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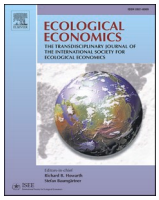

Slavcho Zagorov (1898–1970), A forgotten pioneer of energy and ecological economics

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ABSTRACT

This article aims to rediscover a relatively unknown author to the general public, Slavcho Zagorov, and to revive his ideas. Zagorov was a Bulgarian economist and statistician whose main works date back to 1954 and are mainly devoted to the concept of energy flows in the economy and human metabolism explained through the prism of thermodynamics. His work and career are reminiscent of another Balkan economist, Nicholas Georgescu-Roegen. We first present Zagorov's theoretical work on the importance of energy in economic activity and secondly on the measurement of national income and productivity through energy. Thirdly, we show the relation he establishes between energy and utility. Finally, we discuss his texts in relation to his professional and personal trajectory and point out some preliminary elements of comparison with Georgescu-Roegen's work.

1. Introduction

> "It is unthinkable that in the long run economic theory can close itself against the ideas which dominate the development of biology and physics, as it is impossible for biology to evolve ignoring the state of knowledge by physics. [...] Speaking more concretely, this means to explain economic phenomena in terms of biology and physics; to coordinate the fundamental concepts of economic theory with those of physics, considering physics as a basic science; and to find the pace of economics in the system of natural philosophy" (Sagoroff, 1954, 84–85).

In 1966, as a statistics professor at the University of Vienna, Slavcho Zagorov[1] wrote an extensive review in the journal *Metrika*.[2] It was a review of a collection of essays by various authors called *Essays in Econometrics and Planning*. Among the collected papers was the one by the Romanian-born American economist Nicholas Georgescu-Roegen,

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[1] *A previous version of this article in Bulgarian has been made available by the Munich Personal Archives in 2022 (https://mpra.ub.uni-muenchen.de/115938/7/MPRA_paper_115938.pdf). The present version in English has been substantially extended and improved after reviewers' comments. We thank the three referees for their extensive and detailed reviews. The first referee offered us an extremely rich historical and literary context for a better understanding of Zagorov's theory; the second referee, among other things, helped us clarify and correct formulas in the text; and the third referee, in addition to directing us towards modern literature on energy economics, suggested some wordings we used in the text. Although any shortcomings in the text can be considered as ours, the present article can be considered as a collective work, the fruit of our efforts and those of the three referees. The quotations in the article from Zagorov's texts and fonts were written originally in English by Zagorov himself and are exact reproductions of the originals (if there are any inaccuracies in the English expression, these are Zagorov's own inaccuracies).Zagorov's name is spelled differently. It may be found, for example, as Sagoroff or Zagoroff. Later in the text, we choose its official Bulgarian spelling - Slavcho Zagorov.

[2] The journal *Metrika was* founded in 1958 by Zagorov by merging the Austrian statistical journal *Statistische Vierteljahresschrift* and the German journal *Mitteilungsblatt für Mathematische Statistik*.

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interestingly titled "*Measure, Quality, and Optimal Scale*". Georgescu-Roegen discussed the problems of economic and statistical distinction between "quantity" and "quality", which was quite unusual for quantitative economics at that time. Slavcho Zagorov spoke favourably of the study, concluding his review as follows:

> "The paper (of Nicholas-Roegen) ends with the fascinating statement: 'As a more speculation, one may however regard efficiency as a quality of "thinking matter"' (ibid). This statement of Georgescu-Roegen is even more evident, when economic production is analysed in terms of energy" (Sagoroff, 1966, 238).

Zagorov published the above review ten years after he published his two pioneering articles on the role of energy in economic activity and economic science, namely "The Concept of Energy in Economics" (1954) and "National Income and General Productivity in Terms of Energy" (1955). He also conducted empirical analyses of the energy and food balances of Balkan countries in *Food-Energy Balances of the Danubian Countries before and during World War II* (Sagoroff, 1953a) and published the collective monograph *The Agricultural Economy of the Danubian Countries, 1935–1945* (Zagoroff et al., 1955). Zagorov's works appeared a decade before the pioneering work of Nicholas Georgescu-Roegen (1971, 1976, 1995). They remained, however, beyond the attention not only of the researchers of those years, including Georgescu-Roegen himself, but also of today, when numerous attempts are being made to recover the history of ecological and energy economic thought (Vianna Franco and Missemer, 2022).

Slavcho Zagorov, a Bulgarian who emigrated to Austria, had a remarkably similar fate to that of Georgescu-Roegen, not only in terms of education - both were statisticians and agricultural economists - but also in terms of career - both held leading positions in statistics and government between the wars in Bulgaria and Romania respectively (Adam, 1969, Bruckmann, 1970, Penkova, 2008). Both subsequently emigrated and turned their research interests to the role of nature, energy and biology in the development of economic theory. One can only guess to what extent they knew each other and knew of each other. The only evidence is Zagorov's review mentioned above and Zagorov's references to Georgescu-Roegen's agrarian research in the collective monograph published during Zagorov's stay at Stanford (1950–1954/55).[3] But while Georgescu-Roegen is extremely popular today and has taken his rightful place in the development of ecological economics and bioeconomy (Georgescu-Roegen, 1978; Vivien et al., 2019), Slavcho Zagorov is completely forgotten.

We will first present Zagorov's theoretical work on the importance of energy in economic activity and secondly on the measurement of national income and productivity through energy. Thirdly, we show the relation he establishes between energy and utility. Finally, we discuss his texts in relation to his professional and personal trajectory and point out some preliminary elements of comparison with Georgescu-Roegen's works (see Appendix A). Our article is interspersed with quotations to allow the reader to directly grasp Slavcho Zagorov's texts.

2. The energetic, physical and biological foundations of economic activity

The basic tenets of Zagorov's energy economics are concentrated in the two theoretical articles already mentioned in the introduction, which appeared in English in 1954 and 1955 respectively. However, they were preceded by a publication in German, namely "Die energetische Betrachtung des wirtschaftlichen Geschehens" (Sagoroff, 1954a), and the article "The Concept of Productivity in Physics, Economics and Biology" (1953). In 1961, Zagorov summarized his research in a monograph in German, *Theorie der volkswirtschaftlichen Energiebilanzen*. He also wrote a short article in German in which energy transformation coefficients are presented in matrix form (Sagoroff, 1959) and an interesting text *Technical Progress and Human Mind*, summarizing his ideas (Sagoroff, 1970). These are, broadly speaking, the publications on which we draw to synthesize Zagorov's energy economic theory. Zagorov's Bulgarian publications are extremely numerous and varied (agrarian economics, demography, statistics and economic policy), and his statistical works in German can be interpreted as the general framework within which his energy theory developed and took shape.

According to Zagorov, "life represents transformation of matters and energy" (1954, p. 85), and is a series of metabolisms that form the cycle of reproduction of matter. Among metabolisms Zagorov lists - soil metabolism, plant metabolism, physically primary production, including animal and human metabolism (Fig. 1).

In Zagorov's original diagram (Fig. 1), the motion of energy and matter should be interpreted inside out and can be represented by the following Fig. 2.

Following Fig. 2, human production is a flow of energy and matter starting from the physical primary output, i.e. the primary source of energy (primary materials and raw materials), and ending in human consumption of services (personal, household and social). The two parts of the flow (energy and matter) become smaller and smaller in the direction of the phases of the reproduction cycle, and finally disappear (from the human point of view). Furthermore, following the laws of physics, Zagorov writes:

> "On the other hand, the quantities of useful energy which the production process absorbs and the losses of energy in the thermodynamic sense steadily increases. Speaking metaphorically, every good produced is piled-up useful energy, mainly mechanical work" (1954, 87).

Within the cycle of reproduction of matter, there is also a cycle of economic and social reproduction, social circulation (Fig. 3). It represents the reproduction of labour and capital. It is within its framework that circulation takes place, the circulation of goods and money moving in opposite directions. Economic reproduction, according to Zagorov, is represented by Leontiev in his model of "input-output matrices".

Zagorov defines the categories "net and gross energy costs" (*energy expenditure* or *energy cost of production*), where net costs are related only to useful energy and gross costs include energy losses in a thermodynamic sense. Further, Zagorov links human consumption[4] to two categories, namely (i) food consumption and (ii) production of direct services (final consumption, *end-consumption*).[5] The consumption of food is related to digestion and metabolism, through which human organs are reproduced, while the services that disappear in consumption are mostly related to transport, social and government services, etc. It is the latter that constitute the core of national income.

