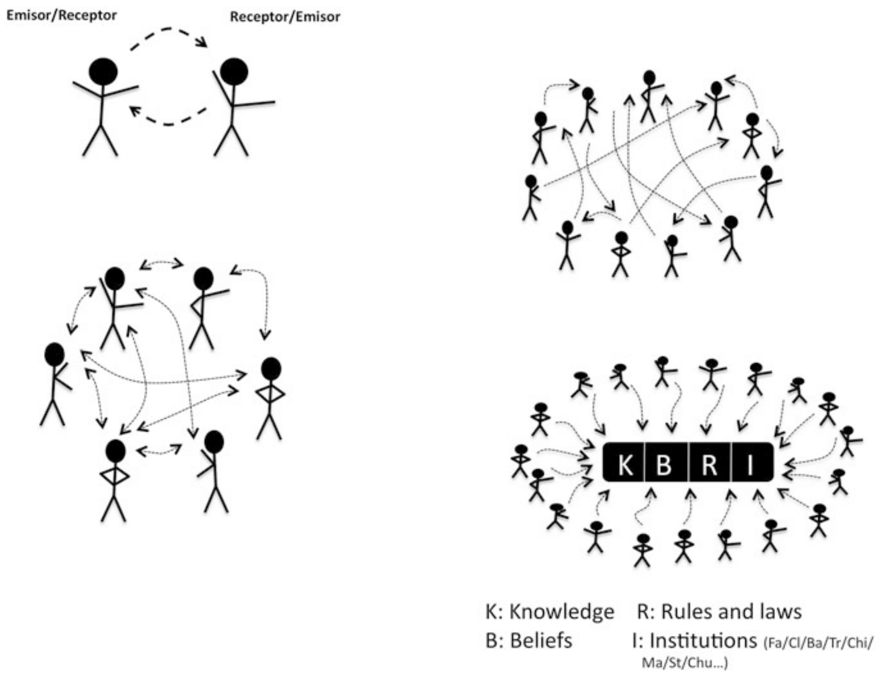

Fig. 14.3 According to a Luhmann (1984), for whom the social system is essentially a system of communication, of symbolic relations between individuals, the increase in complexity of societies gradually generated emergent properties such as knowledge (*K*), beliefs (*B*), rules, ordinances, and laws (*R*), and a gamut of social and political regulation institutions (*I*). Among the institutions created are, in order of historical appearance, the family (nuclear and extensive), the clan, the band, the tribe, the chiefdom, the market, the state, the church, and others, all with numerous variations

or collective decisions are made, i.e., autocratically or democratically, respectively. A *political ethology* exists that in the case of the human species has its origins in its nearest genetically related primates, the great apes of Africa: bonobos, gorillas, and chimpanzees. The analysis of political behavior of hominoids reveals complex mechanisms of control, exercise of power, submission, alliances, etc. are present in the hierarchical societies of the three primate species more closely related to humans, in human egalitarian societies, bands, and tribes—encompassing nearly 98 % of human history (Flannery and Marcus 2012), and in the once more hierarchical societies of the past five millennia, in chiefdoms, kingdoms, and the several kinds of states (Boehm 1999). In primates, a hierarchical society implies dominance and submission, relations that give place to well-defined domination structures. For instance, among chimpanzees a male (called the alpha male) always dominates over all members of the troops formed by between 50 and 100 individuals, followed in hierarchy by a second male dominating all but the alpha male, and thereafter in pecking order. In these social structures, females are always under male domination (Goodall 1986).

14.9 Cooperation: The Evolutionary Basis of Altruism

Beyond the rainstorm of propaganda, biased information, and false views to which citizens of the twenty-first century are exposed, there are underground contributions from scientific research that revalue the high evolutionary and civilizatory relevance of cooperation. This alternative current opposes deification of individualism and competition, values on which the modern world is being built.

The amount, variety, and quality of scientific contribution appeared during the past half-century about cooperation, altruistic behavior, and mechanisms of social reciprocity is surprising. These topics are crucial for making decisions, organization, and governability in a world threatened by a species reaching a population of seven billions that will increase to nine billions by the year 2050. Among the seminal works are the books of Axelrod (1984) *The Evolution of Cooperation*, and the more recent *A Cooperative Species* by Bowles and Gintis (2011), and *Supercooperators: Altruism, Evolution and Why need each other to Succeed* by Nowak and Highfield (2012).

