EUROSTEELMASTER 2022

XIII Edition - Online course

European Advanced Training Course for the Worldwide Steel Sector

16 - 20 May 2022

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Optimal off-gas management in integrated steelworks

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  - Energy management in integrated steelworks
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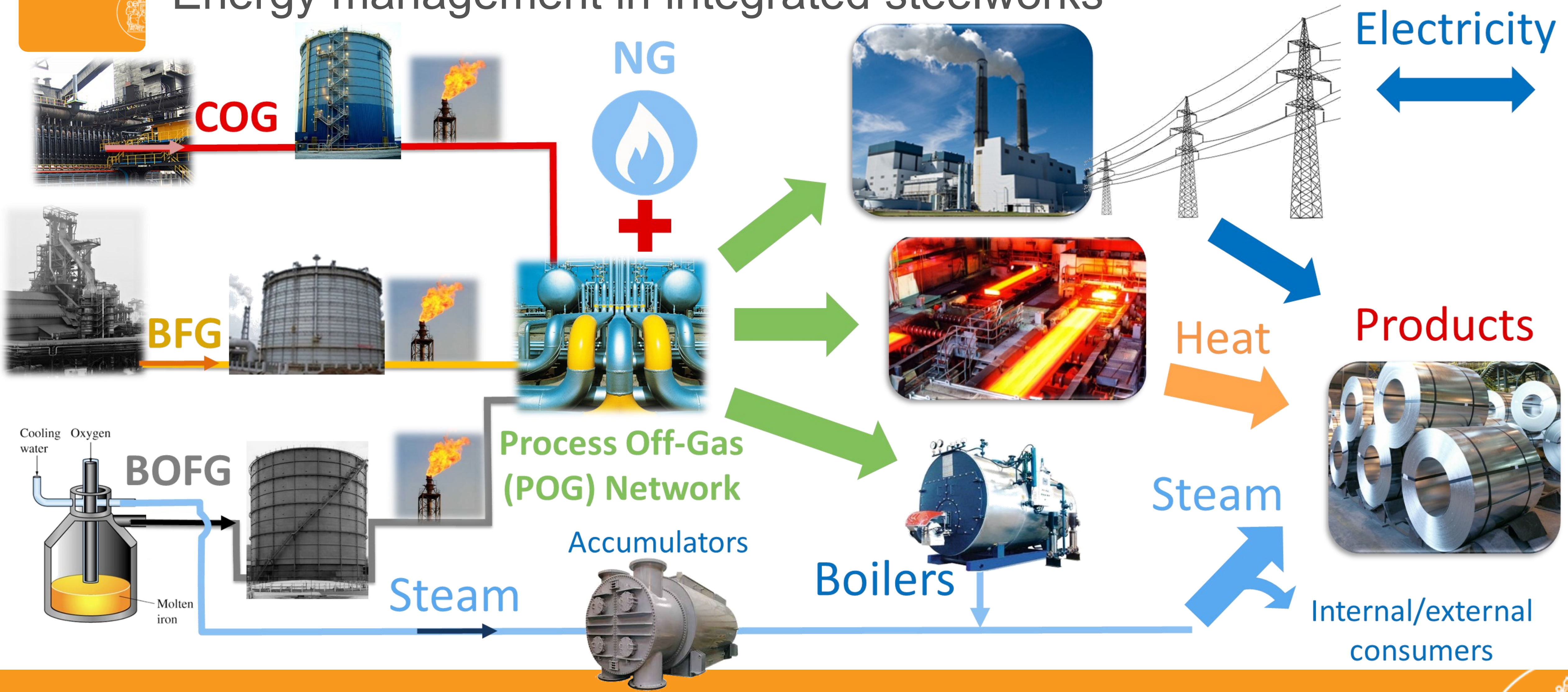
- Discussion, conclusions and future works

Introduction

Energy management in integrated steelworks



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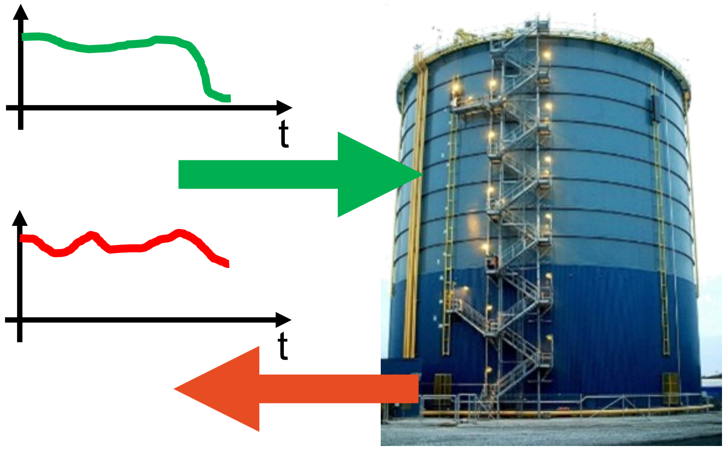
Introduction

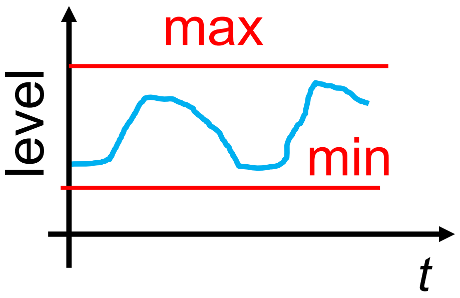
Energy management in integrated steelworks

Two different point of view:

Local supervision/control strategy

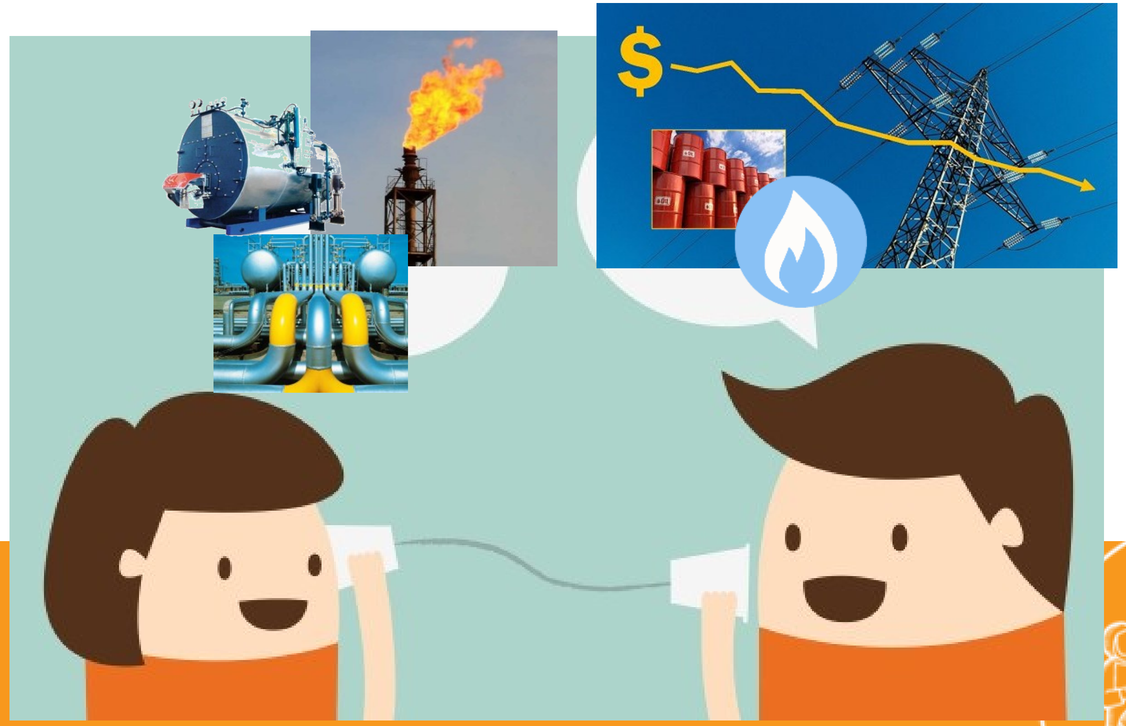
- Gasholder level prediction based
  - Supervision systems (the decision are formulated by operators)
  - Control strategies: No mutual interaction between POG networks





