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Sant'Anna
School of Advanced Studies – Pisa

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

OPTIMIZING INTEGRATED STEELWORKS PROCESS OFF-GAS DISTRIBUTION THROUGH ECONOMIC HYBRID MODEL PREDICTIVE CONTROL AND ECHO STATE NETWORKS

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- Methods
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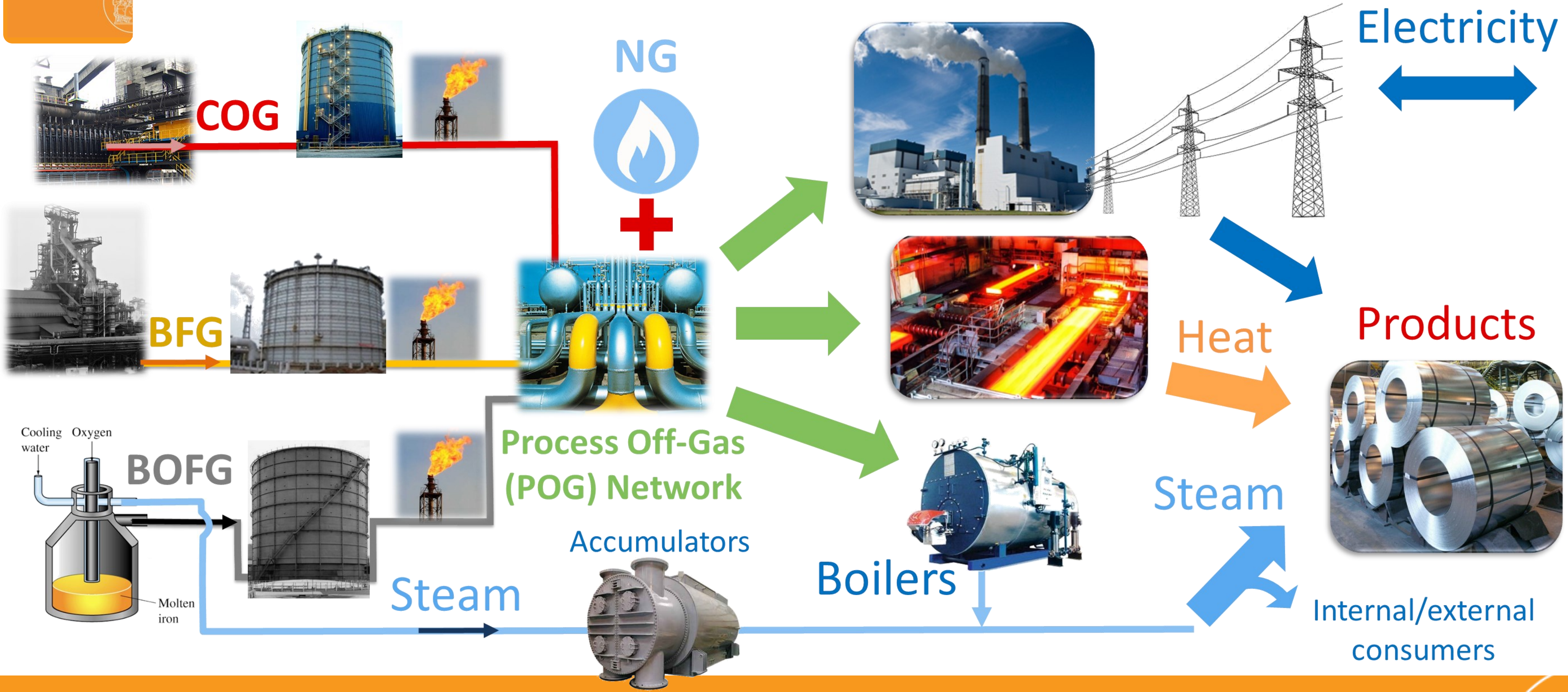
- Control results
- From simulation to online tests
- Discussion, Conclusions and future works

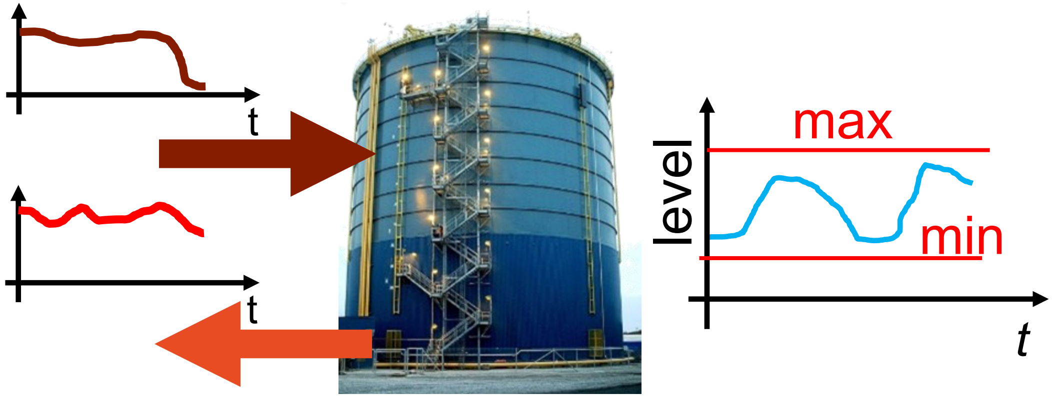
Introduction



Introduction

Issues:

- Discontinuous POG production and consumption
- Gasholder with limited capacity
- Synchronizing processes/producers/consumers is a difficult task for process operators



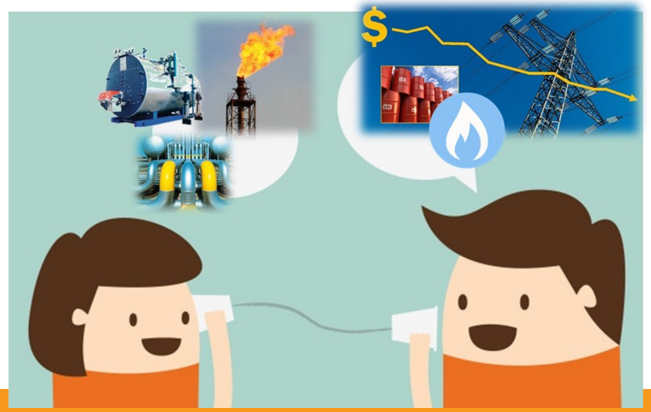
State of the art:

Local supervision/control strategy

- Gasholder based ctrl/supervision strategy
- No mutual interaction are considered → Non optimal