Given the evidences coming from the ethology of primates, and of chimpanzees in particular, it is to be expected that the evolution of hominoids was also a gradual transformationof fully hierarchical groups to egalitarian social systems. As far back in time as we go we observe in humans behaviors more like those of primates. *Humanization of animality* also implies a leap towards social systems—bands in this case—in which cooperation, sanction of antisocial individuals, egalitarian allotment of foodstuffs, and altruistic attitudes determined a highly successful evolutionary modality. Christopher Boehm, one of the main authorities in the matter states: "…I suggest that our species (and our species alone) was given a unique chance to develop altruistic traits, precisely because social dominant hierarchies were definitively reversed for a long period of evolutionary time… Aside from this relatively recent refinement in favor of altruism, we will see that human nature consist of a mixture of ancient mammalian traits, general primate traits, and specific traits exhibited by hominoids—the great apes and humans (Boehm 1999, p. 12)."

To the conclusion we reach is that during the long duration in time of the *Paleolithic politics* the species made a significant leap to socialization, an advance that many thousands of years later was overcome by a return to despotic or authoritarian societies, which as we will see in the next section reached to its maximum expression in modern industrial societies. The gradual transformation of hominoids leading to our species therefore implied more than anatomical and physiological (bipedalism, stereoscopic vision, opposite thumb, noticeable increase in brain size, etc.) and ethological transformations, but also modification of social systems, i.e., in the structure and organization of bands. Subjugation or even elimination of asocial—i.e., egotistic, or individualistic—members was in charge of various types of sanctions, isolation, and even physical annihilation (Boehm 1999). Nevertheless, inter-tribal conflicts, mostly of a territorial character, were present (Wilson 2012, Chap. 8). It is very likely that about 60–70,000 years ago, when *Homo sapiens* began its migratory expansion from Africa to all regions of the planet, the structure and functioning of bands as egalitarian societies was already well consolidated together with the use of language, weapons, and tools. That implied a period of perfection of nearly 100,000 years.

Following the detailed review of numerous cases, both past and current, made by Flannery and Marcus (2012), about 5,000 years ago, a process of conversion of egalitarian to stratified societies began taking place when the human species increased its numbers and created cities, giving origin to chiefdoms, kingdoms, and various types of states: "By 2500 BC, virtually every form of inequality known to mankind had been created somewhere in the World, and truly egalitarian societies were gradually being relegated to places no one else wanted (Flannery and Markus 2012, p. x)." This countercurrent phenomenon occurred in the past makes our perception of history to change radically. We are thus seeing a clear act of *sociopolitical involution, and not of a stage of superior development as the dominant ideology have made us believe*. All this was accompanied by rapid and iterative improvements in health, communication, sanity, technology, and transportation that allowed for an explosive increase of the human population. The emergent scene is one of a major anomaly in which the advances in some realms enter in conflict with the stagnation or reactionary character of the contemporary mechanisms of governance.

14.10 Social Inequity as Entropy

In the theoretical Chaps. 12 and 13 of this book we have postulated the existence of three types of entropy coming from processes leading to chaos. The first type is metabolic entropy surging from the realm of exchanges of energy and materials with the natural world. The second is social entropy arises from the interactions among individuals (or groups), more precisely, from conflicts or frictions. The third type is political entropy involving governing institutions. In the case of social entropy, the inequality derived from several mechanism of social exploitation is crucial, and as we saw in previous Sects. 14.9 and 14.10 mark the history of human societies in that some individuals dominate and others are dominated.

Although no historical studies have been made to explore the trends followed by inequality through time, the available data indicate that, against what is commonly perceived, the maximum levels of inequality occur in the present times. Also the process of concentration of capital has reached its historical maximum in the present, and every year the wealthiest individuals augment their fortunes instead of diminishing them. According to *Forbes* magazine, between 2012 and 2013, 314 multimillionaires increased their capitals, 22 kept it unchanged, and only 30 diminished it. The same magazine estimates that in 2013, the 400 wealthiest U.S. citizens accumulated a fortune of two trillion dollars, equivalent to the GDP of Russia for that same year.

According to a report from Credit Suisse, global wealth has increased every year during the past decade. However, despite a world economy in recession, a report of the Boston Consulting Group private wealth increased by 7.8 % in 2012, reaching US$135.5 trillions—nearly ten times the economy of the U.S—that was owned by 13.8 million persons (0.9 % of the total human population). Another report from the International Labor Organization (ILO) concluded that during the past three decades the balance of distribution of income leaned further towards the most affluent, while the economic situation of the poorest and of many middle-class laborers was worsened in several countries, including economic potencies. To the above adds that, according to FAO, in the year 2013 a total of 842 million people suffered famine or malnutrition. These trends were presented in the form of a complaint by the civil organization OXFAM during the Economic Forum in Davos in February of 2014.

