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Sant'Anna School of Advanced Studies – Pisa

European Commission

Research Fund for Coal & Steel

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

ADVANCED CONTROL AND SUPERVISION SYSTEMS FOR OPTIMIZING THE MANAGEMENT OF STEELWORKS PROCESS OFF-GASES NETWORKS

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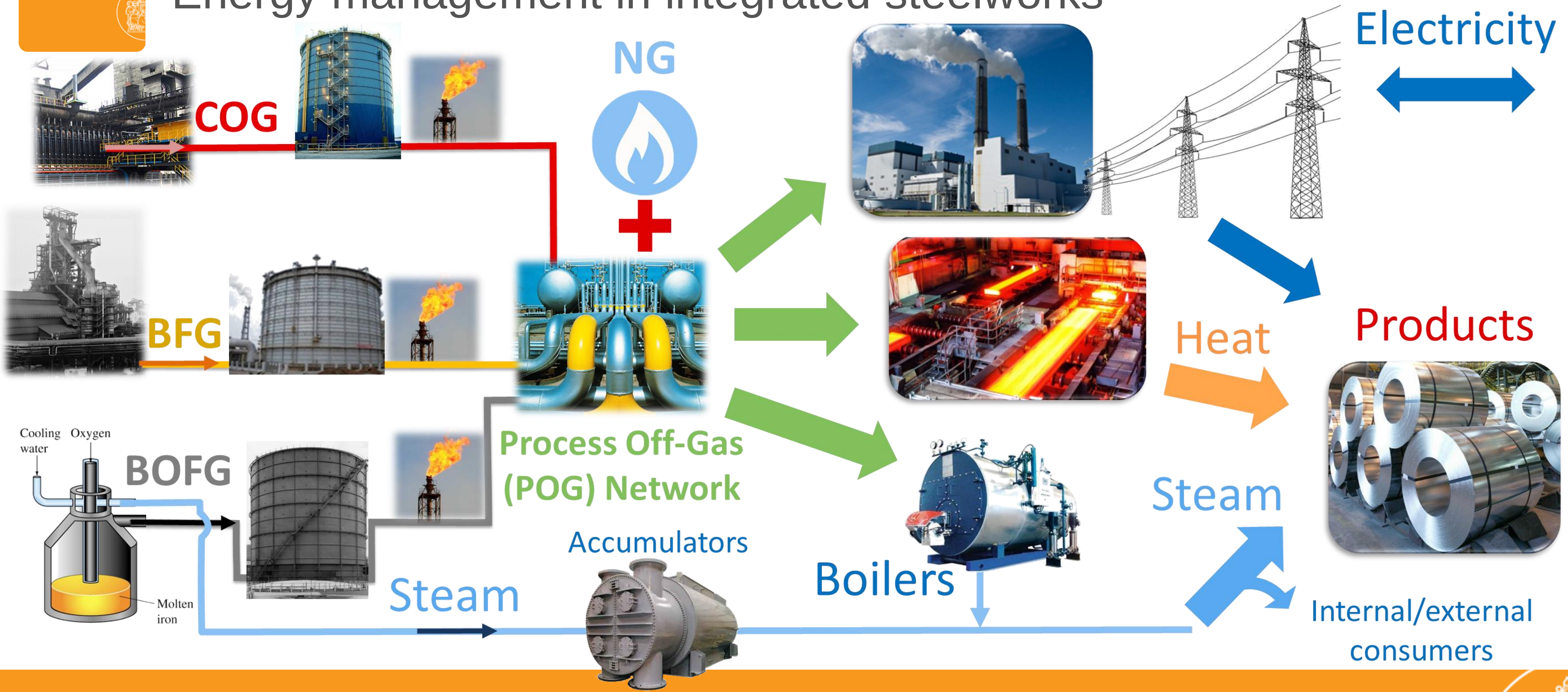
Introduction

Energy management in integrated steelworks



Introduction

Energy management in integrated steelworks

Single POG network supervision/control strategy

- Gasholder level prediction based
  - Supervision systems (the decision are formulated by operators)
  - Control strategies: No mutual interaction between POG networks

Plantwide supervision/control strategy

- Optimization of the POGs distribution through plantwide economical optimization

Not solved Issues:

- Standard modelling methodologies does not allow to predict heavy nonlinear process behavior
- Short prediction/control horizon (30 minutes / 1 hour) is sufficient for control application but not enough for formulating medium/long term decisions

Introduction

The GASNET Project

GASNET → Management optimization of the process gas network within integrated steelworks → DSS for process operators

Objectives of the project:

- Simulation of POGs networks
- Offline optimization of gas network structure
- Online optimization of the distribution of POGs
  - **Scheduling of power generation optimization (Long term)**
  - **Online optimization and support (short term)**