Global supervision/control strategy

- Short CTRL/PRED horizons



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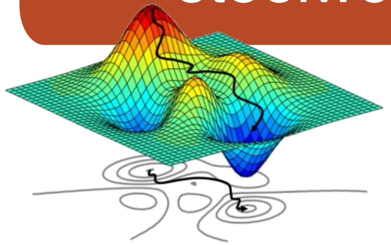
Introduction

Research Fund for Coal & Steel

GASNET

SMARTER

Management optimization of the off-gas networks within integrated steelworks



DSS and control systems for process operators

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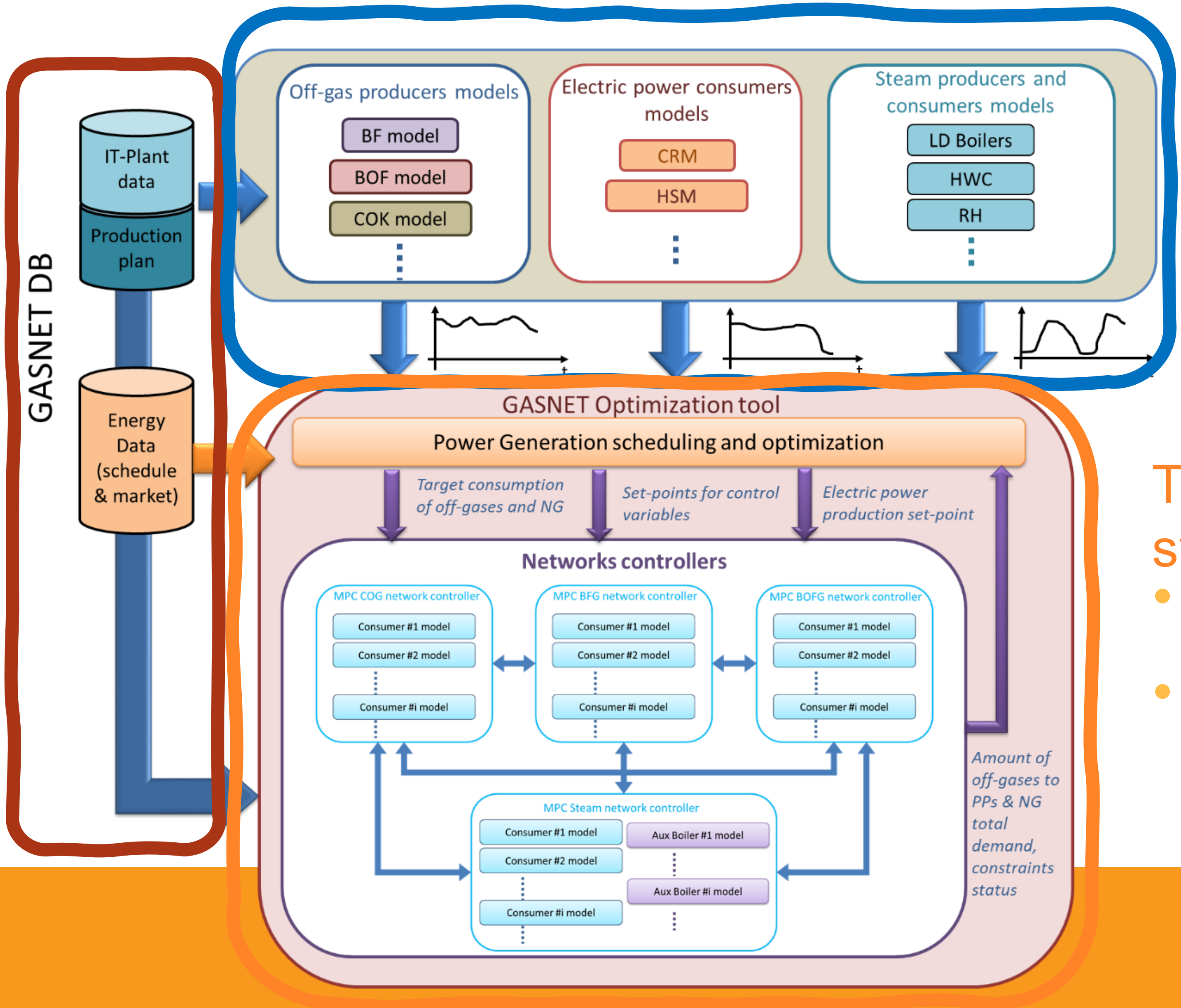
Methods

Control / Supervision architecture

A **structured database** for collecting data

- Scheduling of the production
- Current and past measures



The Digital Twin

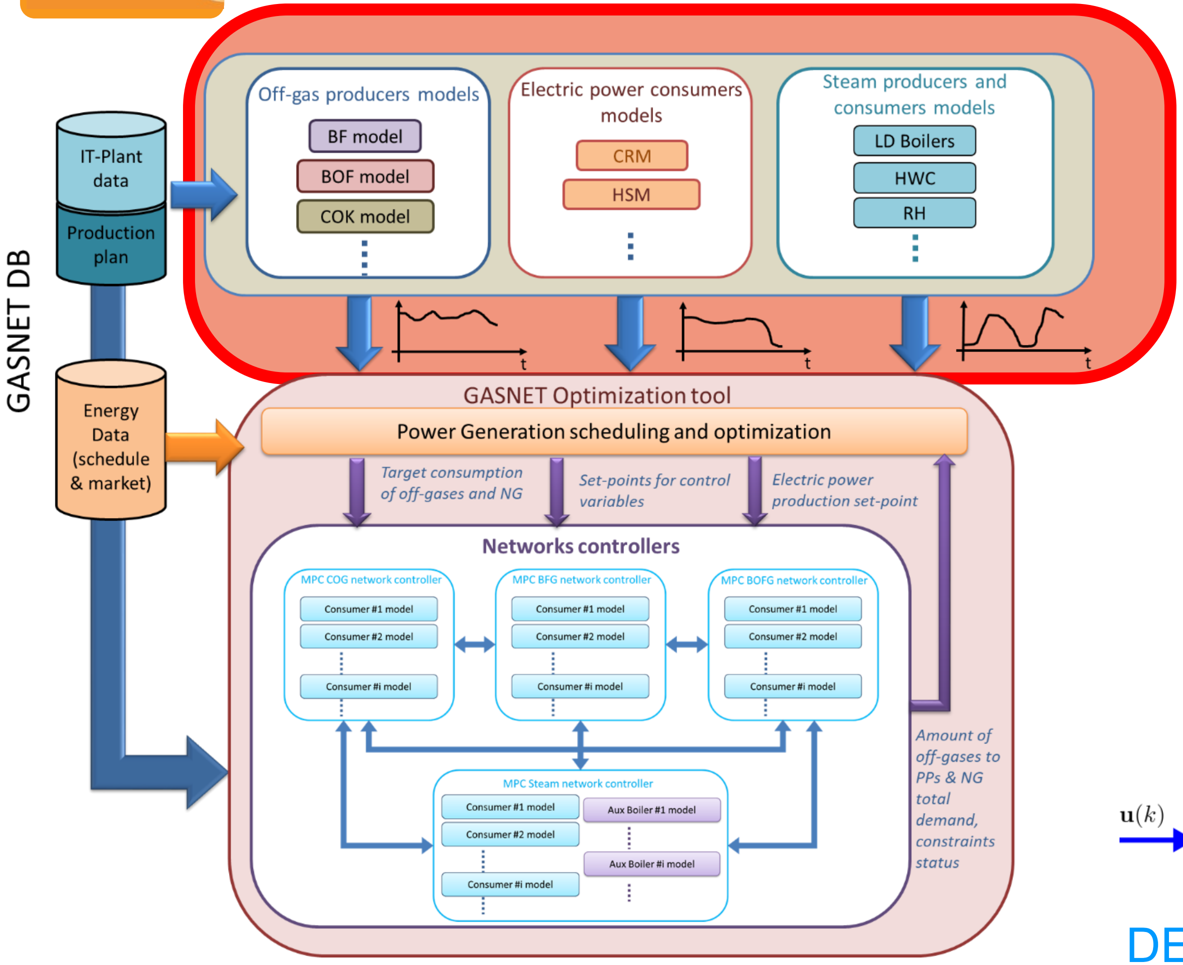
- Describes the current and future behavior of the integrated steelworks
- Modelled and validated through real data