> "In terms of energy national income may be defined for a stationary economy as *useful energy of direct services*. For a non-stationary economy, the definition must be broadened to include also changes in stocks of producers' goods. The term "stationary economy" has here a very strict sense: it implies that even the total weight of the population does not change. The fact that the food intake does not belong to the national income (thought as a "heap" of end -products,

[3] See Zagoroff et al. (1955), pp. 240–241, 262, 284. These are two statistical works on agrarian and demographic problems entitled *"Invenaral Agricol"* and *"Populatia* României*"* by Georgescu-Roegen from 1939 originally published in *Enciclopedia României III.* Interestingly, the section on Romania, published under Zagorov's name, was based on the material of a Romanian expert who wished to remain anonymous. This is mentioned in the foreword by the director of the Stanford Food Research Institute, as well as in the capita itself. There is every reason to believe that it was Georgescu-Roegen (see Appendix A).

[4] "Human consumption is a process in which different forms of energy act upon our sense" (Sagoroff, 1954, 87).

[5] See footnote 12 below.

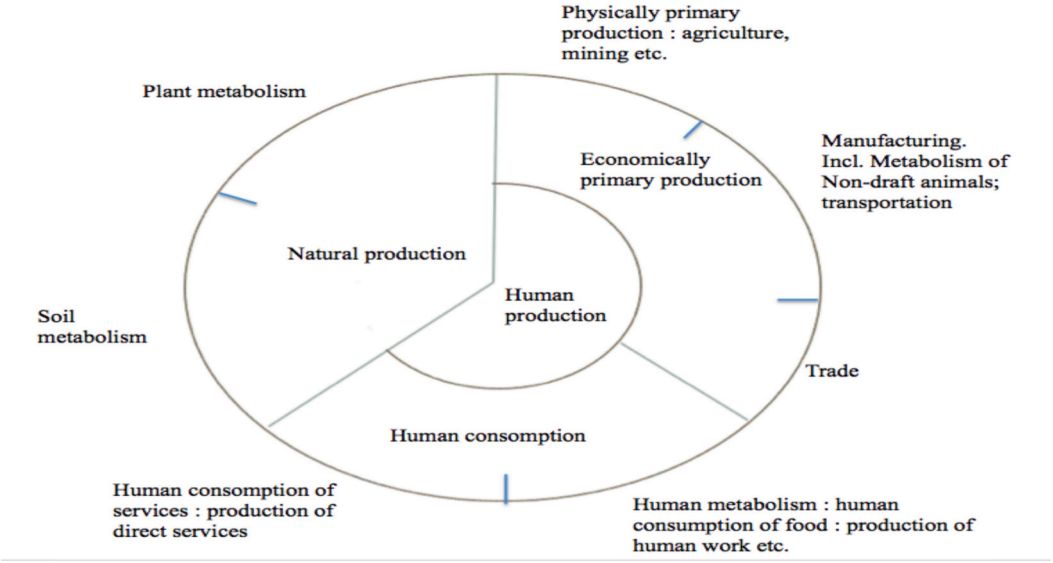


Fig. 1. The reproduction cycle of matter.
Source: Sagoroff, 1954, 85, authors' reproduction of the original. Note: Zagorov used the terms "physically primary production" and "economically primary production". According to one of our referees, "physical primary production" and "economic primary production" would be more correct. We have chosen to keep Zagorov's original terms.

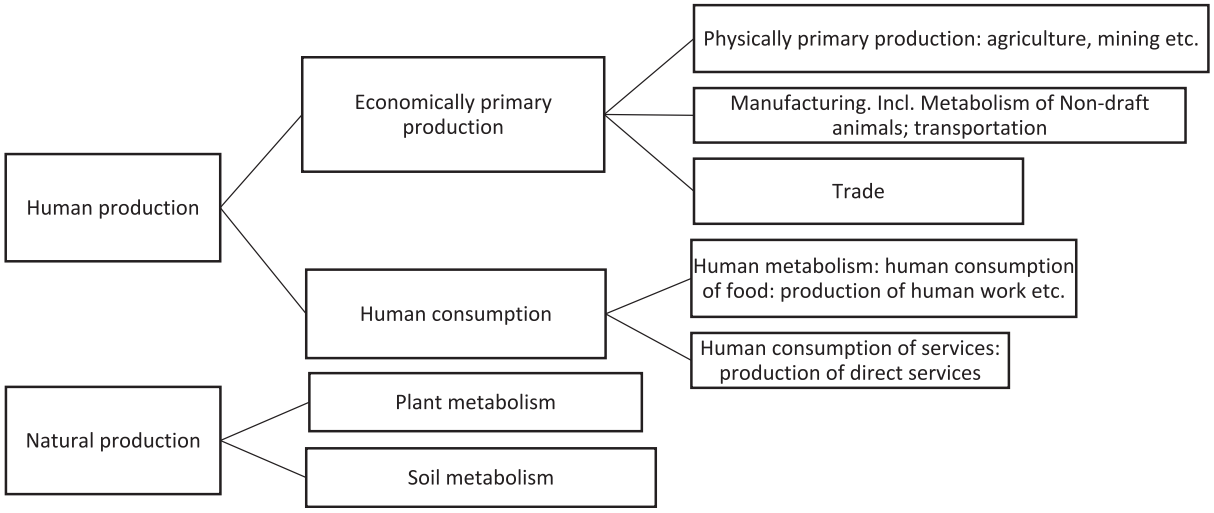


Fig. 2. Classification of energy and matter flows according to Zagorov.
Source: Sagoroff, 1954, 85, authors' interpretation of Fig. 1.

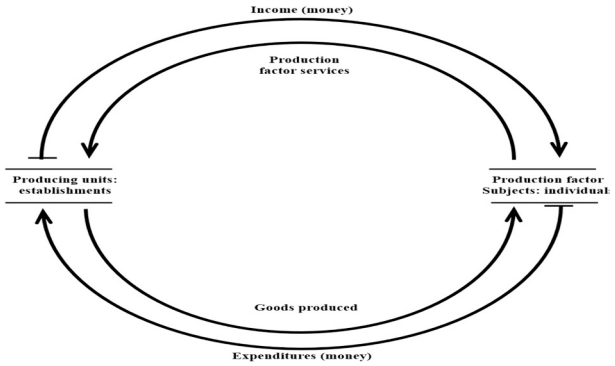


Fig. 3. The social circulation.
Source: Sagoroff, 1954, 86, authors' reproduction of the original.

because it transforms itself into work, leads to a more striking conclusion: *national income is essentially motion*. In a stationary economy national income is nothing else but motion)" (Sagoroff, 1954, 88).

Zagorov reminds that:

"The second Law of Thermodynamics, which must be referred to in this connection, has a much greater importance for economics than most economist are inclined to grant. The economic activity of man is both a fight and adjustment to the "Second Law. Man fights against the 'Second Law' with the help of agriculture; he fights against it when he produced food for the maintenance of life, i.e., when he tries to reduce the increasing entropy of his body by 'sucking negentropy' from the environment, as Schrödinger says[6]. While the individual

[6] Schrödinger (1944), Zagorov refers to a 1947 edition.

eventually loses the fight and dies, humanity as a whole has been so far successful in it. Man adjusts himself to the second Law when he endeavours to reduce the losses in the transformation of energy by improving the 'physical productivity', the efficiency of the machines generating or using heat or mechanical energy" (Sagoroff, 1954, 97–98).

In a general conceptual framework, Zagorov proposes three scientific approaches to economic theory (including the two main categories of cost and value), namely (i) the exchange value approach, here known as measurement by money and prices, (ii) the energy and energy value approach, and (iii) the utility or use value approach. They will be discussed in detail later in the text.

"In addition to the dimensions time and mass national income has three "value dimensions," namely exchange or money value, energy value and utility or use value. Accordingly, we may speak of three fundamentally different kinds of measurement of national income which yield conceptually different results. In the first case the national income appears as total net value (i.e. money value) of output, in the second case as total useful energy of end-products, and in the third case as total utility of end-products" (Sagoroff, 1954, 89).

According to the author, while the first approach, well known to economists, is valid in the short run, the energy approach is crucial in the long run.[7] Moreover, Zagorov seeks and provides a solution (rather, he puts forward a hypothesis) within which the energy approach and the utility approach are closely related and can be explained by general laws (e.g., Gossen's law[8]). Zagorov argues that the energy approach does not negate other approaches, but rather significantly expands our understanding of economic activity. Or:

"Although the flow of energy can be regarded form the economic point of view as continuous, and the energy equations are valid for any accounting period used in economics, the energy value theory examines long run problems only. It has nothing to do with the everyday economic expectations and decisions, which must be shaped in terms of money, or with the exchange of goods against production-factors services, or with goods against goods between the units of the economy. Therefore, it does not enter the domain of those branches of economics which deal with exchange in economics, i.e., with magnitude in terms of money" (Sagoroff, 1955, 91).