Global supervision/control strategy

- Optimization of the POGs distribution through plantwide economical optimization

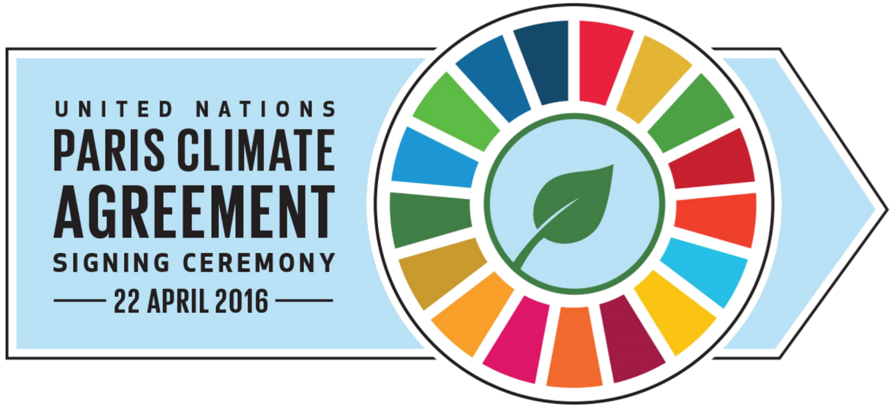


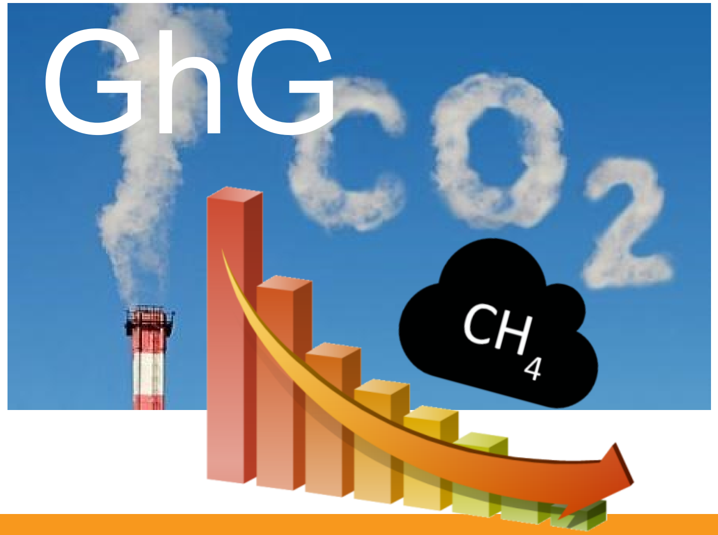
Introduction

Energy management in integrated steelworks

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**
- How to **minimize** economic **costs AND environmental impact**?





Introduction

Projects on off-gas management

Research Fund for Coal & Steel

ENCOP
GASNET
i3Upgrade
SMARTER

→ Management optimization of the off-gas networks within integrated steelworks → DSS for process operators

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Objectives of the projects:

- Simulation of POGs networks
- Optimization of off-gas network structures
- Online optimization of the distribution of POGs
- Minimization of the environmental impact of energy exploitation
- New routes for POG exploitation (CCUS through methane and methanol production)

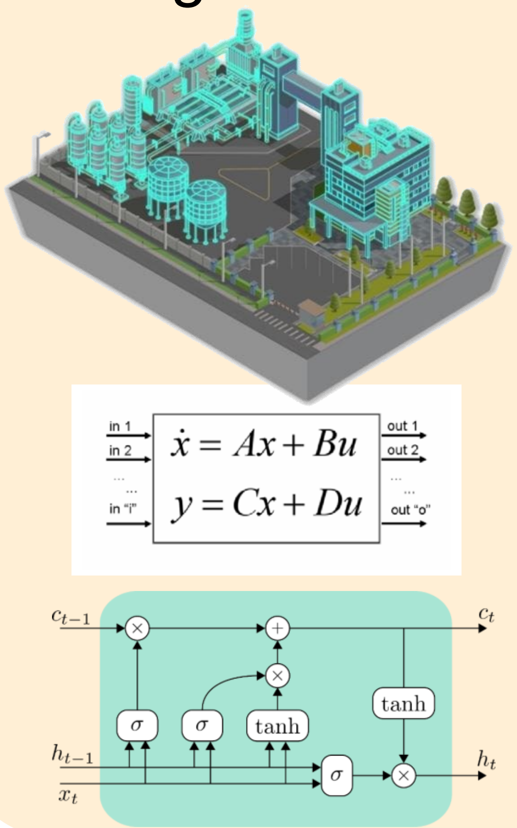
Methods

Hierarchical Control, Economic MPC and Digital Twins

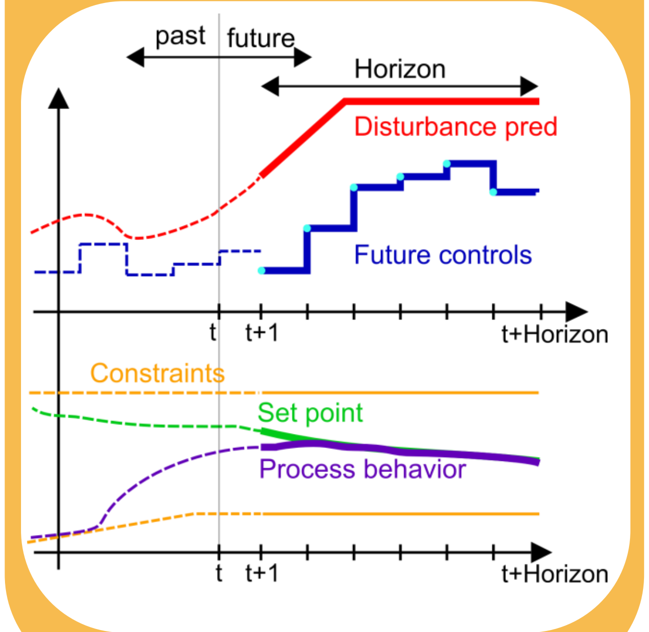
Objective:
Minimize management costs and environmental impact

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, CCUS, etc.).