✓ Minimize the environmental impact of energy exploitation

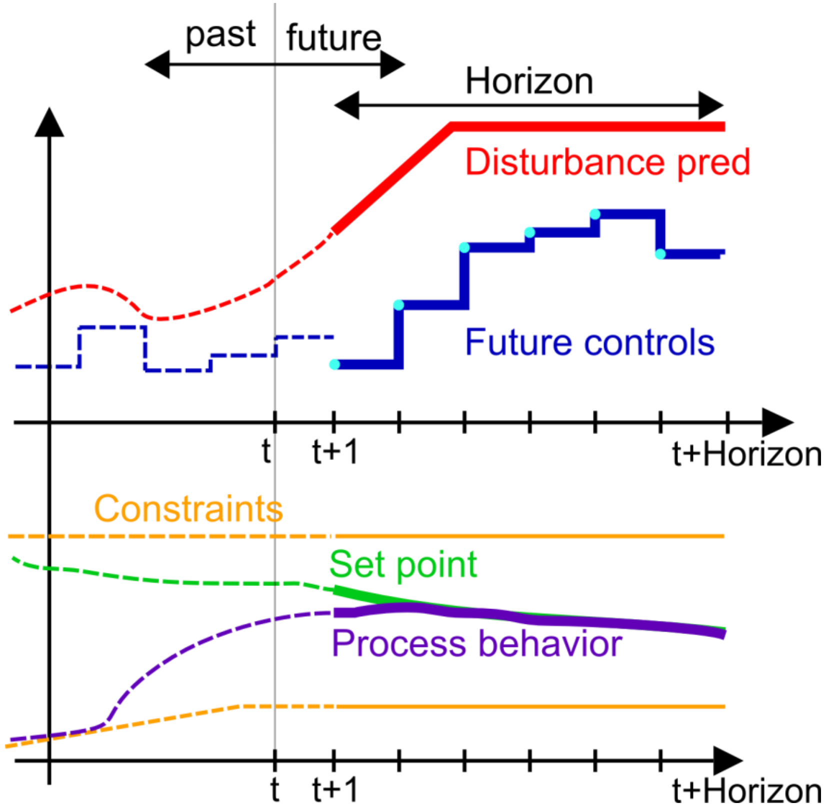
Methods

Hierarchical Control and economic MPC

A plantwide multiperiod controller allows to optimize the POG distribution, also considering the dynamics of the processes connected to the POG network (power plant, gasholders, etc.).

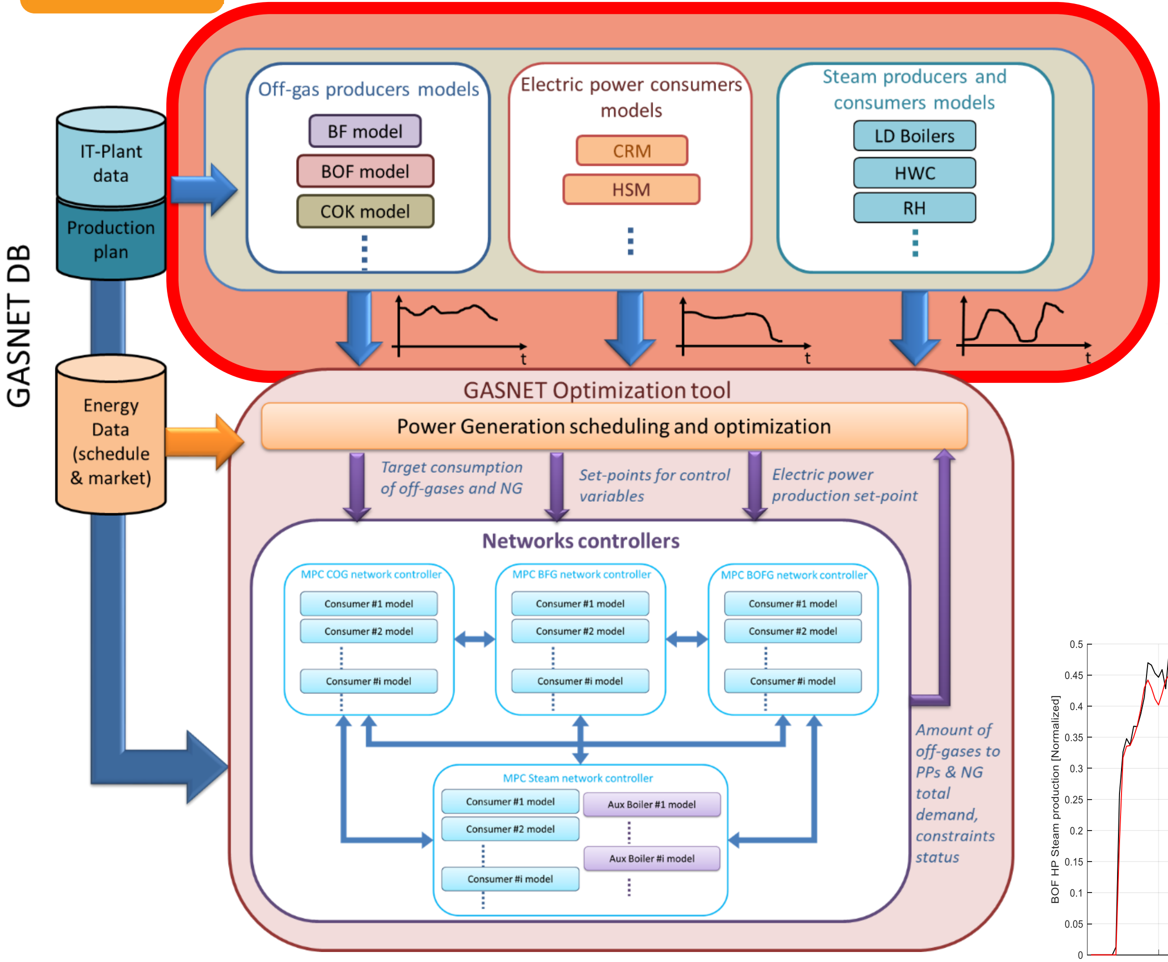
Objective:
minimize management costs and environmental impact

Economic MPC-based Supervision and control system



Control and Supervision approach

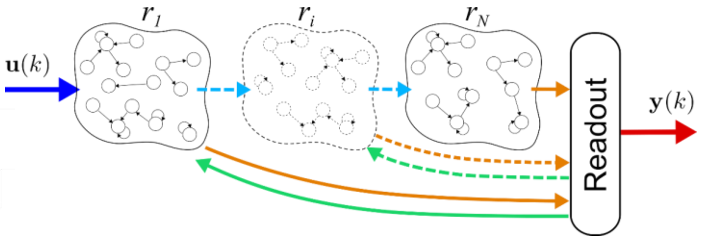
Energy prediction system

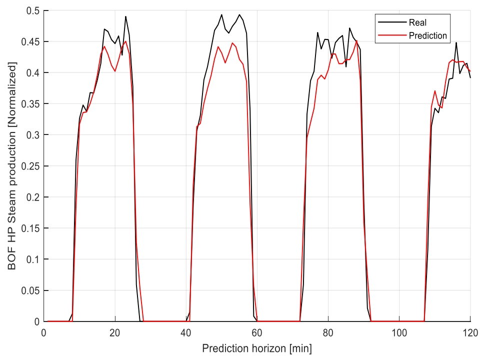


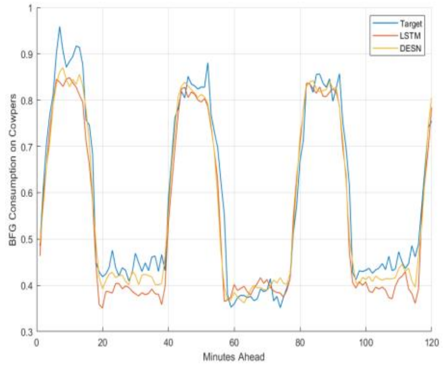
Prediction models:

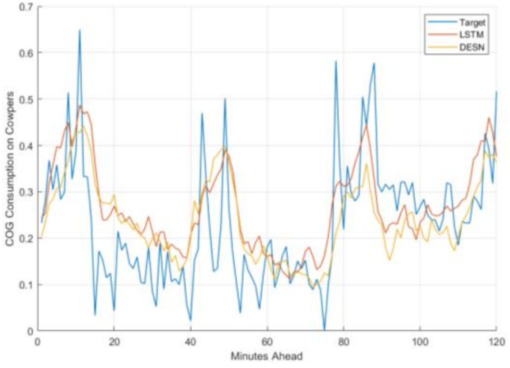
- POGs production and consumption
- Electricity consumption and production (e.g. BFG expansion turbines)
- Steam production and consumption

Deep Echo State Networks [1, 2]





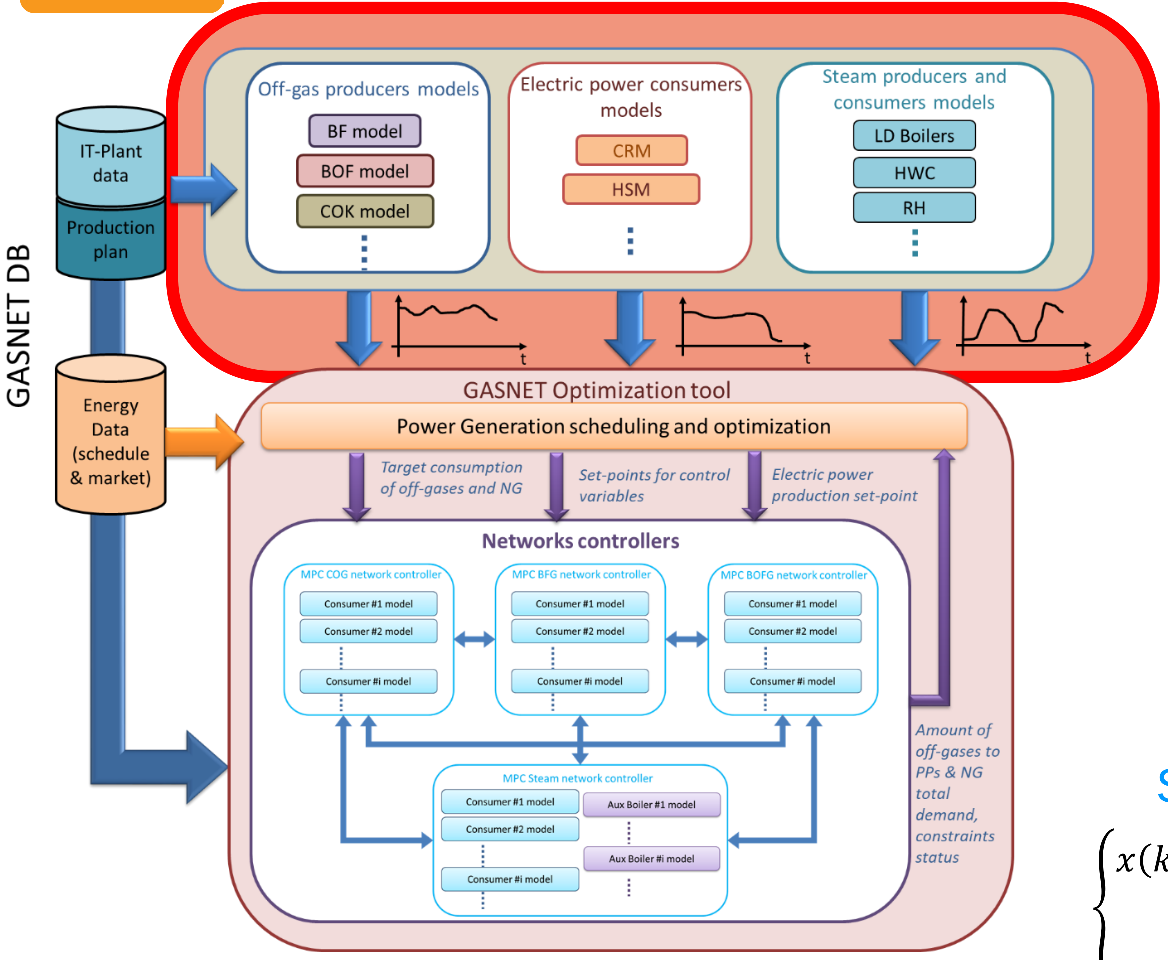




[1] Dettori, Stefano, et al. "A Deep Learning-based approach for forecasting off-gas production and consumption in the blast furnace." Neural Computing and Applications (2021): 1-13.
[2] Matino, Ismael, et al. "Machine Learning-Based Models for Supporting Optimal Exploitation of Process Off-Gases in Integrated Steelworks." Cybersecurity workshop by European Steel Technology Platform. Springer, Cham, 2020.