Zagorov surveys the development of measurement theory and aggregation of individual utilities, cardinal approaches (Walras, Jevons, Menger, Böhm-Bawerk, partly Fisher, Pareto and Pigou), and ordinal methods (Bergson, Lange, Arrow) to arrive at the need for a new, broader indirect method based on energy:

"The utility of a consumers' good is a mathematical function of the useful energy - mechanical work or useful heat - which is supplied to the human organism by its consumption. This function, which we may call the energetic function, contains energy quantities as variable in addition, structural constants determined by the behaviour of the individuals" (Sagoroff, 1954, 94–95).

Finally Zagorov outlines the research program of the new energy approach, including the statistical construction of national economy energy balances[9]:

"The energetic approach may lead to the establishment of a new branch of economic theory which could be called *energy value theory*. The energy value would have to solve many problems. It would have to investigate in a systematic way the conditions of energy production - to go into problems of *money cost of energy*. This is a subject matter of the "*Energiewirtschaftslehre*", as it is called in Germany. Not less important would be the establishment of national energy balances and the study of their improvement (new energy resources and higher efficiencies of energy transformation). Last but not least, the energy value theory would have to develop new methods of measurement of national income, economic growth, and social utility, - methods which will be based on the concept of energy." (Sagoroff, 1954, 99).

3. National income and productivity as energy concepts

Let us turn first to the details of the energy dimension of national income that Zagorov proposes.

3.1. Energy measurement of national income

Zagorov does not stop with the definitions of national income, he develops its concrete empirical representations. First, as mentioned, national income (and any economic activity and economic good), has three dimensions, namely (i) exchange value (money), (ii) energy dimension, energy value, and (iii) utility (or use value). In the first case, national income manifests itself as the total net value of outputs, or the sum of the value added of all phases of production, with the value expressed in money. In the second dimension, national income represents the total useful energy of the final products. In the third case of national income representation, we talk about the total utility of the final products. Or, for this last case, Zagorov uses the following metaphor, for the economy as a body:

"In this study, exploring the field of energy value theory, the national economy is treated as a whole in a twofold sense: all units of the system-individuals, enterprises, households, governmental agencies-are considered, while the relations among them, arising from the social division of labour, are disregarded. In other words, the analysis deals with macroeconomic aggregates, but does not touch on the "circular flow" in the economy-the social circulation of goods and money. Speaking more generally, a "universe" is looked upon as a "body". This is the way in which the energy supply and the energy expenditure of living organisms are ascertained in physiology of nutrition" (Sagoroff, 1955, 91).

Questioning the traditional measurement of national income in exchange value and money, Zagorov shows its limits and shortcomings. In the author's view, it does not give an idea of the product's "real" value, due to the problems with price indices, especially with the dynamics of their structure. But most of all because the boundary between consumption and production, between production and consumption goods cannot be clearly defined and because personal and domestic services are not included in national income. Specifically, regarding the differences between capitalist and socialist valuation of national income (which derives from different concepts of value - based on utility or on labour respectively), Zagorov defines them as follows (see Chart 1):

"According to the Western conception end-products are exclusively services, namely the services which are rendered directly to the individuals. This category of services embraces the household services, the personal services, and a part of the social services. According to

[7] In Zagorov's texts there is no special analysis of the relationship between the two reproductive cycles, energetic and social.

[8] Sagoroff cites the German edition of Gossen (1854) made by Hayek in 1927 (Sagoroff, 1954, 94). Gossen's law describes diminishing marginal utility as consumption of a good increases, i.e. total utility increases but at a decreasing rate, and tends to a given limit. According to Zagorov, this law is universal, and goes beyond the domain of utility, see below.

[9] Something important today in the European context of the energy crisis.

the Eastern conception end-products are not the direct services but the goods which constitute their user cost (i.e., their "Vorleistungen"). What is meant are those material goods, energy supplies (human work excluded) and transfer services (transportation, trade, banking) which are produced for use in the households, in the enterprises for personal services, and in the governmental agencies. In other words, in computing national income, the Western statisticians cut the stream of production in human consumption, whereas the Eastern statisticians cut it at a point *before* it reaches human consumption. The wider the concept of production is, the farther away from the "origin" of human production must lie the point to which the "accounting statement" refers and the smaller must be the energetic content of the "end-products". Hence the Western concept of production leads to smaller energy values of national income than the Eastern concept" (Sagoroff, 1954, 90–91).

For Zagorov, the energy-based measure of national income is much more appropriate because it provides a more accurate and true measure of economic growth as well as of the comparative power of different countries.

"The method of measurement of economic growth or economic power now used can hardly be considered satisfactory. The reasons for that have been just explained. Could we not find a better method, namely, a method which is not subjected to the conditions that limit the validity of the composite index numbers and which is free from the technical and logical shortcomings of the existing computations of national income? There are reasons to think that it is possible to develop such a method. We can consider the primary energy of a country - or, to put it more precisely, the total output of energy from primary sources - as a measure of economic growth and economic power" (Sagoroff, 1954, 92).

Moreover (as we shall see later), according to Zagorov, the energetic approach has the potential to embrace the third dimension of national income, that of utility and psychological satisfaction - the ultimate goal of man and human society.

Zagorov derives the fundamental energy equations for national income by the following steps. At the beginning, he gives the following definitions of primary energy:

"The most important "bearers" of primary energy are fuels-coal, mineral oil, natural gas, fuel wood, peat, etc., the currents of water and air, and the harvest of food and feed plants. Let us define as *net energy-cost* of an economic good (service, inanimate material good, or animal) the work or work equivalent of useful heat used to produce the good itself and its materials; and *as supplementary energy cost* the energy-heat or heat content of matter-lost in its production in the sense of engineering. Net energy-cost and supplementary energy-cost taken together give the gross energy-cost of production. It should be noted that the work used to produce work and useful heat does not belong to net energy-cost; it is a separate net-maintenance item." (Sagoroff, 1955, 92).

Then, in a thermodynamic sense, the energy available for work is equal to the energy transferred minus the energy lost. In an economic sense, for a closed, isolated economy, Eq. (1) is empirically derived (here the energy transferred is the primary energy produced, available for work and heat).

$$Y = \mathrm{E}u = Eup - El \tag{1}$$

where Y is national income, Eu is produced useful energy, Eup *is* the output of primary (transformed) energy, useful energy and El is energy lost in extracting fuel energy. This is for a stationary economy. For a growing economy, the equation becomes (2):

$$Yg = \mathrm{E}ug = Eup - Eum - El \tag{2}$$

where Yg is a national income in a growing economy, Eug is useful energy for final consumption and growth, Eup the primary (transformed) energy output, total useful energy,[10] Eum is useful energy for maintenance *and* El is wasted energy.

According to Zagorov, Eq. (1) can be called the "*fundamental energy equation of economics*" (1955, 92). In an even more expanded form, and for the purpose of statistical measurement, they can be represented as Eq. (6) (here everything is expressed in heat equivalents):

$$WHpds + WHpk + Wphb = Hep - WHpe - WHkp - WHgsin - Hel \tag{3}$$

where $WHpds$ is the work done and useful heat expended to produce direct services, $WHpk$ is the work done and useful heat expended to produce additional capital; stored useful energy, $Wphb$ is the work done to increase the population, useful energy accumulated as additional substance of the human body. On the other side of the equality, Hep is the heat content of the primary energy output, $WHpe$ is the work done and the useful heat expended to produce energy, $WHkp$ is the work done, the useful heat used and the useful heat stored for the reproduction of real capital and population, $WHgsin$ is the work done and useful heat expended in the production of government services and insurance services and Hel represents the heat content of energy losses[11].

We have already mentioned that services are divided into two groups, direct and indirect, according to whether they enter directly into the final consumption of individual consumers or of production units. Direct services, which are the core of national income, include, for example, intellectual and physical maintenance and household services. Indirect services include transport, trade, banking, insurance and social and government services. They are part of the reproduction of capital and population. Government services and insurance are, for example, part of the maintenance of public needs.[12] The above equations hold for a closed economy. In an open economy, imports and exports of energy, matter, lead to changes. Imports of primary energy appear with a positive sign on the right-hand side of Eqs. (1–3), exports of primary energy are added on the left-hand side of the equations. According to Sagoroff, "Imports of inconvertible inanimate material goods and animals have to be deducted from, and exports added to, the respective items in the composition of national income" (Sagoroff, 1955, 94).