Digital Twin



Economic MPC-based Supervision and control system



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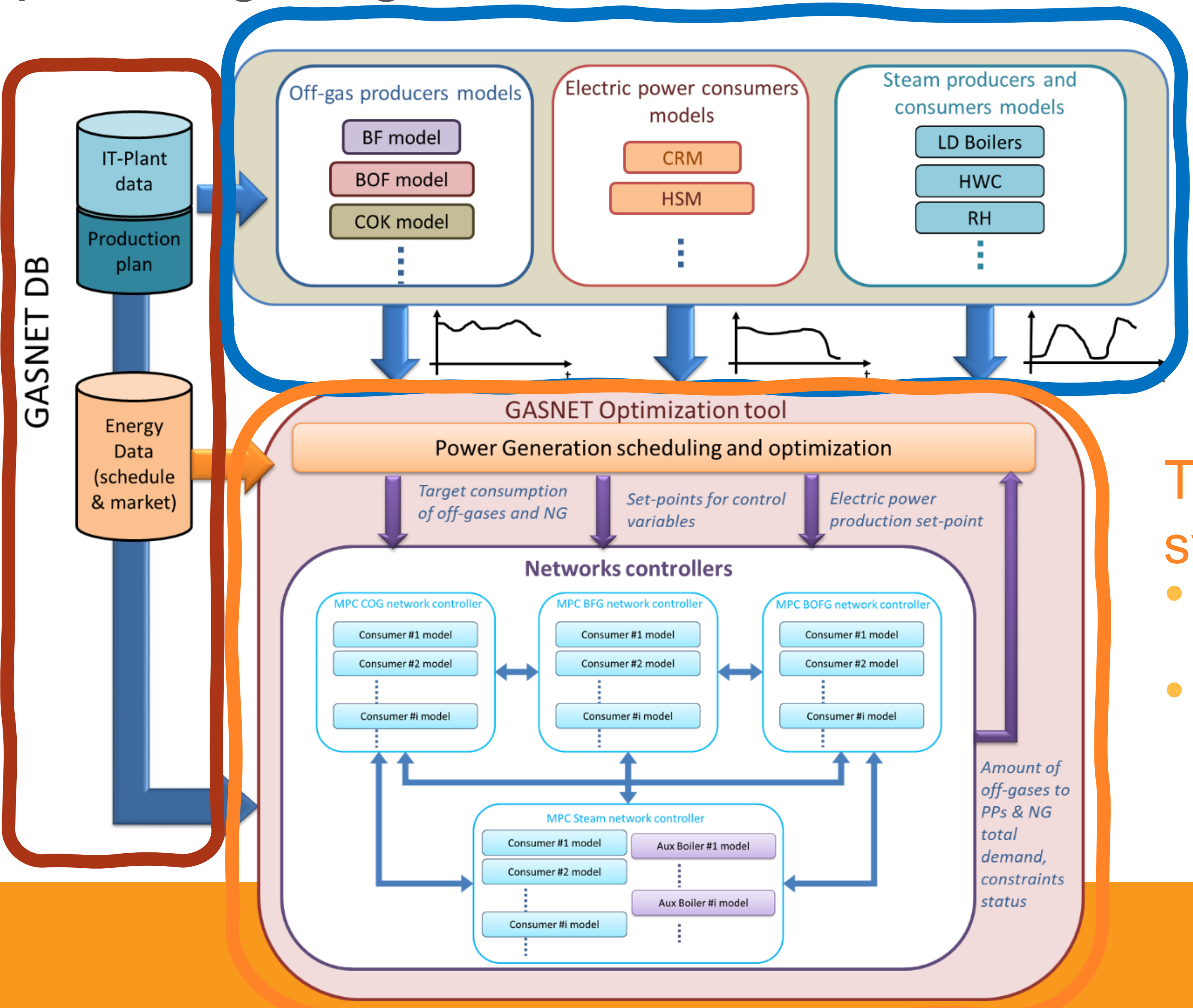
Control and Supervision approach

DSS for optimizing off-gas distribution

A **structured database** for collecting data

- Scheduling of the production
- Current and past measures



The Digital Twin

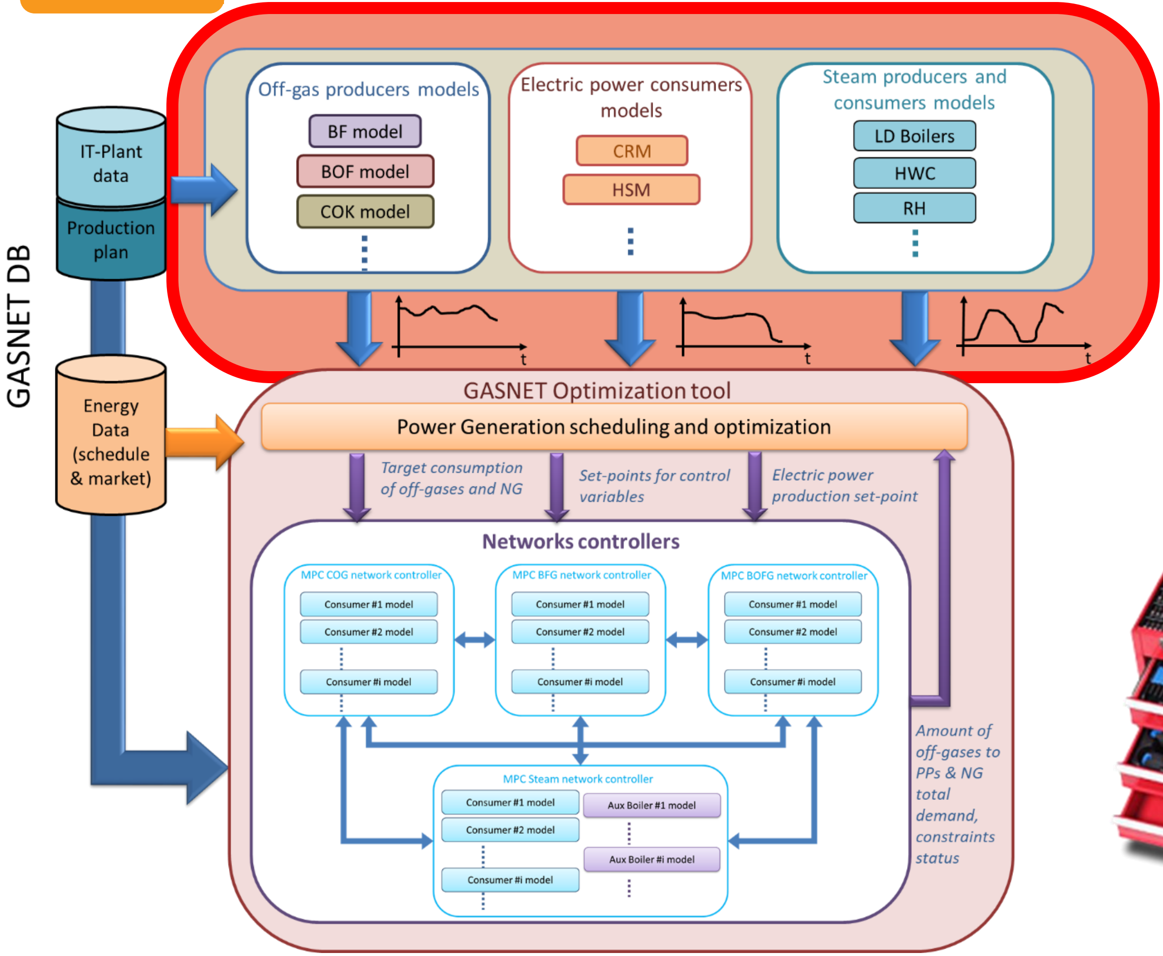
- Describes the current and future behavior of the integrated steelworks
- Modelled and validated through real data

The optimization system

- Optimizes in real-time the control strategy
- Shows KPIs and control strategies to process operators through HMI

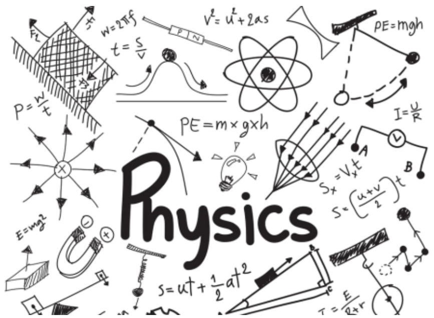
Control and Supervision approach

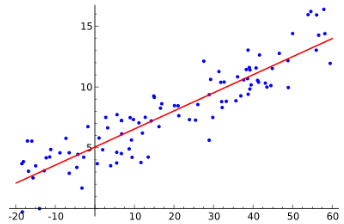
The digital twin



Prediction models:

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





Linear Models

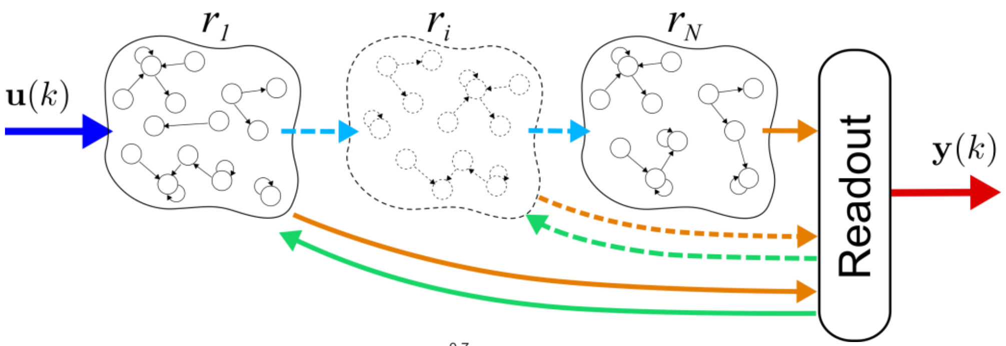
Artificial Intelligence

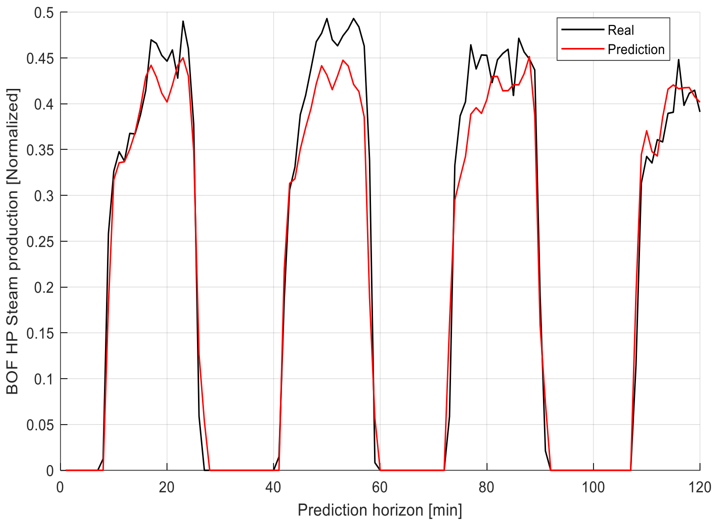
Control and Supervision approach

The digital twin

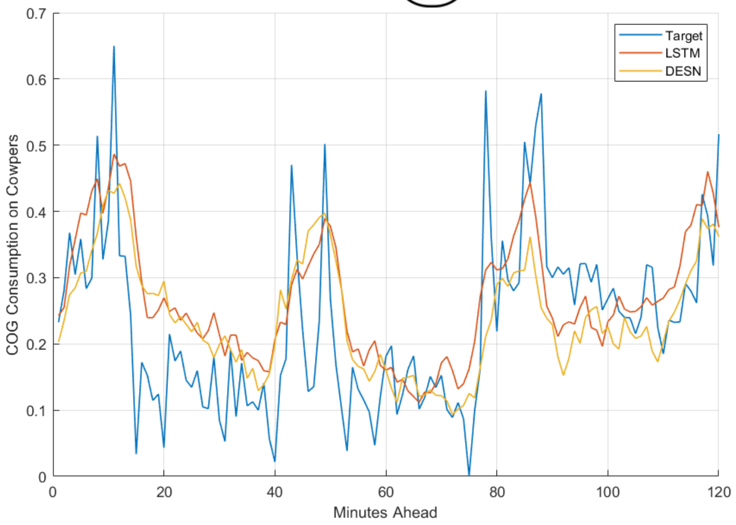
- **Knowing** the **scheduling** and the **main process measures**, it is possible to calculate good predictions
- In general, **3-4 months of** sufficiently informative **data** may be enough for the models (changes in operating points, changes in boundary conditions, etc.)
- Artificial intelligence provides excellent tools for **online model training**

Deep Echo State Networks [1, 2]





Steam production in the LD
Max error: 3.5 %



COG consumption in the cowpers
Max error: 8%

[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.

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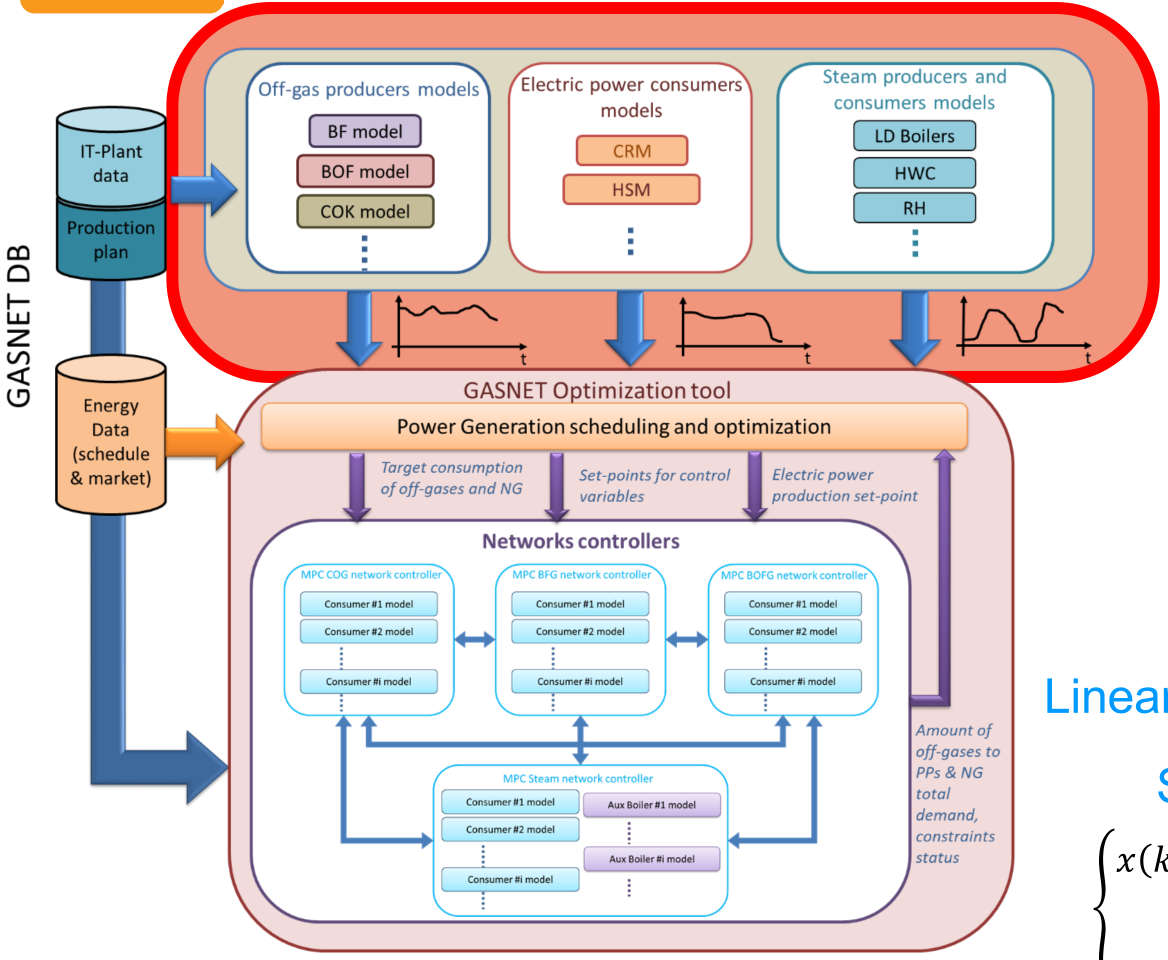
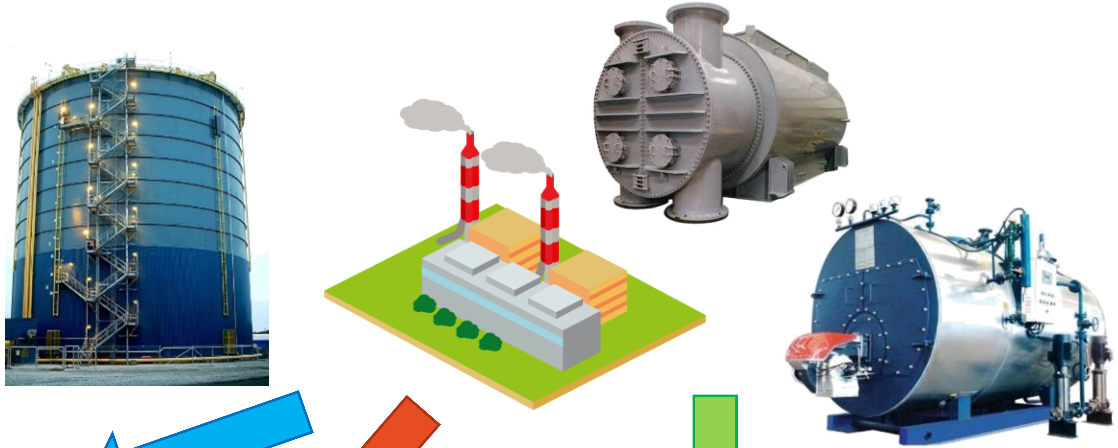
Control and Supervision approach