In a recent study, Vitaly et al. made a mathematical analysis using figures from the Orbis, 2007 http://www.bvdinfo.com/en-gb/products/company-information/international/orbis-(1) "…a database listing 37 million companies and investors worldwide, they pulled out all 43,060 TNCs and the share ownerships linking them. Then they constructed a model of which companies controlled others through shareholding networks, coupled with each company's operating revenues, to map the structure of economic power. The work…revealed a core of 1,318 companies with interlocking ownerships…although they represented 20 % of global operating revenues…appeared to collectively own through their shares the majority of the world's large blue chip and manufacturing firms—the 'real' economy—representing a further 60 % of global revenues (Coghland and MacKenzie 2011)". Vitali and collaborators concluded: "We find that transnational corporations form a giant bow-tie structure and that a large portion of control flows to a small tightly-knit core of financial institutions. This core can be seen as an economic "super-entity" that raises new important issues both for researchers and policy makers (Vitali et al. 2011, p. 1)."

14.11 Sustainable Societies and the Double Emancipation

Once the socioecological complexes along history have been reviewed (Chaps. 9, 10 and 11), which on passing returns memory to historical research making it to reappear as applied knowledge, it can be said that the lessons of the past lead to the urgent need of building a new metabolic regime (Fig. 14.4). Given the importance of the numerous scholar and empirical efforts converging in what has been called *sustainable society*, a search string that renders 80.5 millions of hits in Google Search (February 9, 2014), the main conclusions of this book should be inserted in this innovative current, more so when even when adopting an ample definition of sustainability, no country in the world can be characterized as being sustainable (Moran et al. 2008).

Among the main conclusions of this book, two can be considered as seminal. The first one is that despite the enormous complexity of socioecological processes

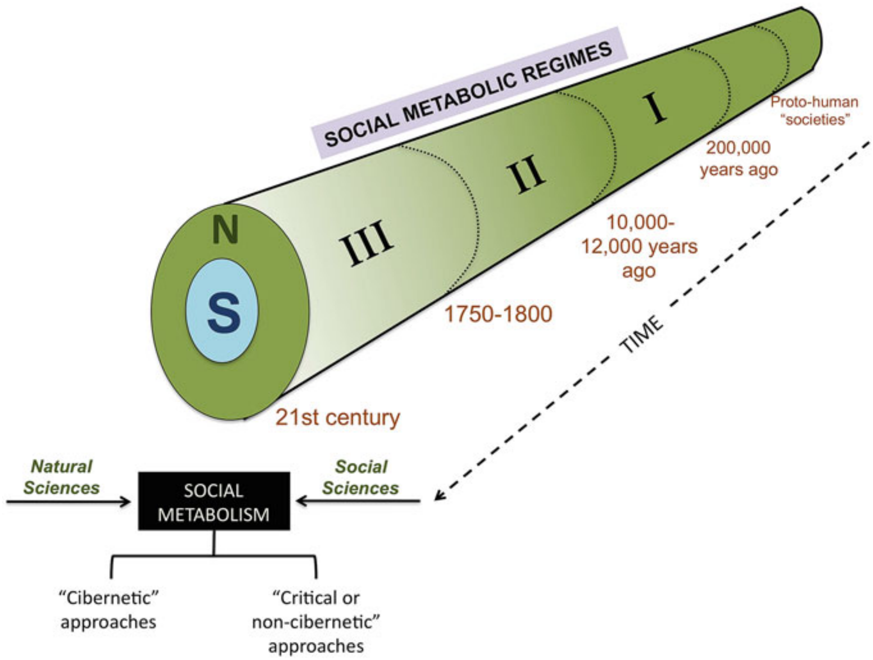

Fig. 14.4 The historical review of social metabolisms, which gave place to at least three well-defined metabolic regimes, allows identify the needing for a new post-modern metabolism

visualized through time, these can be modified by the actions of human collectivities. Conflicts and social protest have operated and can operate as the main factor of change. This thesis is contrary to the *cybernetic approaches* that, consciously or unconsciously, rely on technological, economic, institutional, and demographic solutions, i.e., assign the realization of changes to sectors, almost never defined, having enough power to take them to practice. Therefore, it is the actions of citizens, turned into social processes, what can and should realize the necessary changes for exiting the crisis and building a new metabolic configuration. The second conclusion vortexes around the thesis that social exploitation and exploitation of nature seem to be closely linked. Consequently, if we invoke what was said above, a double emancipation, social and ecological, will be needed for creating a new metabolic modality, i.e., a truly sustainable society.