3.2. The energy dimension of productivity

The energy approach provides a new dimension to the productivity of the national economy. It reflects physical productivity in economic processes.

Zagorov derives the following relations (4), (5) for general economic productivity.

$$Peg = \frac{Yg}{Ep} \tag{4}$$

$$Yg = Ep \times Peg \tag{5}$$

where Peg is the general economic productivity, Yg is the national income for a growing economy, and Ep is primary (raw) energy. Eq. (6) is for general physical, i.e., energy productivity in a sense of

[10] Sagoroff (1955, 94).

[11] The notations are ours, but closely follow the representations in (Zagoroff et al., 1955, 93).

[12] Zagorov notes: "In *The Concept of Energy in Economics* (1954), I had adopted the division of the social services -into direct and indirect- accepted by all official statistical agencies of the Western world. However, the idea of maintenance supplied new and decisive arguments to treat all social services as "overhead cost" of the national economy, i.e., as "user cost" of the producing units. Personal services produced by governmental agencies, e.g. public education, belong to national income."(Sagoroff, 1955, 93).

thermodynamics, and usually called (economic) energy intensity today[13].

$$Pfg = \frac{Eup}{Ep} \tag{6}$$

where *Pfg* is general physical productivity[14], *Eup* the total useful primary energy, and *Ep* is the primary (raw) energy.

National income represents the difference between the total useful energy and the useful energy for maintenance and lost energy, or (7).

$$\frac{Yg}{Ep} = \frac{Eug}{Ep} = \frac{Eup}{Ep} - \frac{Eum}{Ep} - \frac{El}{Ep} \tag{7}$$

where *Eug* is the useful energy for consumption and growth, *Ep* is the primary, raw energy, *Eup* the total primary useful energy and *Eum* is the useful energy for maintenance, and the *El* is a lost energy.

Then derive Eqs. (8) and (9). In (8) general economic productivity equals total physical productivity minus $Mn = Eum/Ep$, which is the net maintenance ratio, and minus the wasted energy ratio $Ln = El/Ep$[15].

$$Peg = Pfg - Mn - Ln \tag{8}$$

Therefore, national income equals primary, raw energy multiplied by the difference between total physical productivity and the net maintenance ratio[16].

$$Y = Ep\ (Pfg - Mn - Ln) \tag{9}$$

According to Zagorov this last equation has important economic significance. It helps define an economic policy aimed at increasing national income. It boils down to the following four policy options, namely (i) increasing the total supply of primary, raw energy, (ii) improving energy transformation, physical productivity, and (iii) reducing the net maintenance ratio, or (iv) a combination of these options.[17]

Subsequently, Zagorov deepened the representation of economic and physical productivity by defining four types of productivity. The first group is physical productivity of the system overall and physical productivity of an individual resource. Here the units of measurement are matter and energy. The second is economic productivity of the system, i. e. total, and economic productivity of an individual resource, which are measured in matter and money. The economic productivity of the system can also be measured in energy.

The physical productivity of a system "in its efficiency in transforming energy or matters. It is the capacity of the system to produce a certain product from given resource in an unspecified time or in a given time from an unspecified resource" (Sagoroff, 1955, 95) and is expressed as a ratio of "total product/total resources".

As for the physical productivity of resources, then "one can speak *of physical productivity of a resource* in the sense of "natural productivity" or "fertility, "which is something absolute, i.e., it does not depend on the efficiency of the transforming system" (Sagoroff, 1955, 95). And while in inorganic systems, from the point of view of physics, the individual resource to be transformed is not included in the system, and its increase or decrease has no influence on it, and everything obeys the general law of physics, in living beings, the specific "*Law of the Diminishing Increment in Product*", or "*Law of Diminishing Returns*" is observed. In a biological system, metabolism is observed (the organism is born, grows, ages and dies), and this distinguishes biological productivity from physical productivity.

Economic productivity is more often resource-based than system-based. What is special here is that it is influenced by the interrelationships between economic variables; it is the result of combining resources and interrelated systems. Economic productivity is the productivity of the unit of production. A national economy is a "system of systems".

> "Like biological productivity, economic productivity obeys the Law of the Diminishing Increment in Product (the Law of Diminishing Returns). While the First and Second Laws of Thermodynamics are empirical law, this law can be rationally derived from the physical (chemical) laws governing the structure of matter; only its parametric constants have to be found by experiment. It has economic significance, because - economically considered - the resources combined for production belong to the system. A change in any input means a change in the system" (Sagoroff, 1955, 98).[18]

The theoretical foundations of the energy approach to national income, productivity and economic activity in general, presented so far, are, on the one hand, the result of Zagorov's empirical and statistical research on food and energy balances in the Balkan countries, which he did as a fellow of the Stanford Food Institute (Sagoroff, 1953), as well as his long-standing research on agrarian processes in the Balkans (Zagorov, 1936b, 1937a; Zagoroff, 1952; Zagoroff et al., 1955).[19] On the other hand, his theoretical analyses themselves gave impetus to research on the statistical analysis of energy balances, using for this purpose Leontief's input-output matrices in the energy dimension (Sagoroff, 1959; Sagoroff, 1961b).

Zagorov kept in touch with Leontief, both personally and professionally (regarding Leontief's input output tables) as evidenced by their correspondence (Appendix B).[20] According to Frank:

> "In Austria we have since about ten years an overall system of energy statistics published yearly by the Austrian Central Statistical Office which corresponds to the Input-Output Matrix of the National Economy. The idea to establish such a system of national energy statistics was developed by S. Sagoroff, K. Schagginger, K. Turetschek and myself in a study concerning the relations which exist between the national economy as a whole and its energy supply (Frank et al., 1970). These energy statistics show the input and output of 25 different energy carriers to 43 economic sectors into which the whole national economy is divided. These statistics serve as data base for two important models" (Frank, 1981, 5–6).[21]

As stated by Zagorov, the construction of a national energy balance becomes a leading task. In his words:

[13] This formulation was suggested to us by one of the referees.

[14] According to one of the referees, it is "usually called (economic) energy efficiency today".

[15] According to Sagoroff, the term *net maintenance ratio* was proposed to him by P. Stanley King (Sagoroff, 1955, 95). King was a cartographer and an editorial assistant for the Stanford Food Research Institute journal.

[16] For one of the referees: "this makes sense only in a growing economy, where one might have a perfectly good stable economy if all net energy went into maintenance metabolism".

[17] In Zagorov's original formulas in his 1955 article, a stationary economy is considered, not a growing one. This leads to the neglect, in equations 4, 7, 8 and 9, of the expression for lost energy *El*. Here we decided to correct Zagorov's formulas for a growing economy by including *El*. This does not fundamentally change Zagorov's ideas.

[18] See for details between physical, economic and biological productivity, another article by Zagorov especially appreciated Young (1946) and Sagoroff (1953).

[19] In measuring the energy balances of the Balkan countries, and Bulgaria in particular, Zagorov relied on the primary studies of the caloric budgets of the Bulgarian population measured by the Bulgarian Christina Mocheva (1938), themselves based on Soviet empirical studies of the 1920s. This analytical link, as well as Mocheva's research, is extremely interesting and remains to be explored. See also Mocheva and Dimitrov (1947).

[20] Leontief's letter to Zagorov dated 6 October 1969, University of Vienna archives, in which Leontief thanked him for a book and for the data and graphs on the Austrian Input-Output Matrix.

[21] See also Sagoroff (1959a, 1961a, 1967a).

> "National energy balances show the sources of primary energy and the uses of useful energy; furthermore, they reveal the quantitative relations in each phase of energy transformation: from primary energy into secondary energy (and primary energy for direct use) into useful energy (work, useful heat, living matter). In short, from a national energy balance we can see how primary energy is reduced to national income (useful energy for consumption and growth). The energy approach can be applied to measure economic growth and economic power,[22] to examine productivity, and to foresee changes in location of industries. […] In long term investigations of growth and in global comparison of economic power the energy approach is to be preferred to the money approach" (Sagoroff, 1955, 100–101).