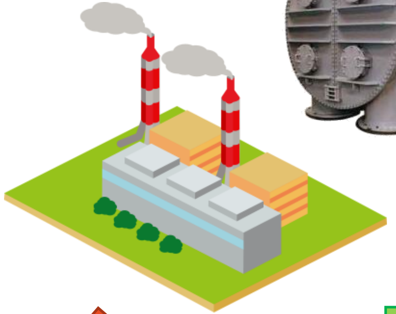
Control and Supervision approach

Energy prediction system



Plant models

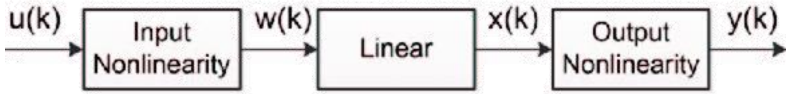
- POGs networks and gasholders
- Power Plant
- Steam network, boilers and accumulators



State space models

$$\begin{cases} x(kT+T) = Ax(kT) + Bu(kT) \\ y(kT) = Cx(kT) + Du(kT) \\ x(0) = \boldsymbol{x}_0 \end{cases}$$

Hammerstein Wiener models



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Control and Supervision approach

The POGs distribution optimizer

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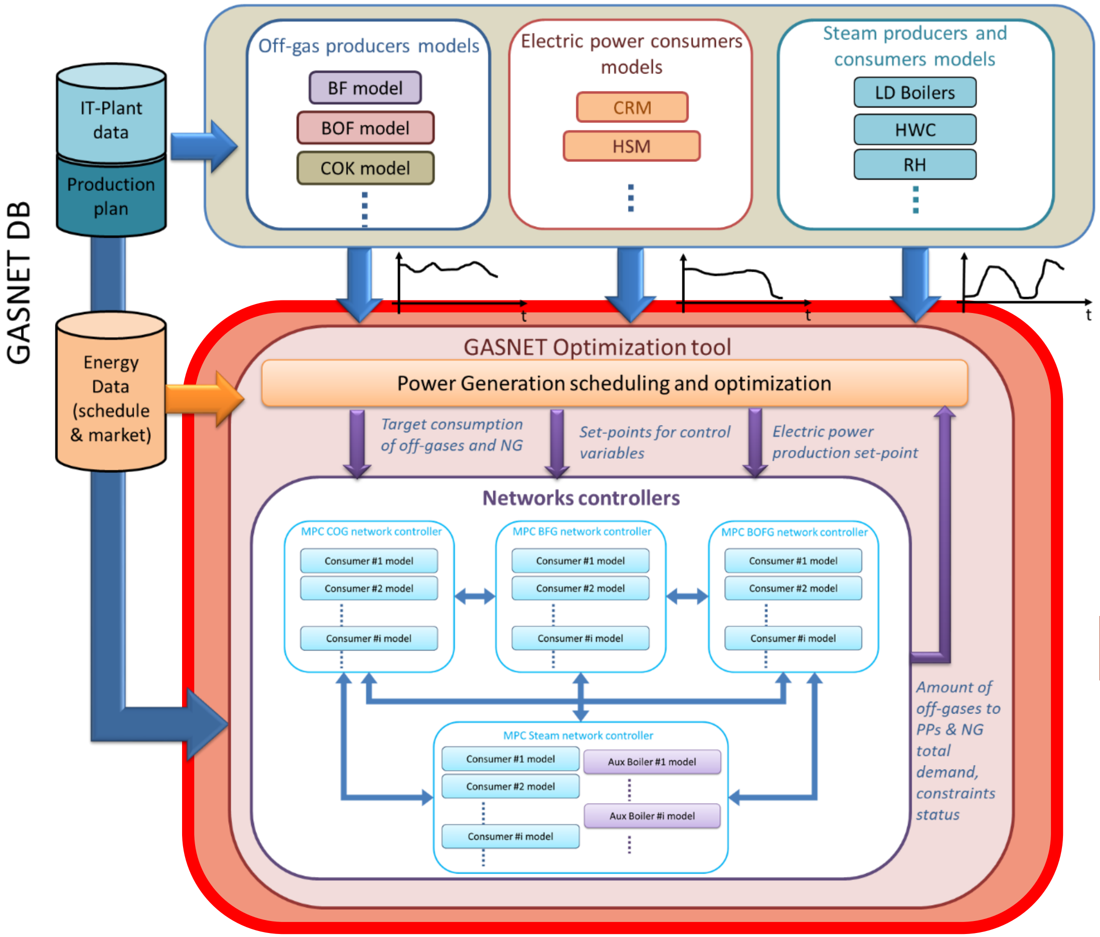
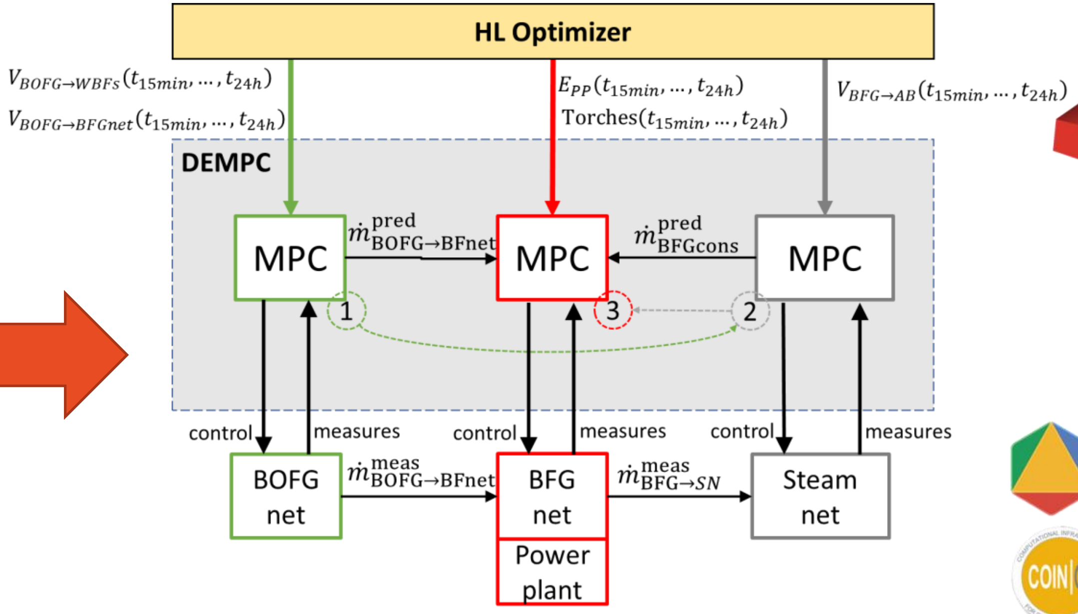