The digital twin



Plant models

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

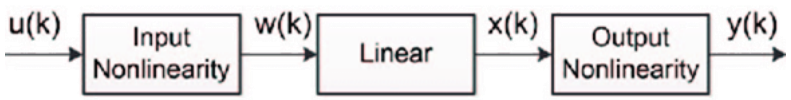


Linear correlations

State space models

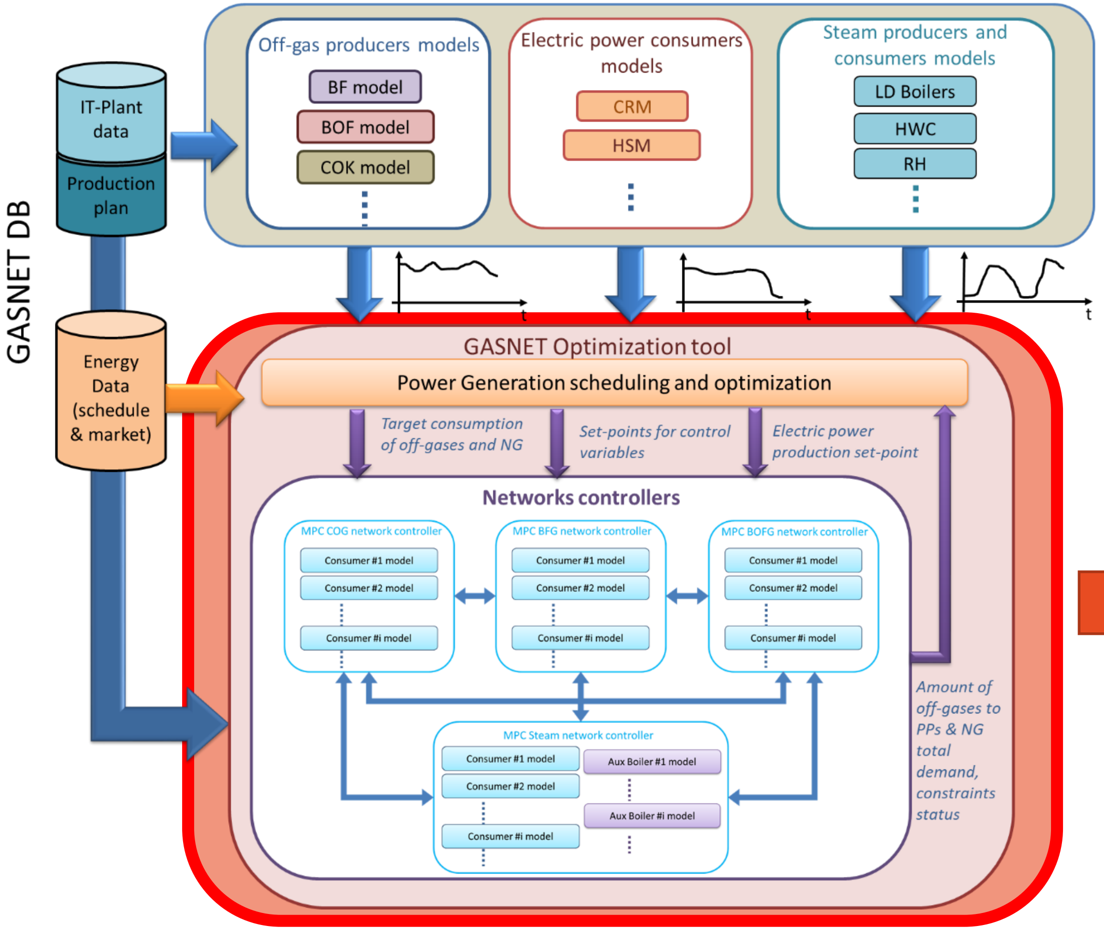
$$\begin{cases} x(kT+T) = Ax(kT) + Bu(kT) \\ y(kT) = Cx(kT) + Du(kT) \\ x(0) = \boldsymbol{x}_0 \end{cases}$$

Hammerstein Wiener models



Control and Supervision approach

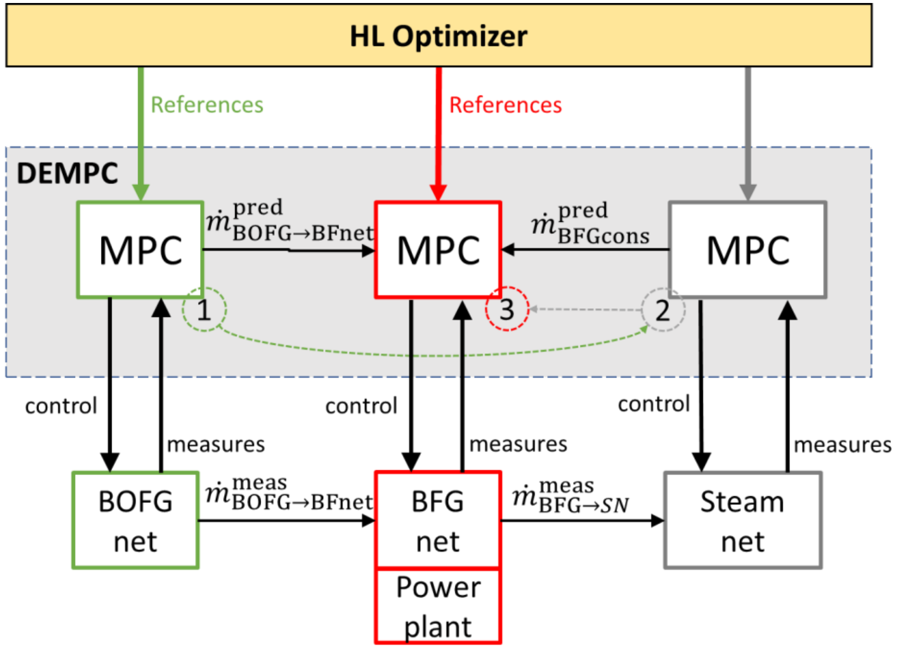
The POGs distribution optimizer



POGs Optimizer

Calculates a possible optimized POG distribution:

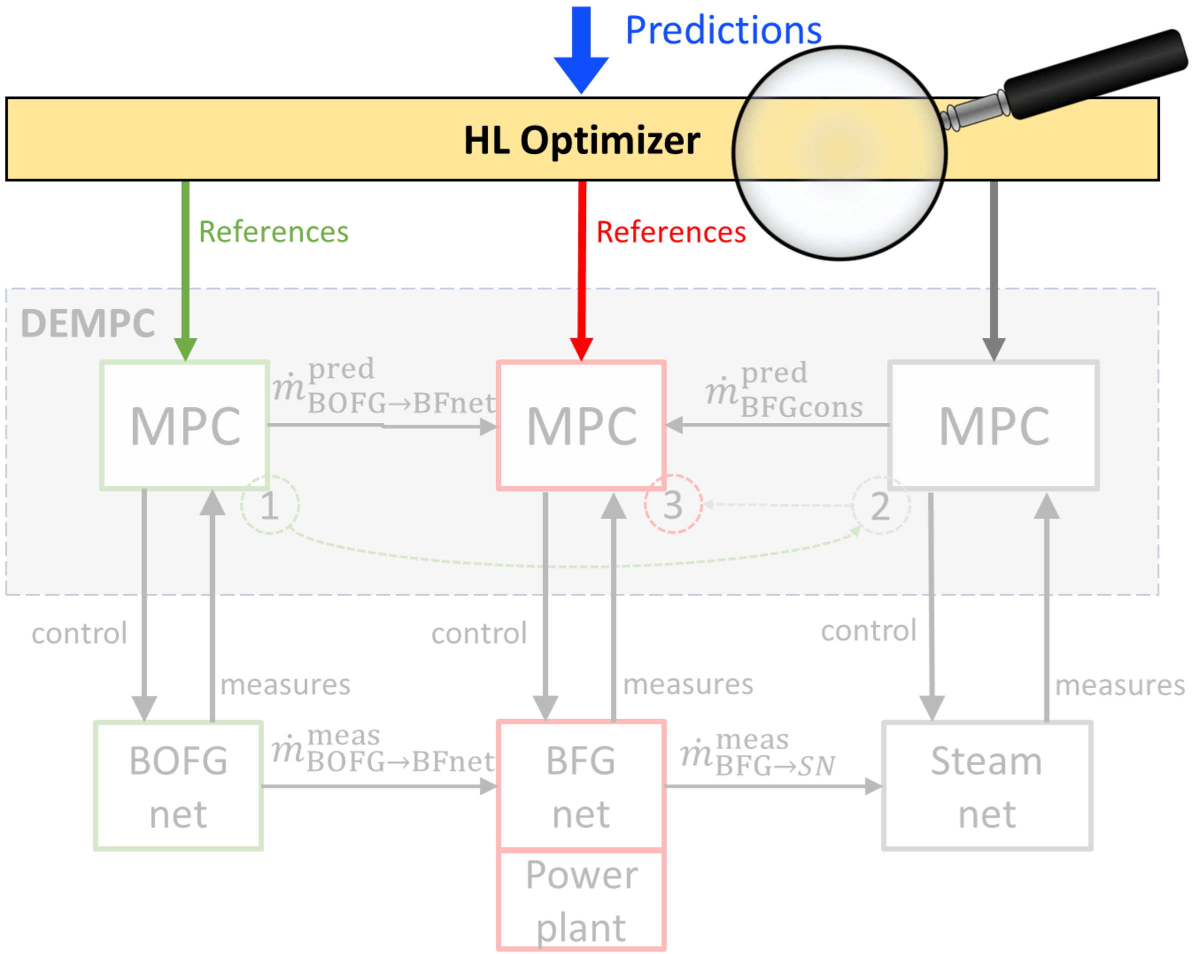
- HL Optimizer: up to 1 day ahead, CP 15 minutes
- LL Optimizer: 2 hours ahead, CP 1 minute



MATLAB
YALMIP
GUROBI OPTIMIZATION
Google OR-Tools
CBC (CoinOR branch and cut)

POGs distribution optimizer

High Level Optimizer: Economic MPC Formulation



The High-Level Optimizer solves a “simplified” problem

Costs:

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

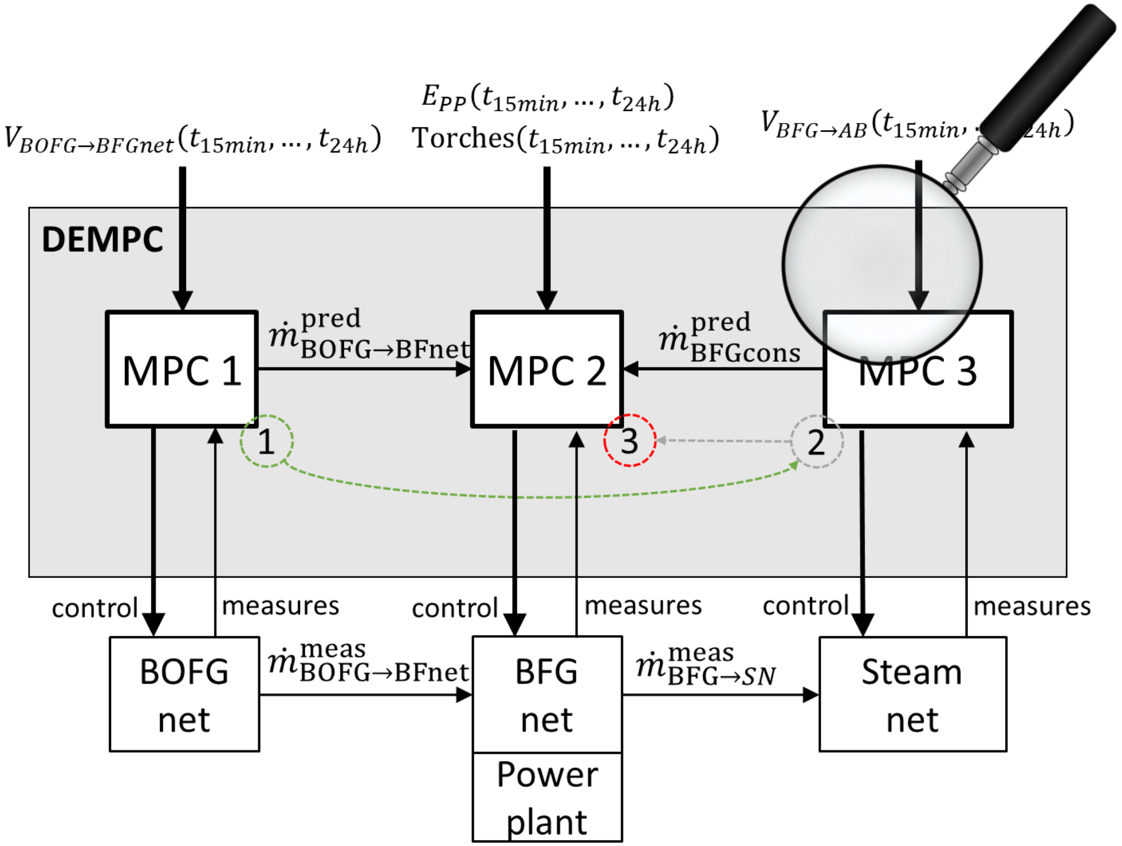
- Natural gas consumption
- Electric energy purchased
- Revenues of POG based electricity production
- Environmental impact: POG waste in the torches
- Cost of steam waste in the steam network

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

POGs distribution optimizer

Low Level optimizer: Economic hybrid MPC Formulation



Distributed Hybrid Economic MPC

Minimize the costs in each specific POG and Steam network while ensuring safe operating conditions.

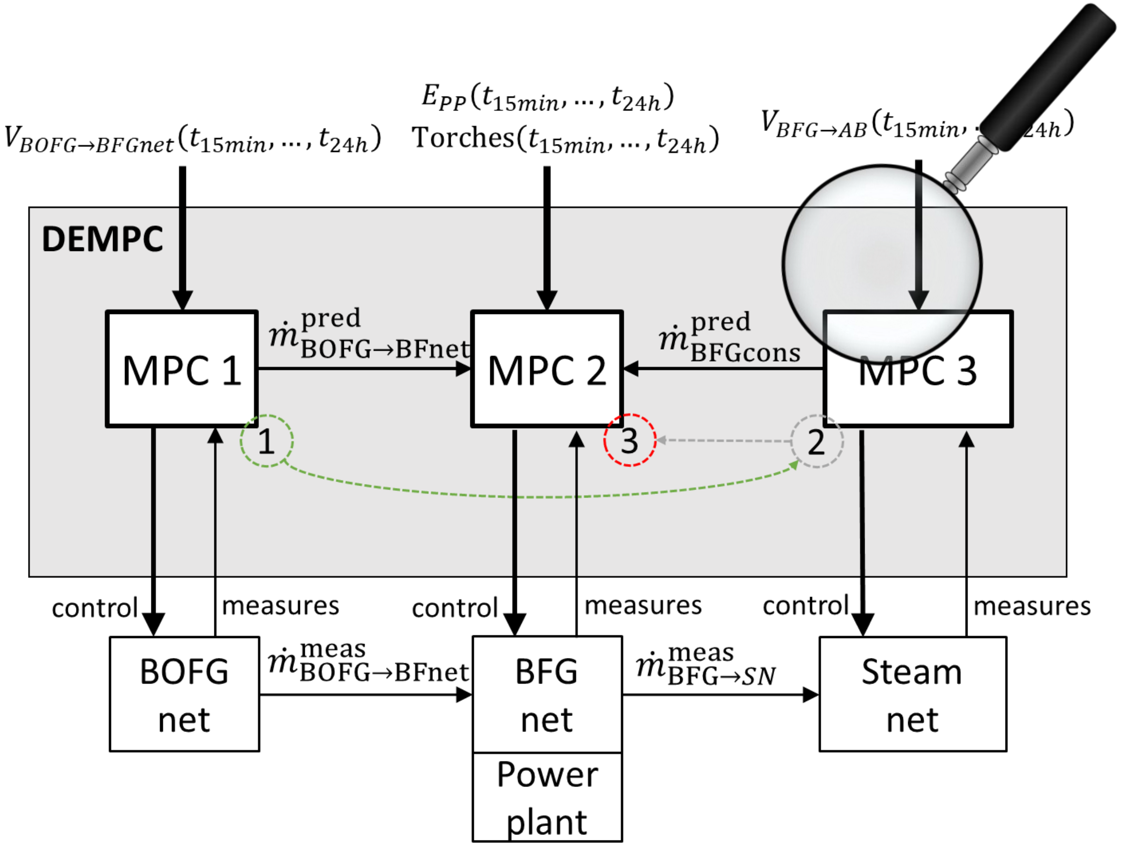
The optimization is formulated as a **Mixed Integer Linear Programming** (MILP) problem.