The optimization system

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

Methods

Modelling approach

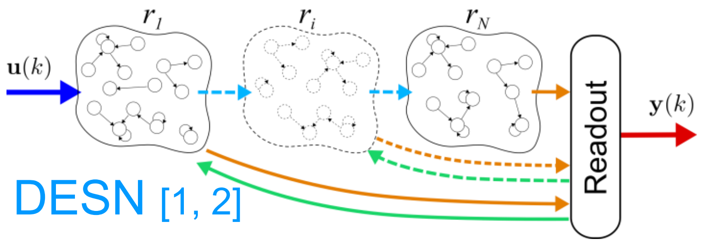


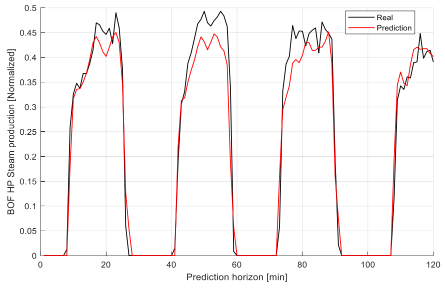
Prediction and plant models:

- POGs production and consumption
- Electricity consumption and production (e.g. BFG expansion turbines)
- Steam production and consumption (LD steam, RH steam consumption, etc.)
- Power plant, gasholders, boilers, etc.

Methodologies

- Deep Echo State Networks (DESN)
- Moving average models
- Linear correlations and state space models
- Gaussian regression models
- Feed forward neural networks



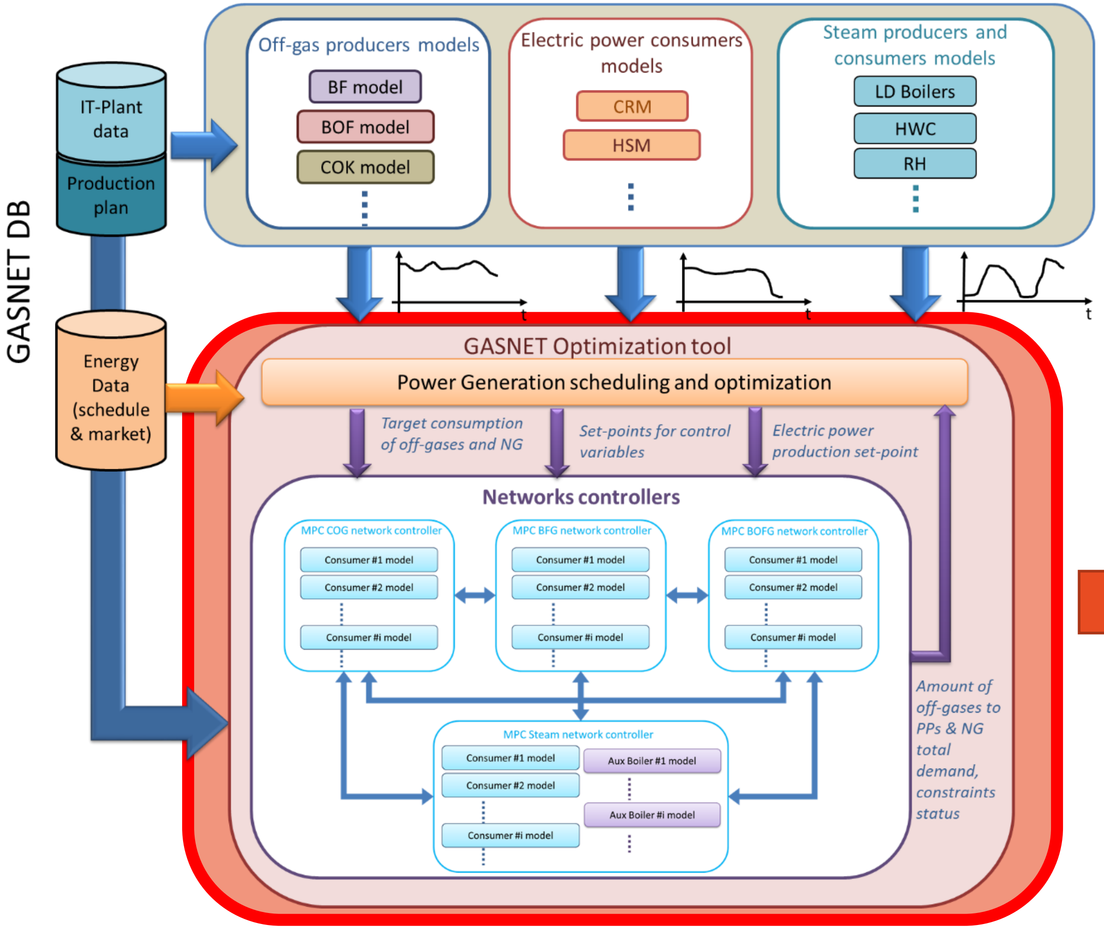


[1] Dettori, Stefano, et al. "A Deep Learning-based approach for forecasting off-gas production and consumption in the blast furnace." *Neural Computing and Applications* (2021): 1-13.

[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.