As for the units that can be used in measuring, they must be able to be converted into each other. Among these stand out "calories", "horsepower hours", "kilowatt hours", "tons of coal equivalent", etc. Zagorov gives specific illustrations of energy calculations of national income and productivity, using data from the USA (for which he uses calculations done by other authors). Zagorov shows that in the US between 1850 and 1950 it is not labour productivity that grows, but total physical productivity. As an example, Zagorov gives calculations showing that in a comparative perspective, the total energy ratio between the US and the USSR (measured in tons bituminous-coal equivalent) in 1950 was 3 to 1, and per chapter 4 to 1. As well as that, on the eve of WWII, Germany and the USSR had equal energy reserves, and from an energy position Germany could not open a second war front. In his empirical evidence, Zagorov points out J. Frederic Dewhurst (1947, 1955) and Thomas T. Read (1933, 1945) as successful calculations for the USA and Georg Wagener (1950) for Germany. An important source for Zagorov is the publication *Energy Resources of the World* (US Department of State, 1949).

As a summary of Zagorov's theoretical empirical search in the field of productivity and efficiency, we can use his words:

> "Against the background of the logical difficulties and unrealistic assumptions which the exchange value approach raises, the advantage of the energy approach in the exploration of general economic productivity are obvious. The productivity of a national economy is reckoned as its efficiency to transform energy onto welfare and life (utility and population) by *organised* application of physical productivity" (Sagoroff, 1955, 98).

4. The hypothesis of functional dependence between energy and utility

As maintained by Zagorov, the energy approach not only provides a more accurate and correct view of national income but can also be related to another dimension of national income, that of utility (or use value).[23] This possibility stems from the unity that Zagorov suggests exists - the unity of physical and mental processes. Although not standing on empty ground, Zagorov's hypothesis is highly original.

As we have already noted, economic goods (economic activity in general), in addition to dimensionality such as mass and time, have three value dimensions, (i) exchange value (or money), (ii) energy value, and (ii) utility (in labour theory, this is called use value). The latter two approaches, according to Zagorov, are directly related, and the author develops his arguments through the following steps.

Advances in the development of social utility measurement serve as the basis for the author's reasoning. According to him, in modern economic theory, utility and social utility (welfare) cannot be measured cardinally, i.e. directly as an object. Zagorov notes the pioneering ideas of Gossen, the subsequent achievements of marginal utility theory (Walras, Jevons, Menger and Böhm-Bawerk, and in part Pareto and Fischer), Pigou's definition of social utility, and the subsequent efforts by Bergson, Lange and Arrow, who developed an ordinal theory of welfare (without, however, overcoming the problem of comparing individual utilities). According to Zagorov, utility and social utility can be expressed in terms of energy. In the words of the author:

> "Utility has been defined as the feeling of pleasure - of higher or lower order - which accompanies the satisfaction of a human want, the fulfilment of a human desire. In this sense (not in the sense of usefulness, in which the word is used in common discourse), *utility is a product of our psychological activity*. […] *The utility derived from a consumer's good is a mathematical function of the useful energy which is supplied to the human organism by consumption.* […] The function which describes the relationship may be called *utility function in terms of energy*" (Sagoroff, 1955, 104).

According to Zagorov, the functional relationship between utility and energy is logarithmic: $y = klog_{10}x$ where y is the utility level, x is the primary energy input, and k is a structural constant.

This functional dependence is similar, according to Zagorov, to the *Weber - Fechner Psychological Law*, in which the sensitivity and functioning of the human nervous system (S) grow in direct proportion to the logarithm of the stimulus (E), i.e. $S = klogE$ (here Zagorov refers to the definition of Weber's Law made by Wundt, 1922).[24]

Moreover, Zagorov finds parallels between Gossen's first principle (1854), according to which "the magnitude of a pleasure decreases steadily, if its indulgence is continued without interruption, until satiety sets in", and Mitscherlich's law of diminishing returns in biological productivity, in particular of crop production[25]. Correspondingly, Gossen's law about pleasure and Mitscherlich's law can be expressed as Eqs. (10) and (11).

$$\frac{dW}{dE} = \frac{P-E}{\propto} \text{ where, if } \beta = 1 \Big/ \alpha, \text{ becomes } \frac{dW}{dE} = \beta(P-E) \tag{10}$$

where W is the total pleasure derived from all pleasures (indulgence) for a given period of time, E is the time spent on these pleasures, P is the time to satiation of pleasure, and α is a structural constant specific to each individual indicating the initial intensity of pleasure.

$$\frac{dy}{dx} = c(A-y) \tag{11}$$

where y is the current yield, x is the input from an individual plant variable as a growth factor, A is the maximum yield, and c is a structural constant varying for different plant growth factors.

When laying $\frac{dy}{dx} = e$ and $\frac{dW}{dE} = \omega$, the last two Eqs. (10) and (11) are transformed into respectively Eqs. (12) and (13).

[22] By economic power, here is meant the economic strength of a country.

[23] It should be noted that at this stage of our research we didn't have evidence that Zagorov was familiar with Russian and Ukrainian contributions in the field of the energy approach to the measurement of value, including the debates among Marxists (ex. Alexander Bogdanov). The same applies to the publications of Josef Popper - Lynkeus, Frederick Soddy, Otto Neurath and Max Weber. Further research is needed, but one explanation could be Zagorov's ignorance and rejection of Marxist economics, as well as the various agrarian theories, including those of the Narodniks. Zagorov drew his ideas more from neoclassical economics and statistics, from the exact sciences and psychology, and from his personal practical experience. For extensive survey on ecological economics see Martinez-Alier (1990) and about Neurath and Popper-Lynkeus see Vianna Franco (2020).

[24] The psychological theory of utility (using Weber-Fechner Law) was known in Bulgaria, mainly by Bulgarians who studied in Switzerland and Germany (mainly students of R. Liefmann (1874–1941)), as well as Russian marginalist emigrant economists.

[25] There are no details or even a year in this reference to Mitscherlich (1909), except that Robertson (1908) and Lang (1924) contribute to clarify this empirical regularity.

$$e = cA - cy \tag{12}$$

$$\omega = \beta P - \beta E \tag{13}$$

In Zagorov's words,

> "According to formulas (10) and (11), the marginal physical product (e, the increment of yield per unit of resources) is proportional to yield increase yet possible (the difference *A-y*)", while the marginal "psychological product" (ω, the increment of utility per unit of time or energy supply) is proportional to the time or useful energy yet required to attain satiety (the difference *P-E*). As formula (12) shows, the marginal physical product decreases, while the total product increases. In the same way, according to formula (13), the marginal "psychological product" decreases, while the time of indulgence or - under the condition mentioned- the useful energy supplied in that time increases. In the moment in which the total product reaches its maximum ($y = A$), or the time of indulgence is equal to the time required to attain satiety ($E = P$), the increment of yield or utility becomes zero. It would be a common task of psychology and economics to verify the hypothesis of *Gossen*" (Sagoroff, 1955, 107).[26]

Here is the place to make a digression about Zagorov's current sounding on the relationship between energy flows and well-being, personal and public, as well as the quality of life. In modern literature, this topic is developed not only theoretically, but also empirically. For example, in an article by Lambert et al. (2014), a complex econometric analysis is carried out on the relationship between EROI (Energy Return on Investment), a concept built by Ch. Hall, and a number of indicators for the quality of life and well-being (HDI, percent children under weight, health expenditures, Gender Inequality Index, literacy rate and access to improved water).[27] The authors use various approximators of available net energy, including a composite energy index (Lambert Energy Index) and check the presence of « a causative chain: higher EROI → higher GDP → higher social well-being (p. 154). Their conclusion is that:

> "… that energy indices are highly correlated with a higher standard of living. We also find a saturation point at which increases in per capita energy availability (greater than 150 GJ) or EROI (above 20:1) are not associated with further improvement to society"(Lambert et al. (2014, 153).[28]

In his last article, published in 1970 (paper presented in California in 1965) on the driving forces of technical progress and human reason, Zagorov once again notes:

> "As a general phenomenon in the frame of a national economy, technical progress gives us the possibility to produce more from the same quantities of natural resources. In term of energy, we get a very simple definition: technical progress is the improvement of the general efficiency of energy conversion. Speaking economically - with regard to utility - we may say that the technical progress allows us to maximize social welfare". (Sagoroff, 1970, 7).