POGs Optimizer

- Calculates a possible optimized POG distribution:
  - HL Optimizer: up to 1 day ahead
  - LL Optimizer: 2 hours ahead



MATLAB

YALMIP

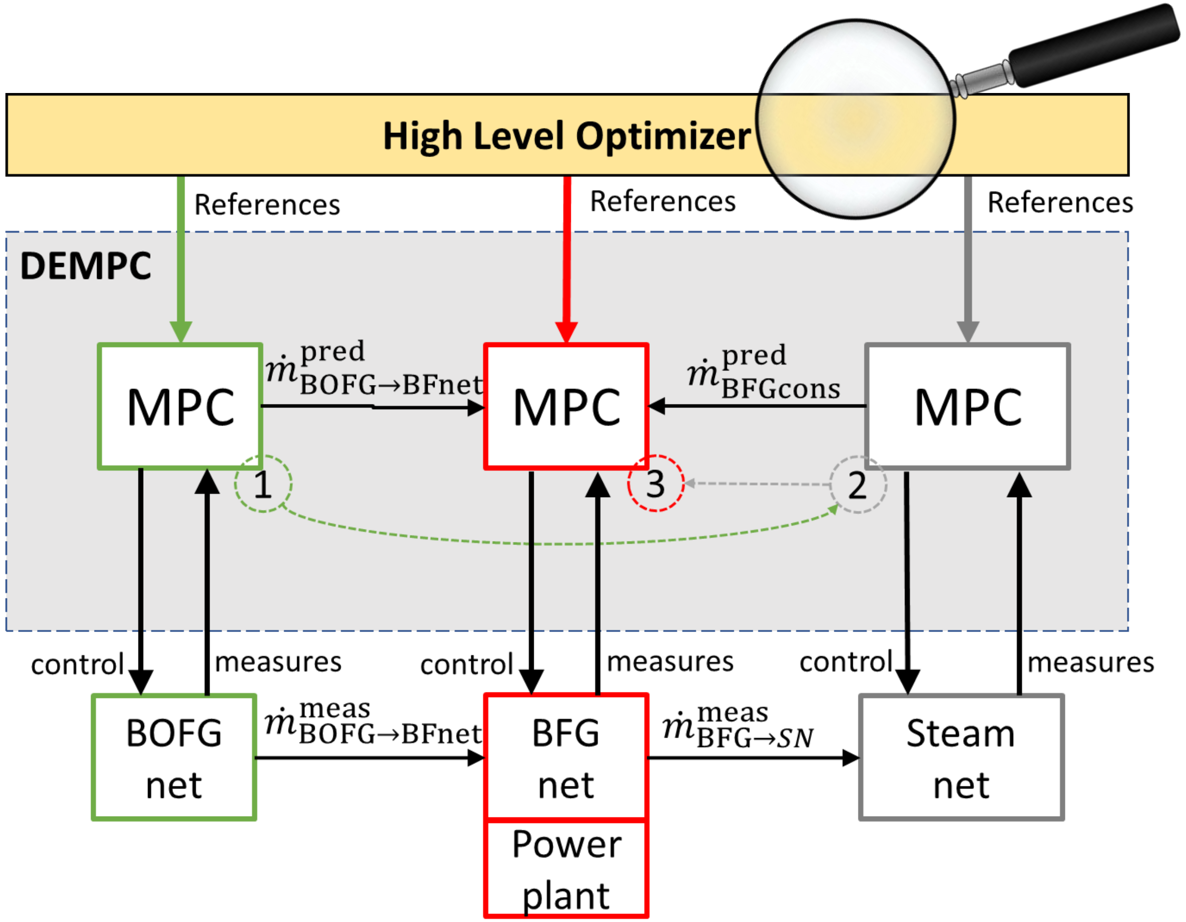
GUROBI OPTIMIZATION

Google OR-Tools

CBC (CoinOR branch and cut)

POGs distribution optimizer

High Level Optimizer: Economic MPC Formulation



High Level Optimizer

Costs:

$$\sum_{k=t}^{t+N_p} \gamma^k \left(c_{NG} E_{NG}(k) + C_{EP}(k) E_{EP}(k) - C_{ES}(k) E_{ES}(k) + C_T E_T(k) + C_{CS} V_{S_{CS}}(k) \right)$$

- Natural gas consumption
- Electric energy purchased
- Revenues of POG based electricity production
- Environmental impact in terms of natural gas savings in the power plant
- Cost of steam waste in the steam network

Constraints:

✓ Powerplant: min/max power, min/max thermal power, min/max power variation

✓ POGs networks: Energy conservation, Min/max gasholder level, Min/max transferable POG to other networks, Min/max POG flow in the torches

✓ Steam boilers: min/max thermal power, min/max steam mass flow

✓ Steam network: Steam mass conservation, min/max steam mass in the accumulator, min/max condensed steam