Methods

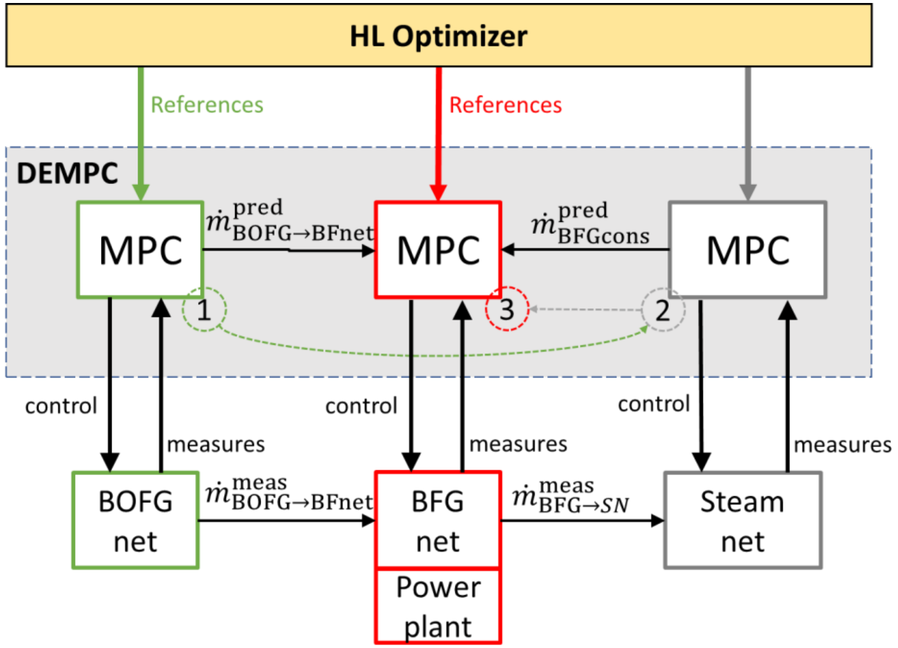
Control approach



POGs distribution 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

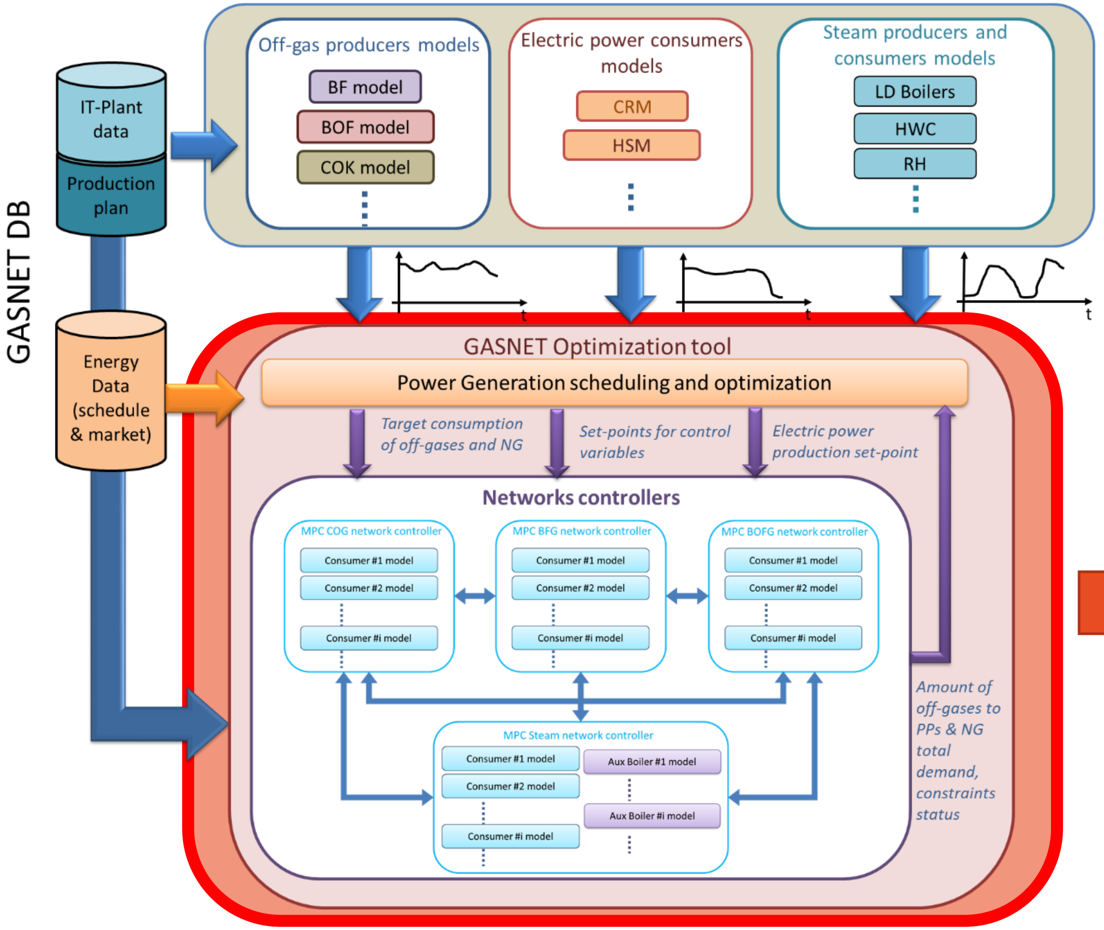
GUROBI OPTIMIZATION

Google OR-Tools

[3] Lofberg, J. (2004). YALMIP: A toolbox for modeling and optimization in MATLAB. In 2004 IEEE international conference on robotics and automation, IEEE. 284-289.