14.12 The Final Challenge: The Final Opportunity

During nearly 2 million years our ancestors followed an evolutionary route as uncertain as that of any other species, involving complex synergies between genetic variations and cultural innovations, both in turn molded by environmental changes, mainly of climate and vegetation, whose more patent evidence has been the increase in complexity of the brain, together with other less spectacular anatomical and physiological changes. That represented a strenuous walk from transformation to transformation deriving in the presence of the present human being, and that allowed for the reader of this book to be able for deciphering what the authors have written. The present we stand at is then the result of a lengthy, nearly eternal, historical process with no apparent direction beyond the increase in complexity of what exists.

The human brain is today the most efficient system known in the universe. Weighting only between thirteen and fifteen hundred grams, measuring 1,500 cm^3 and consuming about 400 cal of energy, the human brain harbors over 100 billion neurons capable of developing 1 million synapses per second, with a total potential of interneural connectivity density of ten to the fourteen (the largest connectivity density known in the universe). For comparison, a model of supercomputer designed by IBM (BG) that simulates the activity of 10,000 neurons consumes 100 kW of energy.

And yet, as we have shown in this book, paradoxically, seven billion brains cannot agree to *cooperate* in the construction of a strategy allowing for and fomenting that all the members of the human species have a dignified and secure life, together achieving the *domestication of risk*, which is the only way in which we may avoid continuing our advance towards the abyss. Each one of us makes or will make their contributions in that regard, or will do nothing. The authors offer this book as our personal contribution to what may be the final challenge; the final opportunity for stopping our sliding towards collapse.

References

Axelrod R (1984) The evolution of cooperation. Basic Books, New York

Beck U (1986) Risk society: towards a new modernity. Sage, London

Beck U (1992) From industrial society to risk society: questions of survival, social structure and ecological enlightenment. Theory Cult Soc 9:97–123

Berman M (1981) The reenchantment of the world. Cornell University Press, New York

Boehm C (1999) Hierarchy in the forest: the evolution of egalitarian behavior. Harvard University Press, Cambridge

Bowles S, Gintis H (2011) A cooperative species: human reciprocity and its evolution. J Econ 104:191–194

Capra F (1982) The turning point: science, society, and the rising culture. Simon & Schuster, New York

Coghland A, MacKenzie D (2011) Revealed—the capitalist network that runs the world [WWW Document]. New Sci. http://www.newscientist.com/article/mg21228354.500-revealed–the-capitalist-network-that-runs-the-world.html#.UwlifvR5PgU

Echeverría B (1998) Valor de Uso y Utopía. Siglo XXI Editores

Fernández-Durán R (2011) El Antropoceno. La expansión del capitalismo global choca con la biosfera. Virus editorial, Barcelona

Fischer-Kowalski M (1997) Societýs metabolism: on the childhood and adolescence of a rising conceptual star. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Edward Elgar, Cheltenham, pp 119–137
Flannery K, Marcus J (2012) The creation of inequality: how our prehistoric ancestors set the stage for monarchy, slavery, and empire. Harvard University Press, Cambridge
Fromm E (1941) The fear of freedom. Farrar & Rinehart, USA
Fromm E (1946) Psychoanalyse & Ethik. Seiten, Zürich
Fromm E (1955) The sane society. Henry Holt, New York
Goodall J (1986) The chimpanzees of Gombe: patterns of behavior. Belknap Press, Cambridge
Holling CS (1998) Two cultures of ecology. Conserv Ecol 2(2):4
Klein N (2013) Naomi Klein: How science is telling us all to revolt. News Statesman. http://www.newstatesman.com/2013/10/science-says-revolt
Koestler A (1967) The ghost in the machine. Hutchinson, London
Koestler A, Smythies JR (eds) (1971) Beyond reductionism, new perspectives in the life sciences. Beacosn Press, Boston
Luhmann N (1984) Social systems. Stanford University Press, Stanford
Moran DD, Wackernagel M, Kitzes JA et al (2008) Measuring sustainable development: nation by nation. Ecol Econ 64:470–474
Nowak M, Highfield R (2012) Supercooperators: altruism, evolution, and why we need each other to succeed. Martin Free Press, New York
Toledo VM, Barrera-Bassols N (2008) La Memoria Biocultural. La importancia agroecológica de las sabidurías tradicionales. Icaria Editores, Barcelona
Vitali S, Glattfelder JB, Battiston S (2011) The network of global corporate control. http://arxiv.org/pdf/1107.5728.pdf. Accessed 9 Nov 2013
Wilson EO (1975) Sociobiology: the new synthesis. Harvard University Press, Cambridge
Wilson EO (2012) The social conquest of earth. W. W. Norton and Company Inc, New York

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