Why?

- Manipulable variables are energy flows (continuous var.s) but also integer/Boolean (number of active groups in the power plant, on-off and modalities of steam boilers, on-off zones of Walking Beam Furnaces, etc.)
- MILP can approximate also complex nonlinear behaviors (e.g.: Efficiency of the power plant in function of the operating point, PWA models, etc.)

POGs distribution optimizer

Low Level optimizer: Economic hybrid MPC Formulation



The low-level optimizer implements a detailed representation of POG, steam and electricity networks.

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

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Results

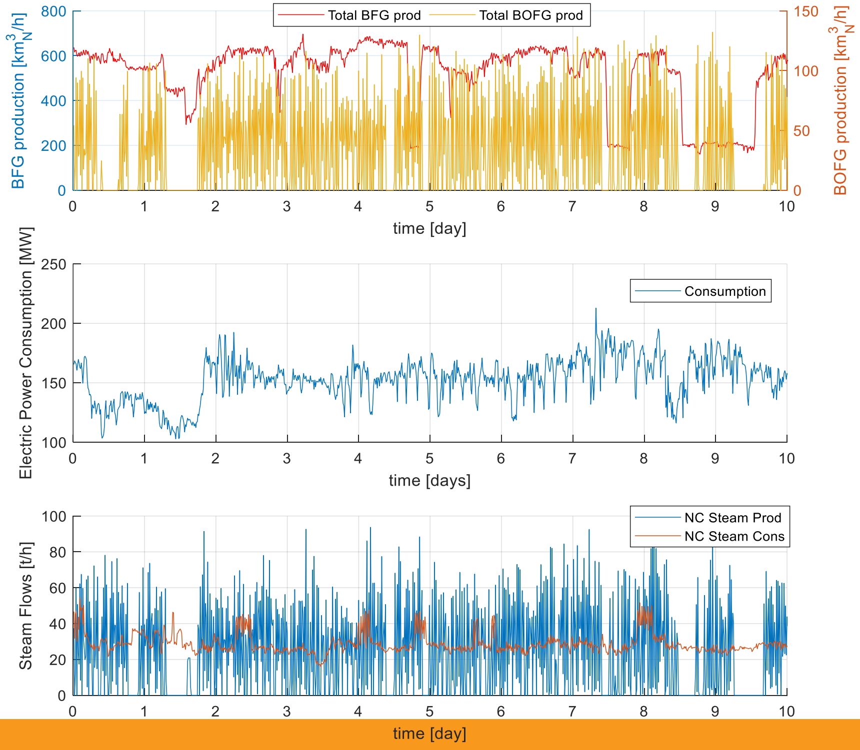
Offline simulations

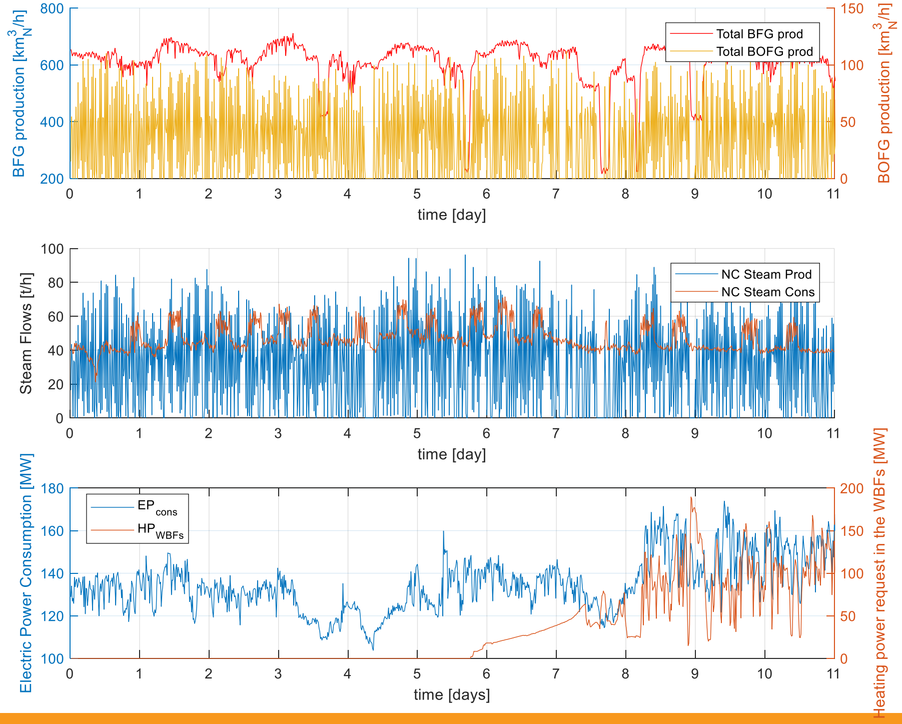
ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