Methods

Control approach

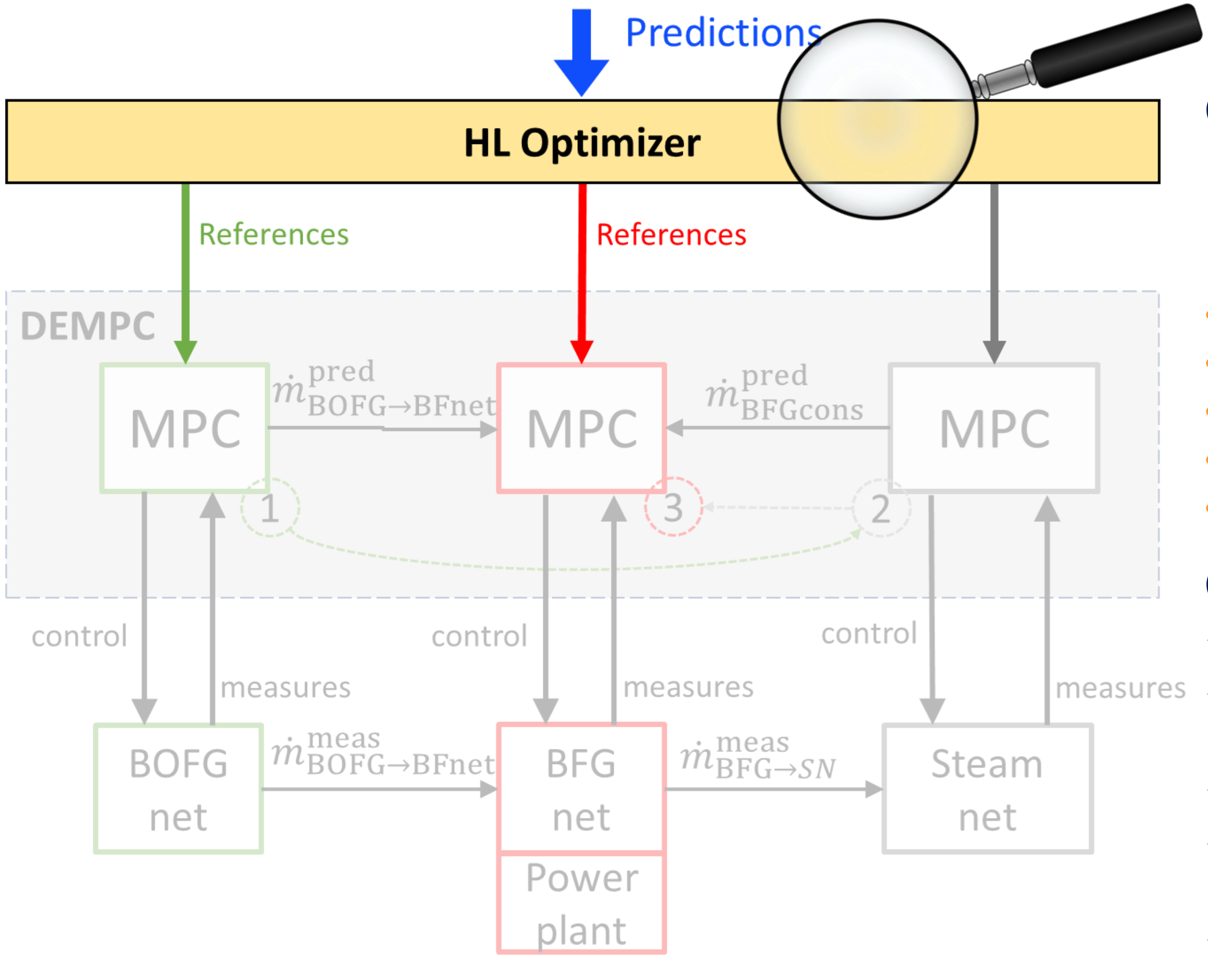


Control actions:

- POG + NG mixture to Power Plant (setpoints for electricity production scheduling)
- POG + NG mixture in walking beam furnaces and modality of the furnace's zones
- POG + NG mixture to Steam Boilers and modalities
- Steam condensed in the condenser
- POG transfer between different networks
- POG burned in the torches

Methods

Control approach – High Level Controller



The High-Level Optimizer solves a “simplified” problem

Costs:

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

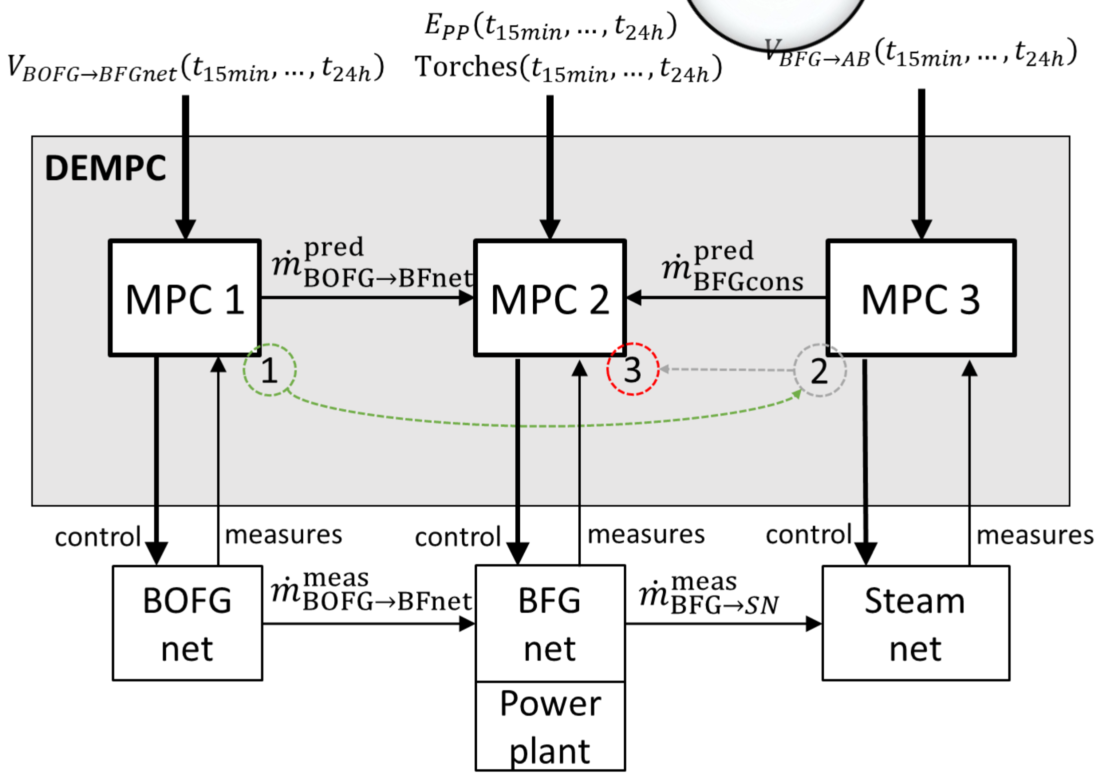
- Natural gas consumption
- Electric energy purchased
- Revenues of POG based electricity production
- Environmental impact: POG waste in the torches
- Cost of steam waste in the steam network