As an addition to Zagorov's theoretical approaches presented so far, it should be noted that he has an affinity and knowledge for economic thought and new ideas in economic theory. In his 1955 article, Zagorov gives a brief overview of the main stages of the development of economic thought and pays special attention to the physiocrats as the forerunners of the energy approach. As well as on the role of classical economists who placed labour at the basis of wealth.[29] Again, we offer the author's own words:

> "From the viewpoint of energy economics, most interesting is *Physiocratism*. As it well known, the "*physique sociale*" of the Physiocrats was inspired by the idea that nature, or "land", is the only source of wealth. Since the productive forces of nature are nothing but energy, Physiocratism cand be regarded as a forerunner of the modern energy value theory. The Physiocrats were aware of the fact that wealth has two aspects - income and capital. This again shows how near they were to the modern concept of energy. For, in the final analysis wealth is energy and energy can be "stored or "released".
> The economist of the Early Classical Period followed the Physiocrats in identifying the original factor of production with a form of energy. However, the one school, born in an agricultural country, attached importance to primary energy (land), while the other, witnessing the rise of an industrial country attached importance to useful energy (labour). The classical economist followed the Physiocrats also in regarding wealth as both stock and flow. Thus, the physical aspect of economic activity was fully realised. Yet two hundred years ago the Law of Conservation of Energy had not been formulated for all form of energy, and concept of energy as a physical common denominator had not entered human thinking" (Sagoroff, 1955, 100).

5. Concluding discussion

After the communists came to power in 1944, and until the end of his life Slavcho Zagorov remained living in exile. His scientific career in emigration began at the University of Regensburg, and from 1950 to 1954/55 Zagorov was an economist at the Institute of Food Research at Stanford University, California.[30] It was there that he developed his original ideas on the role of energy in the economy and made a number of empirical analyses on the agrarian structures of the Balkan countries and their evolution. The question arises as to how Zagorov's own intellectual path led him to radically new ideas for his time about the role of energy in the economy. It is strikingly reminiscent of that of another great scientist, one of the pioneers of ecological economics, namely the Romanian Nicholas Georgescu-Roegen (1906–1994). In this respect, we can distinguish four factors that lead Zagorov to the issue of energy and economics.

In the first place, it is worth mentioning his interest in the practical

[26] The hypothesis of unity between physical and mental processes leads Zagorov to a seemingly eccentric topic, that of the quantitative aspects of schizophrenia (Sagoroff, 1967).

[27] For more information, see Odum (1973), Hall and Klitgaard (2017), Hall et al. (1979) and Hall et al. (2001).

[28] It should be noted that economic measures of GDP measured in USD suffer from the traditional shortcomings of measuring price levels and exchange rates.

[29] One of our referees noted the following comment: "Physiocrats used land when intercepting solar energy was the most important source of wealth, classical economists used labour when that was the most important source of economic energy and neoclassicists (e.g. Solow) capital, when capital was the means of using fossil energy. All correctly identified the main sources of energy of their time."

[30] There is not much data on this moment, but the Stanford Institute archives remain to be studied. Zagorov's activities in the USA can be assessed indirectly by data coming from his two children, Dimiter (Dimitri, Mitko) Zagoroff (1935–2010) and Radka Zagoroff Donnell (1928–2013), who completed their education in the USA during their father's stay. Dimiter Zagoroff was an engineer, an inventor and rationalizer, and Radka Zagoroff Donnell was a pioneer of the modern quilt-making. According to other accounts, Zagorov had another daughter, and his wife died in the US during his stay at Stanford (Fleck, 2000, 152). In addition to being Director of National Statistics, Zagoroff was Minister of Trade, Industry and Labor (1939–1942), and in 1942–1944 was Plenipotentiary Minister in Berlin. He was convicted by the People's communist Court, did not return to Bulgaria, and subsequently was generally inactive in Bulgarian political emigrant communities (at least there is no evidence of this). Zagorov was the first director of the Institute for Advanced Studies in Vienna (1962–1965), where he communicated with world-renowned economists and sociologists. His work as director is featured in a number of publications of Ch. Fleck (2016, 2016a, 2000), according to whom Zagorov's activity was ineffective and controversial. Zagorov was on the board of the Austrian Economic Society in 1956 (Klausinger, 2015).

problems of agricultural economy. Bulgaria in those years was a country where agriculture occupied two-thirds or more of the population. It was at most small-scale and technically poor.[31] Bulgarian agriculture was also of subsistence, self-sufficient character, market and monetary relations penetrated it slowly and patriarchal life prevailed. There was talk of overpopulation in agriculture. The place of animals in agriculture is particularly interesting. According to a summary by the famous interwar Bulgarian economist (and Zagorov's professor), Georgi Danailov:

> "Bulgaria is a rural country. **Bulgaria is the peasant; the peasant is Bulgaria**. Hardly anywhere is the peasant's consciousness of his power and his importance in the life of the country so vividly manifested as in Bulgaria [...]. Bulgaria is, I think, the only country where, under the parliamentary regime, there is not an **agrarian** but a **peasant party**. [...] The Bulgarian peasant is an excellent and passionate cattle-breeder; fine cattle are his ideal. Where and how his child sleeps is of no great interest to him, so his wife takes care of it; but the Bulgarian peasant does not go to sleep before he has rounded up and put in order his cattle. [...] when we speak of the social structure of Bulgaria, we must place the Bulgarian peasant as the central figure from whom the forms and relations of national life in the country proceed" (Danailov, 1936, 3–6, emphasis in original).

Zagorov's interest in agrarian issues was natural for Bulgarian economists of those years (Nathan et al., 1973), but this interest was reinforced by his practical work in the National Statistical Service and especially by the agricultural farm census of 1933/1934, based on the sampling method (Zagorov was one of the practical pioneers in applying this method in Europe, under the leadership of O. Anderson). The Great Depression led to an agrarian crisis, falling prices and a widespread agrarian collapse. Zagorov was one of those who studied the fall and scissors of prices, and their regulation (Zagorov, 1933a, 1935, 1940 and Zagorov, 1941), summarized in the book *The Economic Policy of the Bulgarian Government. Problems of Supply and Prices* (1942)[32]. Zagorov was one of the initiators and architects of the solution of debtors' problems through the creation of the Sinking Fund, which cashed 1/3 of the debts of the most indebted peasants and issued bonds that replaced defaulted loans on banks' balance sheets with Treasury bonds (see Zagorov, 1933; Nenovsky and Marinova, 2022).

The second issue, closely related to the first one, is Zagorov's demographic research and activities. Again, in national statistics, he implemented the population census in 1934/35. This led him to a number of theoretical generalizations about the problems of population reproduction, in particular that of Bulgaria, which he set out in his book *The Reproduction of the Population in Bulgaria* (1934). Zagorov was particularly interested in the problems of fertility (Zagorov, 1930/1931, 1936, 1936a).

Third, in addition to Zagorov's practical work as a statistician, we may note his theoretical and applied interests in index construction (Zagorov, 1929, 1938a; Adam et al., 1961). Indexes were a new and fashionable topic in those years. Zagorov applied indices to different variables, such as prices, exchange rates, incomes, etc. In 1934, he published an article testing the relationship between the dollar exchange rate and prices in the United States as a test of purchasing power parity, published in *The Journal of Political Economy* (Zagoroff, 1934). Zagorov summarized his theoretical research on indices in a monograph as early as 1929, *The Theory of Index Number for General* Price *Movements*.[33] There is no doubt that even at that time the limitations of the price index method became obvious to him, which later resulted in a critique of the value-based monetary measure of national income.

Finally, we may note the author's knowledge of the history of economic thought and his affinity for new ideas and methods, which he seeks to study, apply and promote.[34] As an example, we will quote his article "*New Methods and New Ideas in Political Economy*" (Zagorov, 1937). Among the new ideas, Zagorov expounds the employment theory of J. M. Keynes, J. Robinson's theory of limited competition and, among new methods, the Input-Output table of V. Leontiev, and a number of others. What is curious for us is that, among the methods, he pays special attention not only to econometrics and the role of mathematics in economics, but also to the parallels between economics and physics.