✓ Dynamics and models in the loop: Power plant, gasholders, boilers

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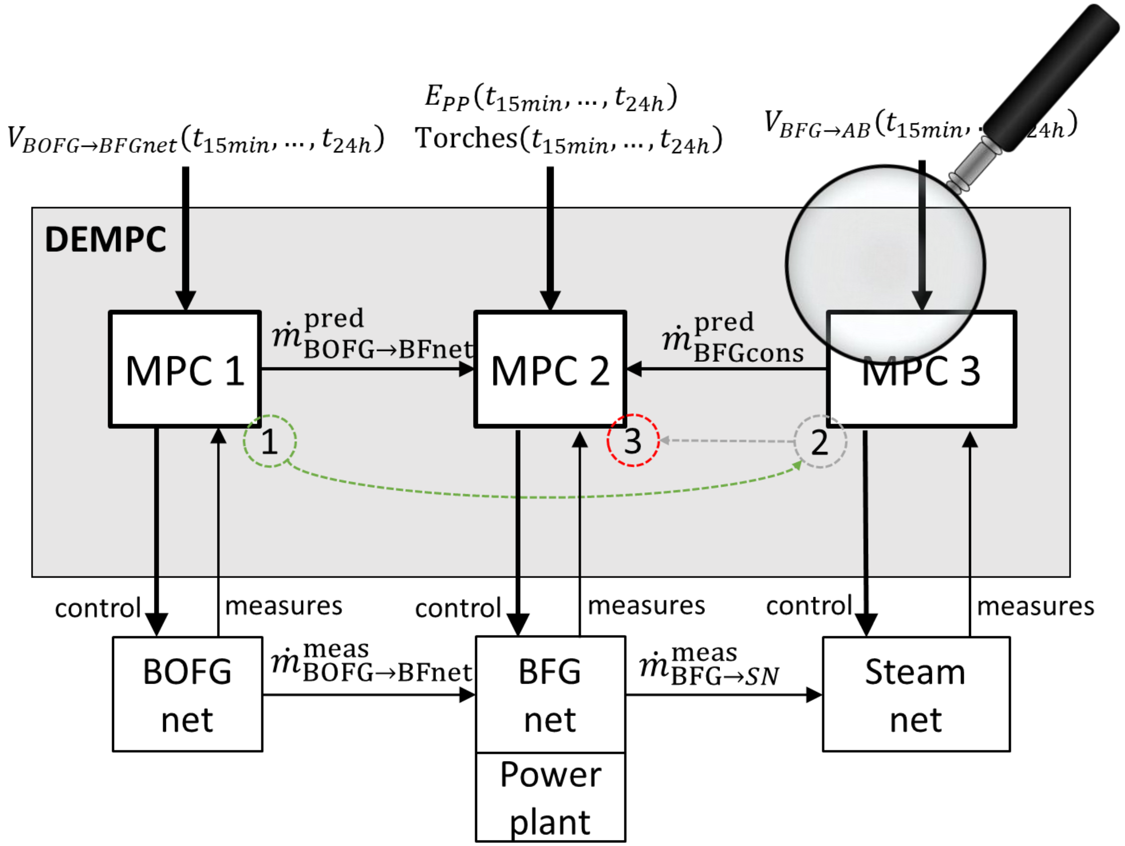
POGs distribution optimizer

Low Level optimizer: Economic hybrid MPC Formulation



Low Level Optimizers: Distributed Hybrid Economic MPC

Costs: the economic balance in each specific POG and Steam network.

Constraints:

- ✓ POGs Networks: Energy conservation, Min/max gasholder levels, Min/max POG flow in the torches, specific operative conditions
- ✓ Electric Network: min/max operative conditions of the power plant
- ✓ Steam Networks: Steam mass conservation, min/max operative points of steam boilers, steam accumulators and pressures
- ✓ Dynamics and models in the loop

Results

Offline simulations

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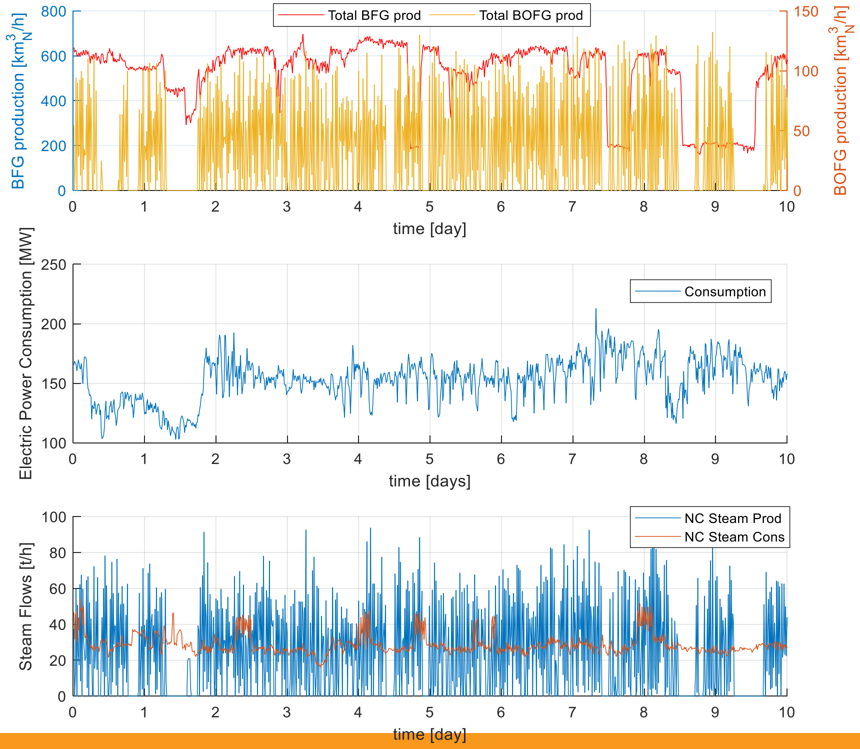
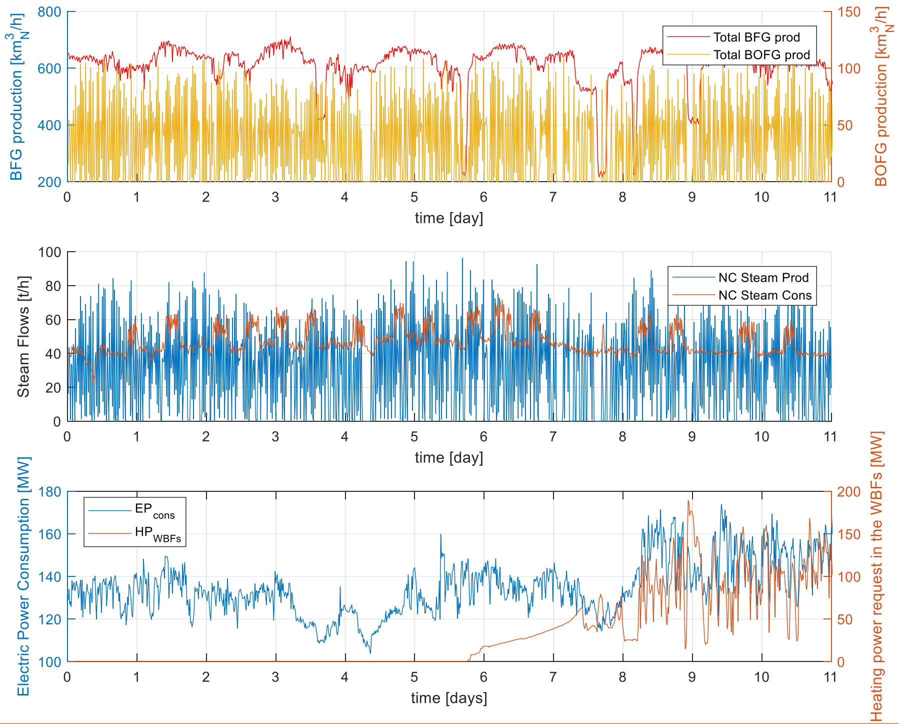
Simulation phase is needed to test the feasibility of the approach.