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

Methods

Control approach – Low Level Controller



Distributed Hybrid Economic MPC

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

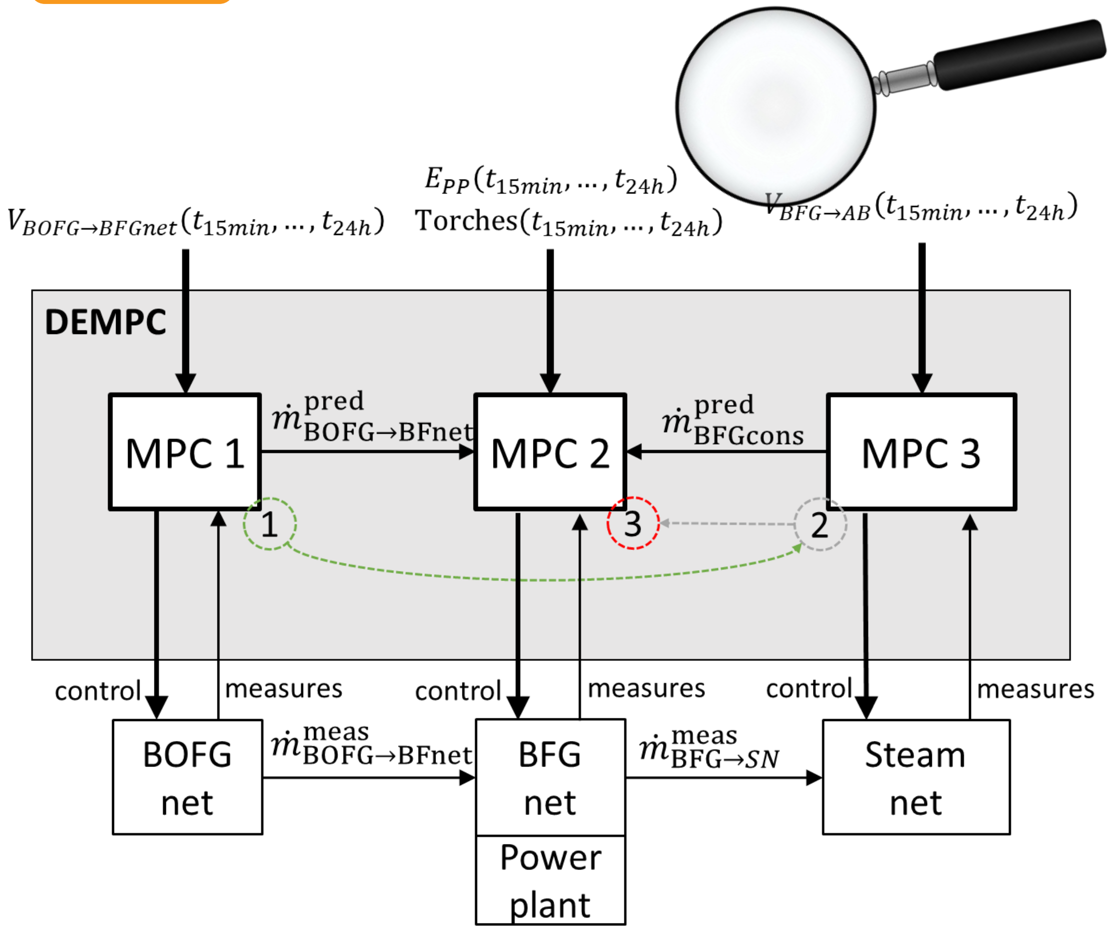
The optimization is formulated as a **Mixed Integer Linear Programming** (MILP) problem.

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.)

Methods

Control approach – Low Level Controller



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 + fictious specific operative costs

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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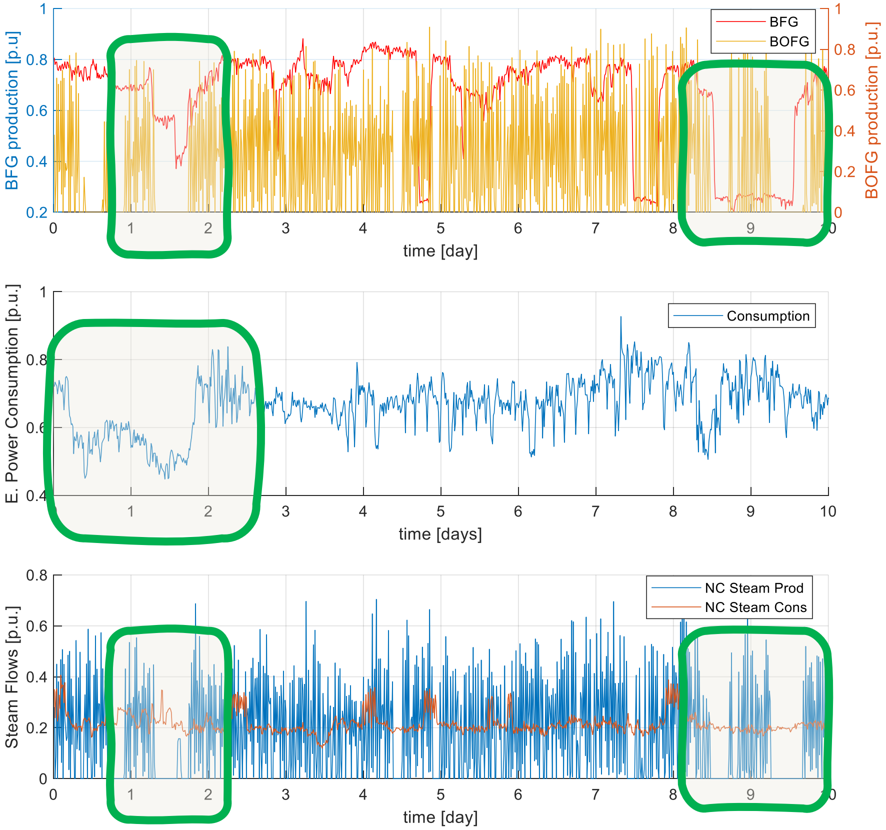
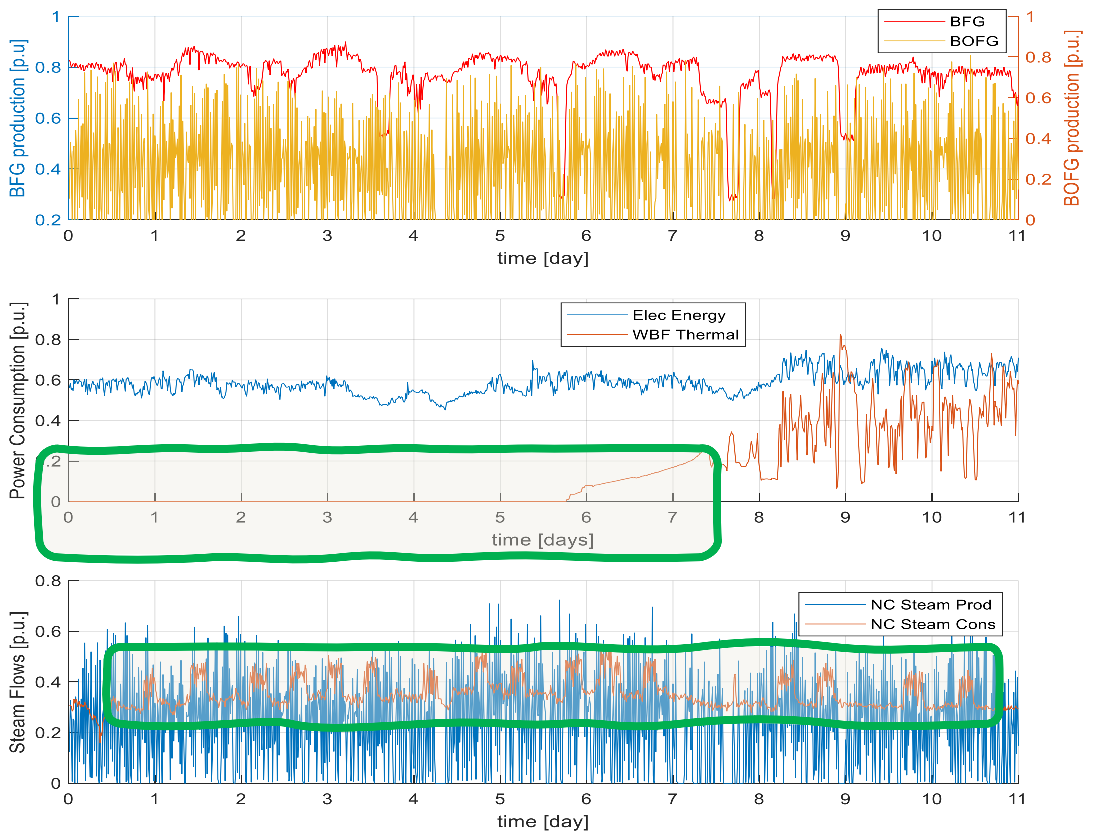
DSS application