As already mentioned, the main source of influence for the formation of his energy theory was his preoccupation with the agrarian structures and energy balances of the Balkan countries, especially during his stay at Stanford.[35] To these must be added intellectual sources in the field of energy problems as well as physics. Zagorov did not list most of them. Among the scant publications cited, those of J. H. Lisman (1949), T. Carver (1924) and A. Pikler (1951)

But more generally, and a priori without any knowledge of Marxist and Russian literature,[36] Zagorov was in line with Eastern European and Russian economists who have been interested in the question of energy in economics since the work of the Ukrainian economist S. Podolinsky (2005), who corresponded with K. Marx. For example, the energy approach was extremely popular in Russia until the October Revolution. We could mention here two original books by Russian scientists S. Goering (1904) and Doctor Shtokman (1914).[37] Very soon after the beginning of the Bolshevik regime, a number of theories emerged, which attempted to measure human activities in human (labour) and mechanical energy, among which the ideas of the famous Marxist scientist Alexander Bogdanov and later by Vladimir Bazarov and Bukharin and Preobrazhensky (1919) stand out. There were also the fundamental contributions of Alexander Chayanov (1921), as well as the technical developments on alternatives to monetary measurement, be it in energy or labour measurements, developed by M. Smith (1921), S. Strumilin (1921), L. Lubny-Hertzyk (1922), A. Dembo (1921, 1921a), A. Vainshtein (1920) and a number of others.[38]

The agrarian theory of A. Chayanov and the Russian Narodniks allows us also to better understand the circulation of ideas to other Eastern European countries, especially in the Balkans, where it had a strong influence on agrarian theories in Moldavia and from there in Romania (e.g. V. Madgearu, C. Dobrogeanu Gerea, S. Lupasco (in France) and of course N. Georgescu-Roegen) and later in the agricultural movements of Croatia, Serbia and Bulgaria. This is of course a topic for further complex

[31] Zagorov devoted an article to this problem (1937a). See also the article on the fundamental problems of Bulgarian agriculture by Dolinsky (1931). And for Bulgarian economy in general, Dimitrov (2014).

[32] In presenting the theory of cycles (booms and depressions), Zagorov particularly emphasized the role of the agrarian character of the country. According to him, in agrarian countries "the natural cycles of agricultural production are intertwined with industrial cycles" (Zagorov, 1938b, 615). See also Zagorov (1939,1942).

[33] For a critical review of this book, see Mikhailov (1930). After Zagorov's death, his work on statistics was published in German as *Wissenschaft und Statistik. Das statistische Denken in den Empirischen Wissenschaften* (Sagoroff, 1973).

[34] As evidence of Zagorov's interest in new developments in economics, we can cite his numerous reviews of new publications, especially after he emigrated.

[35] The written evidence does not allow us to judge how Zagorov arrived at his ideas; he did not make any overviews and syntheses of what was done before him.

[36] So far, there is no evidence that Zagorov was familiar with the debates on value within Marxism.

[37] Magnin and Nenovsky, 2021.

[38] Magnin and Nenovsky, 2021.

and comparative studies.[39] Again, it is specific to Zagorov that Narodnik and agricultural theories were not accepted by Zagorov and cannot be considered as a determining factor in the formation of his energetic ideas.

In this article we have tried to restore "an injustice" by presenting the pioneering insights and publications of Slavcho Zagorov in the field of energy and ecological economics, forgotten by the history of ecological thought. Slavcho Zagorov, a well-known Bulgarian statistician and economist, who after the war emigrated and taught in Germany and Austria, presented his works chronologically before another representative of the Balkan countries, also an emigrant, a pioneer of ideas leading to the founding of ecological economics, Nicholas Georgescu-Roegen.[40] Their lives, taken in parallel, unfolded in a similar way, education, careers in their home countries, where they became interested in agrarian, statistical and demographic problems, and eventually emigration, where they built their new, close-in-spirit, theories, that went beyond the traditional frameworks of conventional economics. However, Zagorov did not wish to challenge the dominant paradigm in economics but only to complement it, considering that economic thought in his time was focused on short term exchange theory while the energy approach concerned long-term problems. This is an important difference with the work of Georgescu-Roegen. Moreover, while in Georgescu-Roegen normative elements and policy directions can be found, in Zagorov these are absent (see for details the table in Appendix A).

"The energy approach in economics is "orthodox". It agrees with the prevailing doctrines of contemporary economics and contemporary physics. It leans on them and makes wide use of their conceptual tools" (Sagoroff, 1955, 91).

However, Zagorov's original and promising idea about energy met with hostility from the mainstream scientific community of the time, as pointed out by prof. W. Winkler, whom he succeeded at the University of Vienna.

> "The most impressive idea of his was to express economic balances in terms of energy, which idea has been worked out in detail and propagated in a book as well as in several articles. Such a reform has been necessary in view of the big sources of error attached to the usual economic balances expressed in money. Against reasonable expectations, his idea met with opposition and even ironic criticism. On a certain occasion, the present writer had to take the floor against such opposition. He is convinced that the time is not far off, when the value of Sagoroff's idea will be generally acknowledged and when the theory of to-day is met in practice tomorrow" (Winkler, 1971, 125).

The parallel trajectories of the life and work of Zagorov and Georgescu-Roegen, representatives of two agrarian and peripheral Balkan countries, are an interesting testimony to the birth of economic ideas and theories, their trajectory, and the fate of their creators. Some remain in the treasury of the history of economic thought, others are irretrievably forgotten.

Irretrievably, until, perhaps, chance makes it so that they are rediscovered. For us, there is no doubt that Zagorov is part of the history of economic and energy thought. However, the mystery remains as to how Zagorov's publications and ideas remained unknown to Georgescu-Roegen, given the high probability, if not certainty, that their paths crossed (see Appendix A). Solving this riddle seems possible and is one of our next research goals.

For Zagorov, as well as many other thinkers from many different disciplines over time, including Frederick Soddy, Kenneth Boulding, Leslie White, Nicolas Georgescu-Roegen, Howard Odum, Charles Hall and many others, it is not possible to understand economies without understanding their fundamental basis in energy. It is sad that mainstream economics remains as ignorant of the fundamental role of energy now as it did in Zagorov's time.[41]

CRediT authorship contribution statement

Nona Nenovska: Writing – review & editing, Writing – original draft. **Eric Magnin:** Writing – review & editing, Writing – original draft. **Nikolay Nenovsky:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Slavcho Zagorov and Nicolas Georgescu-Roegen compared (our interpretations)

	Slavcho Zagorov (Bulgaria, Austria)	Nicolas Georgescu-Roegen (Romania, USA)
Biographical data	1898–1970 Sofia, Bulgaria	1906–1994 Constanta, Romania
Education	Sofia, Switzerland, Germany, England and USA Rockefeller Fellowship (1933/1934 in Harvard, Leontief, Schumpeter), again Rockefeller grant in 1937[40]	Bucharest, France, England, USA Rockefeller Fellowship (1934 in Harvard, Leontief, Schumpeter[41])
Statistical approach	School of A. Chuprov and O. Anderson, collaboration with O. Anderson (Sagoroff, 1960) Founder of *Metrika,* Austrian journal of statistics (1958)	School of K. Pearson, cooperation with K. Pearson (1930–1932) Influence of Emil Borel's mechanical statistics (France)
Main areas of education and basic research	Statistics, Demography, Agricultural economy, Foreign trade	Statistics, Mathematics, Agricultural Economics, Demography
Administrative posts in the native country	Director of National Statistics of the Kingdom of Bulgaria Institute of Business cycle research at Sofia University (director O. Anderson) Minister of Trade, Industry and Labour (October 1939–April 1942)	Deputy Director of National Statistics of the Kingdom of Romania, Institute of Business cycle research in Bucharest Leading negotiator for the Romanian foreign economic relations, Ministry of National Economy, the Armistice Commission

(*continued on next page*)

[39] See Josephson et al. (2013), Magnin and Nenovsky, 2021 and Vianna Franco and Missemer (2022). And also the Bulgarian economist Mateev (1987).

[40] On the life of Nicholas Georgescu-Roegen, see Martinez-Alier (1997), Gowdy and Mesner, 1998, the introduction by J. Grinevald et I. Rens in Georgescu-Roegen (1995); on the Romanian period, see Bobulescu (2013), and recently Suprinyak (2022) and Ferrari (2021, 2023).

[41] This final comment was suggested to us by one of the referees.