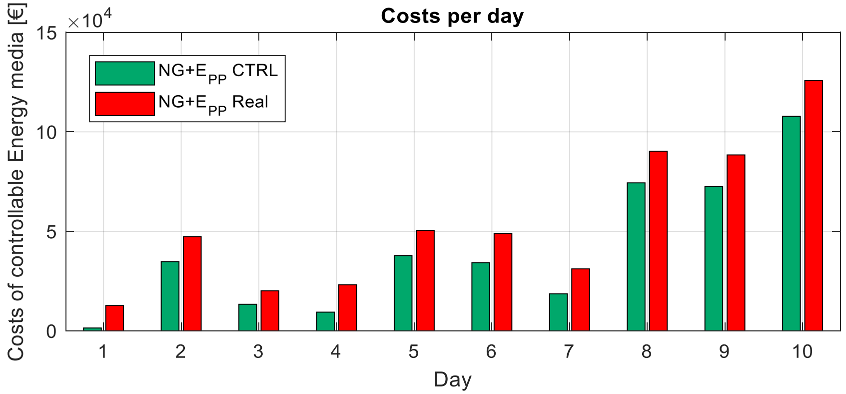
Several scenarios have been simulated, from standard production periods to less productive periods

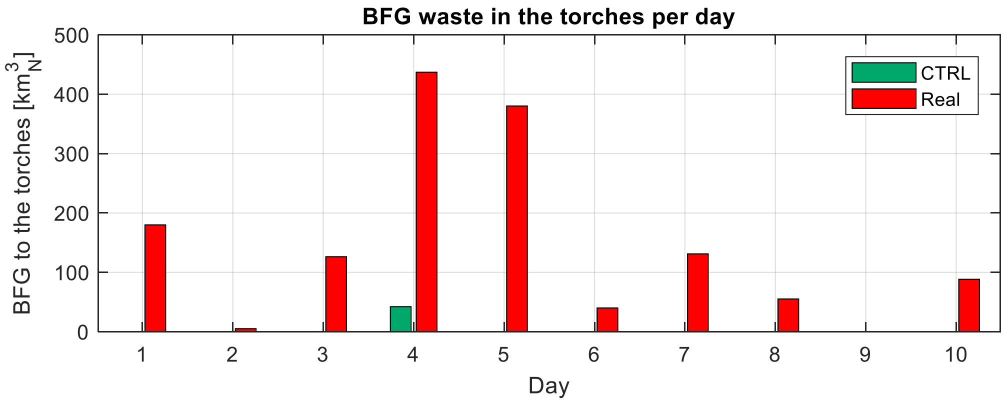


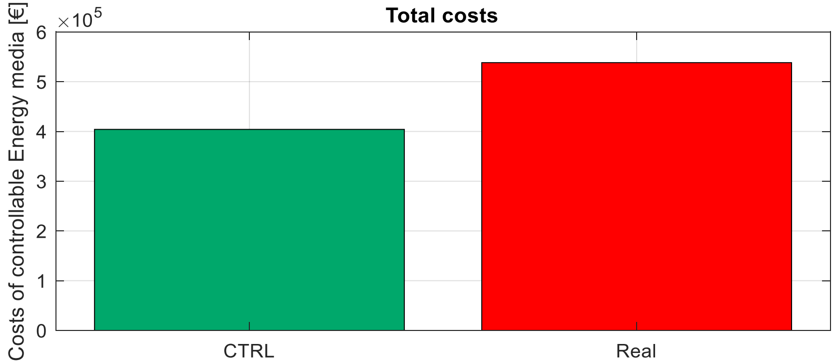


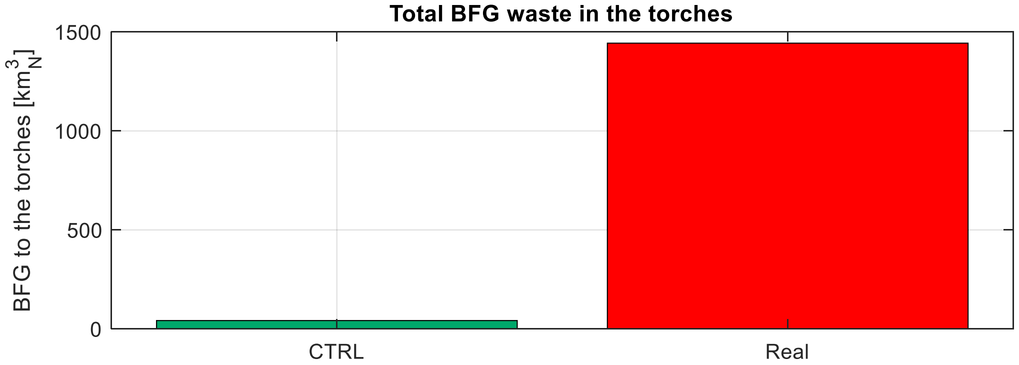
Results

Offline simulation example







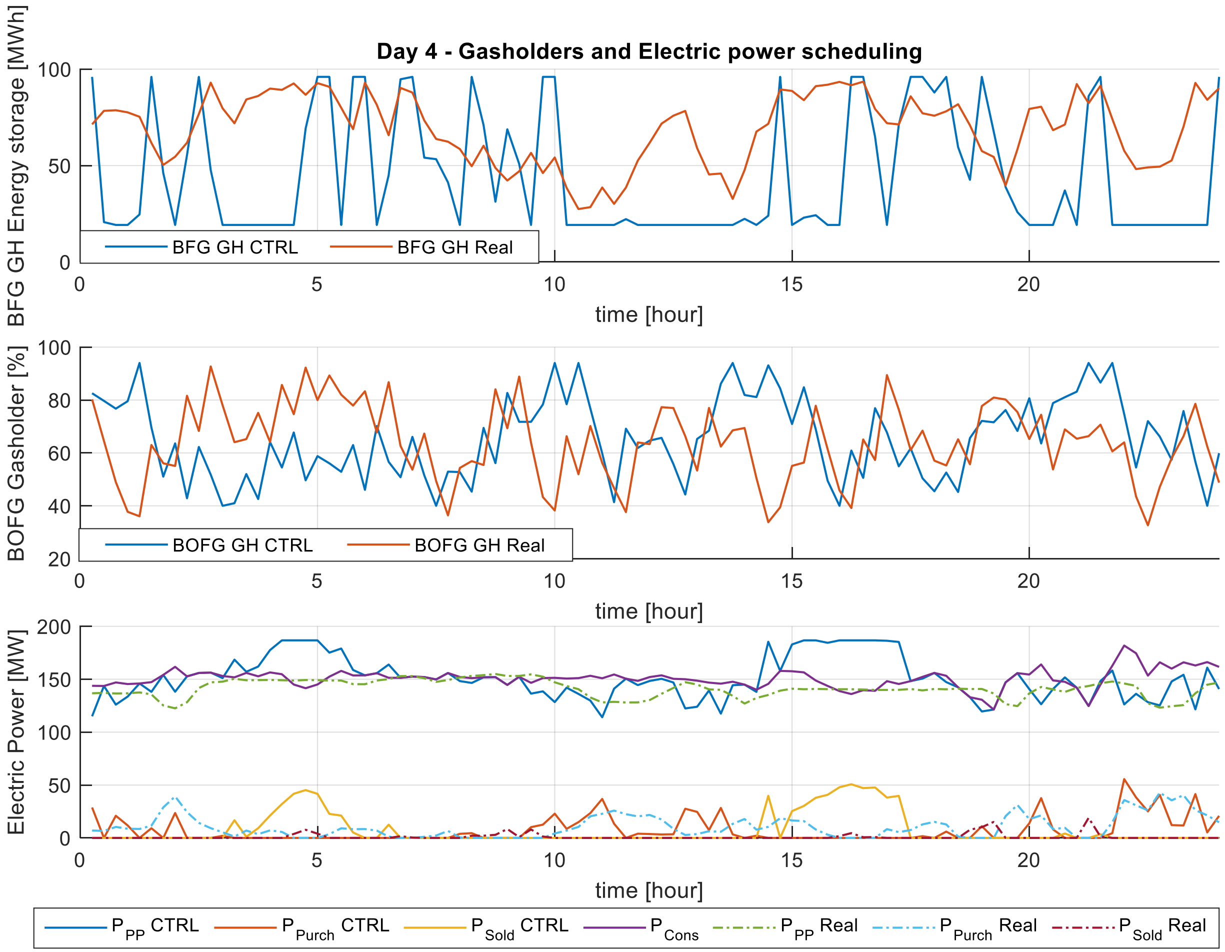


Plantwide hierarchical control strategy allows to reduce energy dependence from the extern and significantly reduce environmental impact due to use of torches

$KPI_{€}$ [k€]	$KPI_{€\%}$ [%]	KPI_{EPPint} [GWh]	$KPI_{EPPint\%}$ [%]	$KPI_{Torches}$ [GWh]	$KPI_{torches\%}$ [%]	KPI_{NG} [GWh]	$KPI_{NG\%}$ [%]
175.1	27.49	0.67	2.46	1.43	96.9	3.72	41.56

Results

Offline simulation example



- The control action maximize the electricity production in the power plant, by using BFG as much as possible
  - Minimize the use of external electricity source
  - Maximize (when possible) the sale of electricity to the grid
- When possible, BOFG is transfered to the BFG network through mixing stations, to avoid torch exploitation

Discussion, conclusions and future works

- AI models allows to effectively predict the dynamic behavior of complex steelwork processes and systems
- Standard (linear) modelling techniques aimed at describing controlled systems allows to simplify the control strategy which is based on Hierarchical Model Predictive Control
- Plantwide hierarchical control strategy allows to effectively optimize the energy distribution within integrated steelworks, by means of an intelligent exploitation of POGs

Discussion, conclusions and future works

- Improve the smoothness of the control strategy through MIQP formulations
- Study the effect of networks revamp and new pipelines connections on the POGs distribution
- Explore coexistence of traditional and innovative processes and production units, such as the Direct Reduced Iron (DRI) /Electric Arc Furnace (EAF) route including Natural Gas (NG) and hydrogen exploitation, and study the implications on the POGs and energy distribution in the steelworks of the future

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Thank you!

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