From simulations to online tests

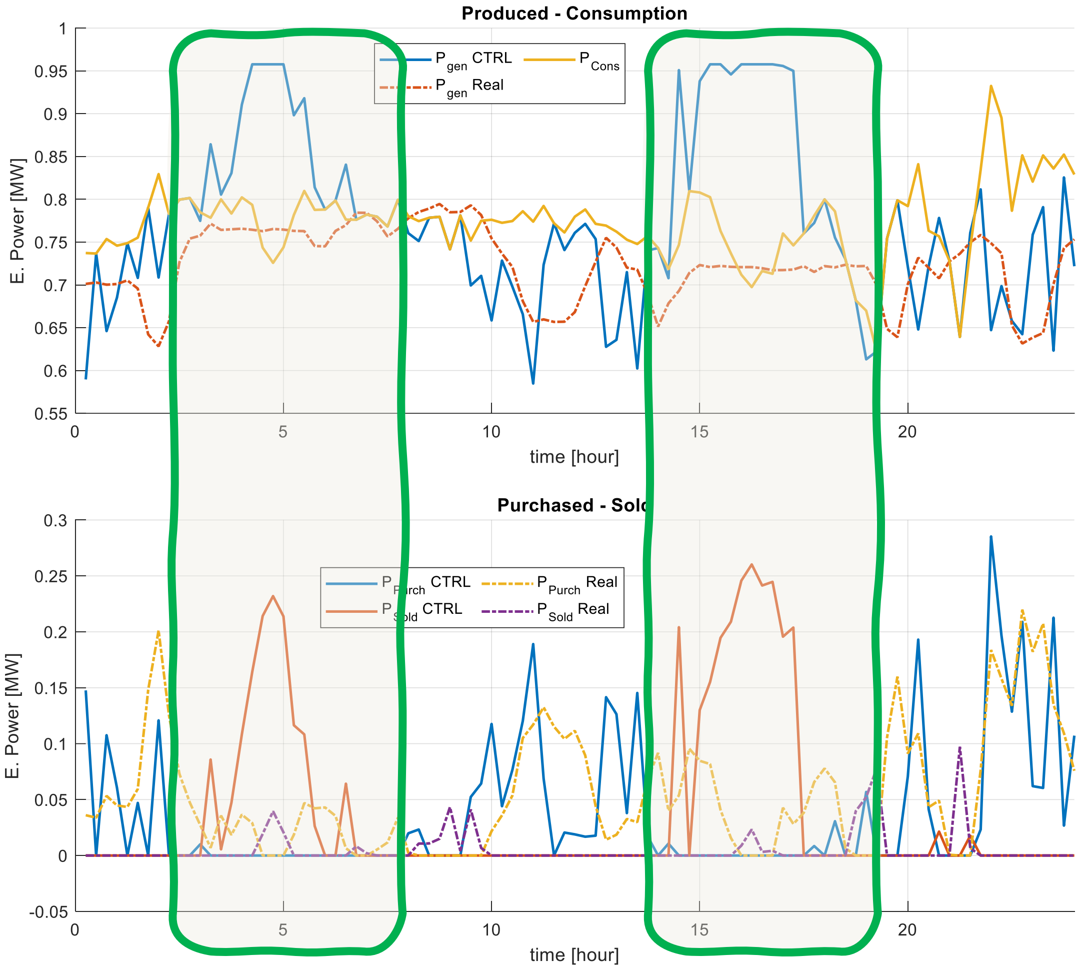
- A simulation phase is needed to test the feasibility of the control approach.
- Several scenarios have been simulated for different periods of steel production
  - Scenarios have been simulated exploiting data of six months
  - Different scheduling of the main processes (BOF, BF, WBF, Vacuum Degasser, etc.)