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

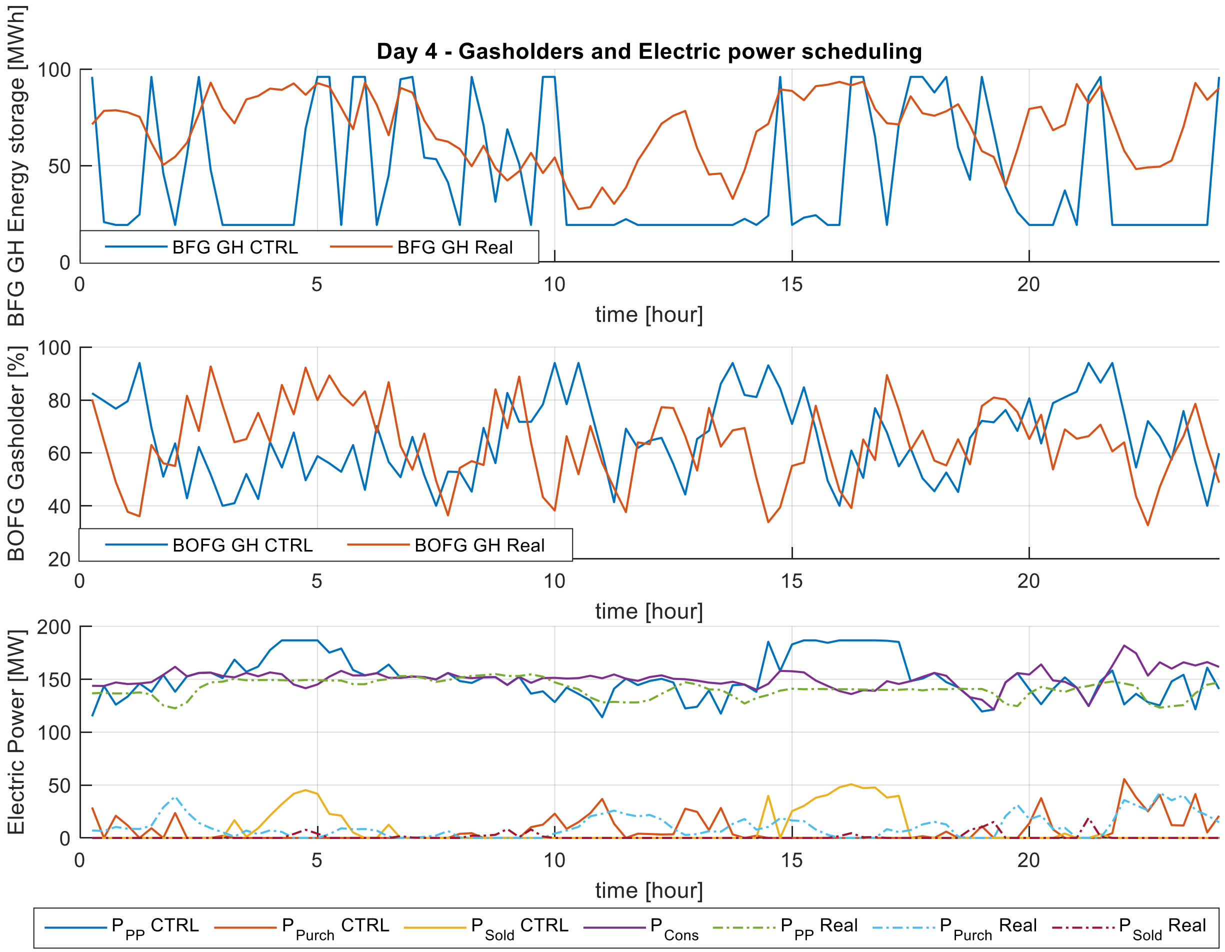
Several scenarios can be simulated, from standard production periods to less productive periods, by exploiting data of a real integrated steelworks





Results

Offline simulation example



The DSS is simulated in closed loop by exploiting the digital twin of the integrated steelworks

- The control action maximize the electricity production in the power plant, by using POGs as much as possible
  - Minimize the use of external electricity source
  - Maximize (when possible) the sale of electricity to the grid
- When a specific gasholder is expected to be full, the POG is distributed to another POGs network through mixing stations to avoid flares in the torches

Results

Offline simulation example

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ICT COISP
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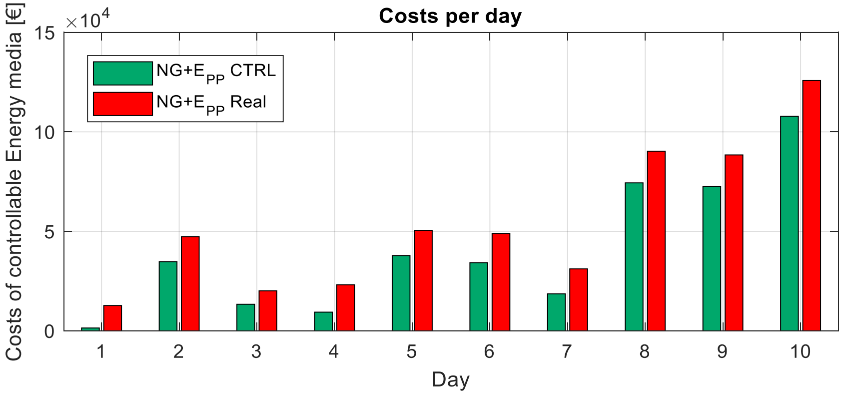

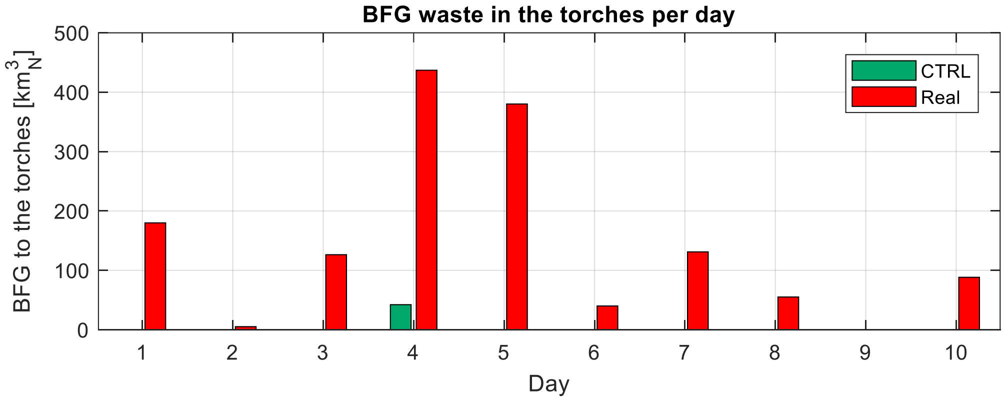

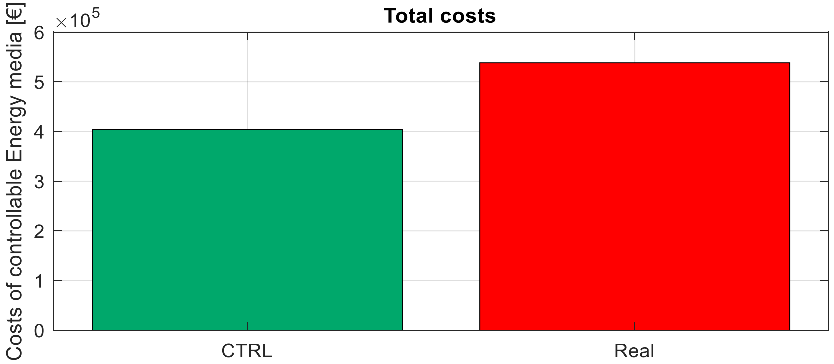

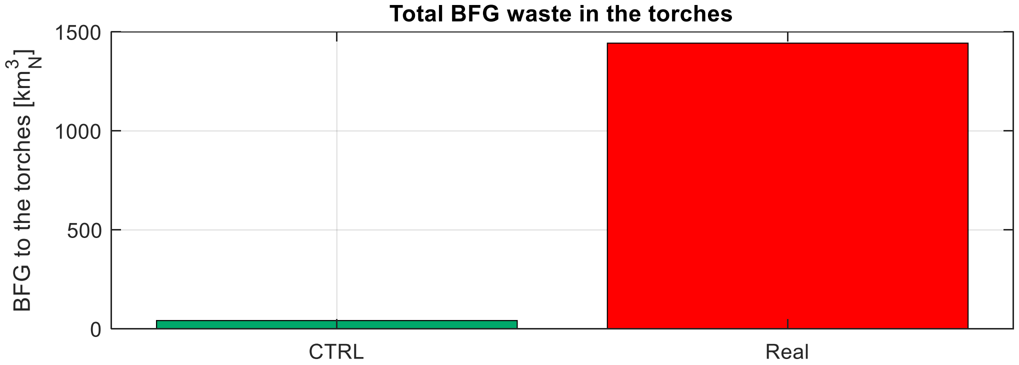

Plantwide hierarchical control strategy allows to reduce energy dependence from the extern and significantly reduce environmental

$KPI_{€\%}$ [%]	$KPI_{EPPint\%}$ [%]	$KPI_{torches\%}$ [%]	$KPI_{NG\%}$ [%]
27.49	2.46	**96.9**	41.56

Discussion and future challenges

Pros:

- 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, through an intelligent exploitation of POGs

Issues and challenges:

the control action must be applied as soon as possible as soon as it is calculated, this can be complex if it is done via DSS/operator.
it is more effective to apply the control strategy automatically

Discussion and future challenges

- New processes will introduce new routes for POGs, for example through the enrichment of exhaust gases with hydrogen to produce methane and methanol
- 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

- Study the effect of networks revamp and new pipelines connections on the POGs distribution
- Improve the smoothness of the control strategy through MIQP formulations (reference tracking)

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Thank you!

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