(*continued*)

	Slavcho Zagorov (Bulgaria, Austria)	Nicolas Georgescu-Roegen (Romania, USA)
Stay in the USA after the WWII	In the period 1950–1954/55 Researcher at the Stanford Food Institute (his wife died in Stanford) Director of the Institute for Advanced Studies in Vienna (1962–1963)[42]	From 1948 to the end of his life First at Harvard, and subsequently as professor at Vanderbilt University
Collective Monograph in 1955, Zagoroff, S., J. Végh, and A. Bilimovich, *The Agricultural Economy of the Danubian Countries, 1935–1945*, Stanford University Press, Stanford	Zagorov wrote the chapter on Bulgaria and Romania. The chapter on Romania is based on notes by a Romanian economist who remained anonymous. In this chapter, Zagorov quoted two articles by Georgescu-Roegen written in the *Romanian Encyclopaedia* between the wars (the only pieces written by Georgescu-Roegen between the wars). In 1966, wrote a review of Georgescu-Roegen, and made references to the energy concept	In our opinion, the anonymous author on Romania in the collective monograph, who chose to remain anonymous due to the danger of persecution of his relatives in Romania, was Georgescu-Roegen. In our opinion, some of these texts were previously written in the framework of projects on the agrarian economy of Romania within the Russian Research Center in Harvard and in 1954 in Vanderbilt's economic department (Suprinyak, 2022; according to him they have not been published).
First publications on the topic of energy in economics	In 1954, 1955 (but before in German, a book in German on energy economics)	In 1971 but claims to have started 20 years earlier. According to Supryniak (2022), and others, the real change in the evolution of Georgescu-Roegen was in the period 1965-1966. Interestingly, 1965 saw the publication of Rao (1965). *Essays on Econometrics and Planning, Presented to Professor P. C. Mahalanobis,* in which Georgescu-Roegen wrote a chapter, and which was reviewed in the direction of energy economics by Sagoroff (1966).
Features of the model	Theory: energy is at the centre, compatibility of the energy approach with neoclassical thinking; energy and neoclassical economic cover different time horizons A supporter of computerization and informatization (Zagorov established the first computer center in Vienna with money from the Rockefeller Foundation, in 1962).[43] Zagorov highly valued John von Neumann, considered him a genius. Zagorov's son Dimiter Zagoroff graduated from Paolo Alto school and MIT Mechanical Engineering in 1957; he was a professional inventor. See also his last publication on technical progress, inventors and human mind (Sagoroff, 1970, written in 1965) Applied part: building a methodology to measure national income as energy-matter and applying to a range of countries, Balkan countries, measuring productivity through energy, etc. Lack of normative part, no policy making implications	Theory: entropy is at the centre, difference between energy and matter, criticism of the neoclassical approach A highly developed epistemology and philosophy of bioeconomics Does not accept computerization and information systems, stresses the difference between entropy and information The applied and empirical part is missing. Attempts to build a normative part (criterium of minimum regret), and a policy of reducing growth and even negative growth, *degrowth*
Integration into the international community	Zagorov knew the leading economists, has been in working groups with them, has correspondence with them, for example: Hayek, Leontief, Morgenstern, etc. (he was active internationally between the wars, and after the war as a director of Vienna Institute for Advanced Studies) But still not so well known because he was in Austria (most of his articles and books written in German) Had no students in the field of energy economics, there were PhD students, but in other fields (mainly economic statistics)	He became one of the leading economists and attended economic circles after WWII (between the wars was in isolation in Romania, especially 1936–1948) Leading American economist Had students and famous followers (e.g. H. Daly)
Intellectual influences (according to us)	Statistics (A. Chuprov and O. Anderson) Neoclassical economy Keynesianism, Leontief method (correspondence with Leontiev on input-output method; Zagorov tried to build energetic matrices, 1959) Physics, biology, mechanics In the last part of his life - psychology (see his last official publication, *Technical progress and Human Mind,* Sagoroff (1970), paper presented in 1965) Zagorov did not know well and did not accept Marxism and agrarian theories	Statistics (K. Pearson) Neoclassical economy Schumpeter, collaboration with Leontiev on improving mathematically input-output matrices (Harvard, at the early 1950s), later correspondence with Leontiev and attempts to apply them to agrarian Romania Agricultural economics and demography (Georgescu-Roegen, 1960) In particular he knew Narodnik's theory (Romanian poporanism) and Chayanov's work, he was a member of Romanian National Peasant Party Georgescu-Roegen knew Marxist theory well, but did not accept it

Source: Authors' compilation. The comparative analysis presented in this table does not claim to be definitive or comprehensive but subject to future developments.

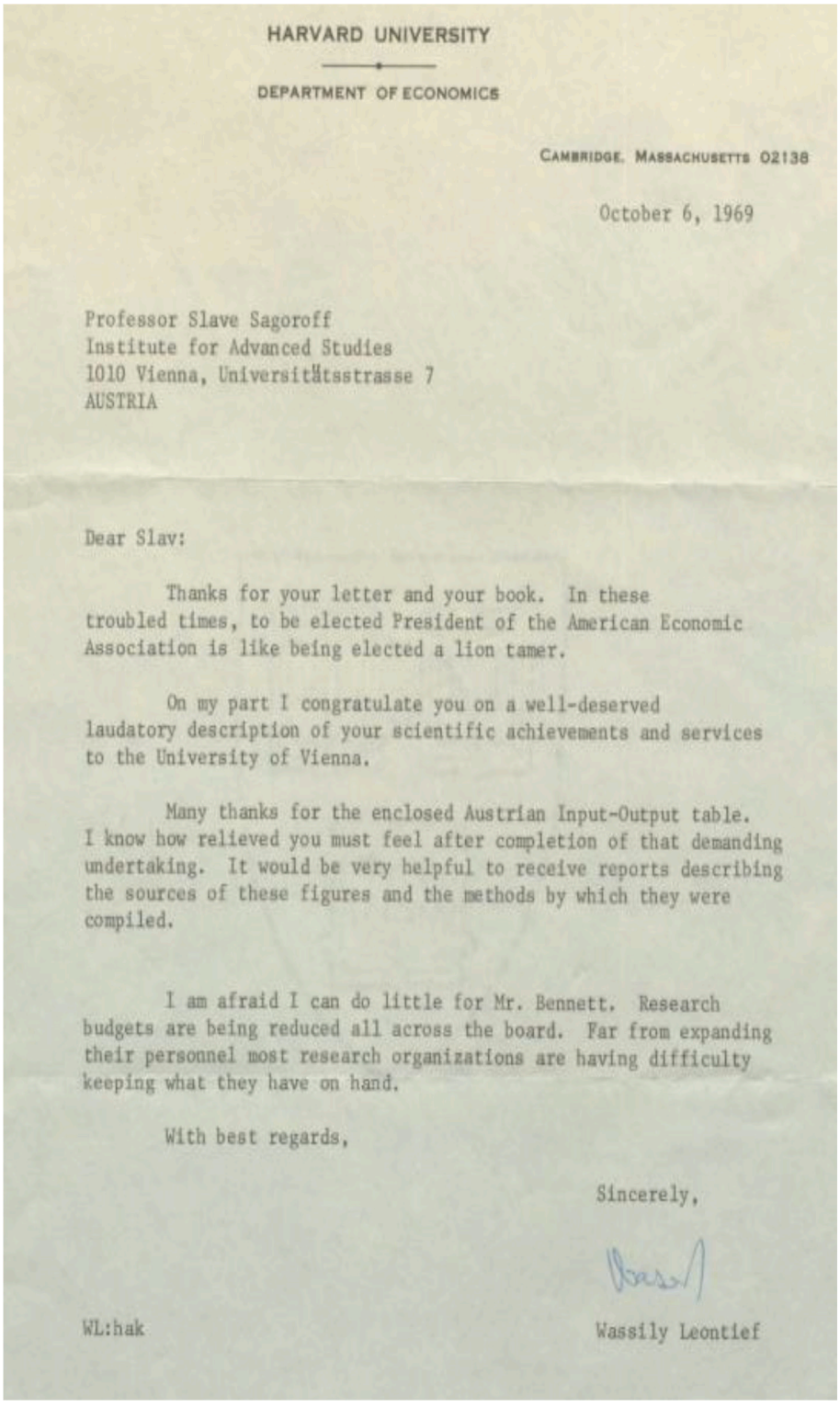
[40] Fleck (2000), 152; Faure (2012), 5.

[41] Gowdy and Mesner, 1998, 138–139.

[42] Fleck (2000, 2016, 2016a)

[43] See also https://geschichte.univie.ac.at/en/articles/how-university-computerizes-itself

Appendix B. Letter from Leontief to Sagoroff (dated October 6, 1969)



HARVARD UNIVERSITY

DEPARTMENT OF ECONOMICS

CAMBRIDGE, MASSACHUSETTS 02138

October 6, 1969

Professor Slave Sagoroff
Institute for Advanced Studies
1010 Vienna, Universitätsstrasse 7
AUSTRIA

Dear Slav:

Thanks for your letter and your book. In these troubled times, to be elected President of the American Economic Association is like being elected a lion tamer.

On my part I congratulate you on a well-deserved laudatory description of your scientific achievements and services to the University of Vienna.

Many thanks for the enclosed Austrian Input-Output table. I know how relieved you must feel after completion of that demanding undertaking. It would be very helpful to receive reports describing the sources of these figures and the methods by which they were compiled.

I am afraid I can do little for Mr. Bennett. Research budgets are being reduced all across the board. Far from expanding their personnel most research organizations are having difficulty keeping what they have on hand.

With best regards,

Sincerely,

WL:hak

Wassily Leontief

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