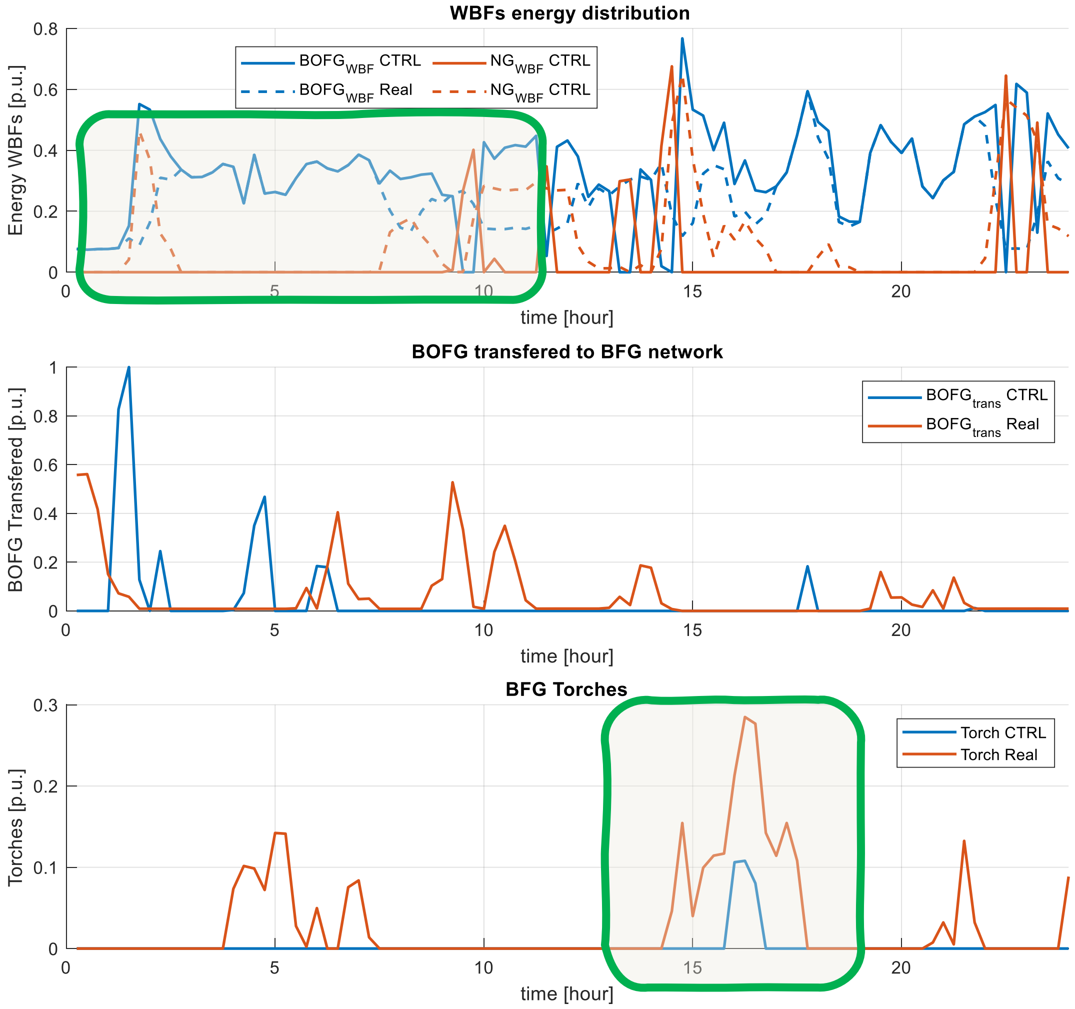




Control results:

Offline simulation – An example (simulated closed loop)





Control results:

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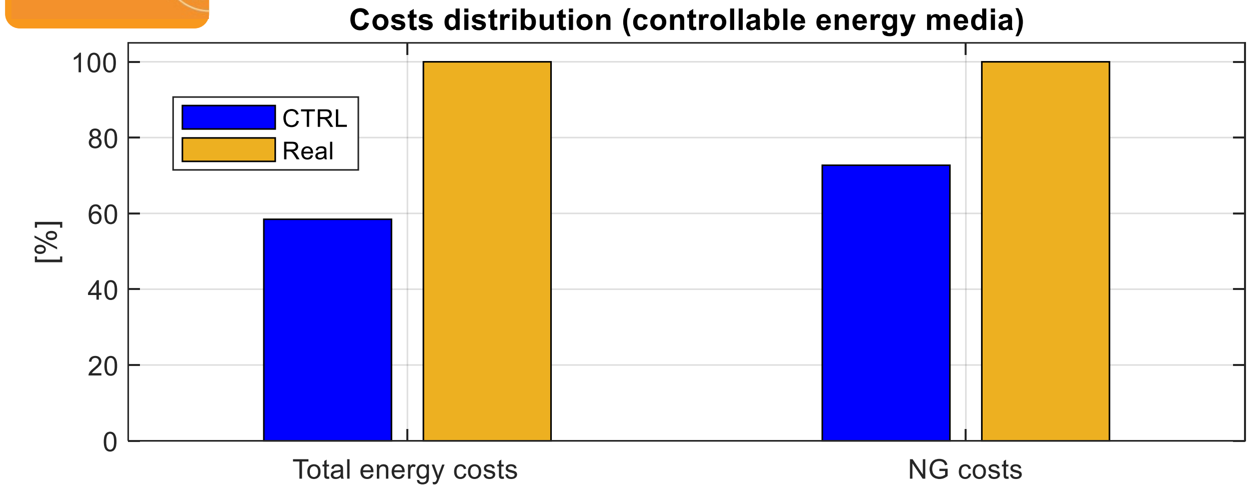

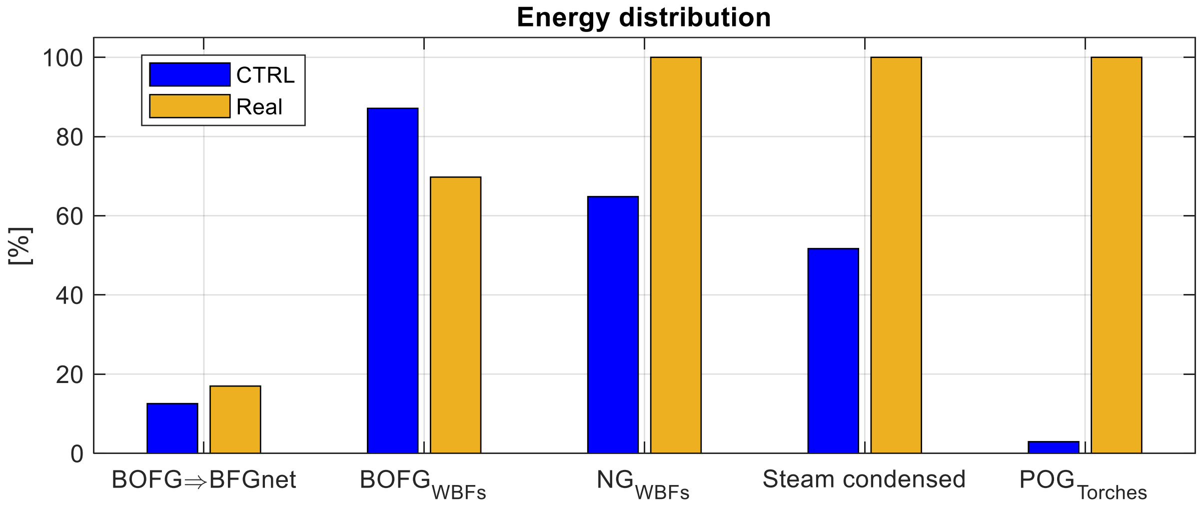

Plantwide hierarchical control strategy allows to reduce energy dependence from the extern and significantly reduce environmental

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

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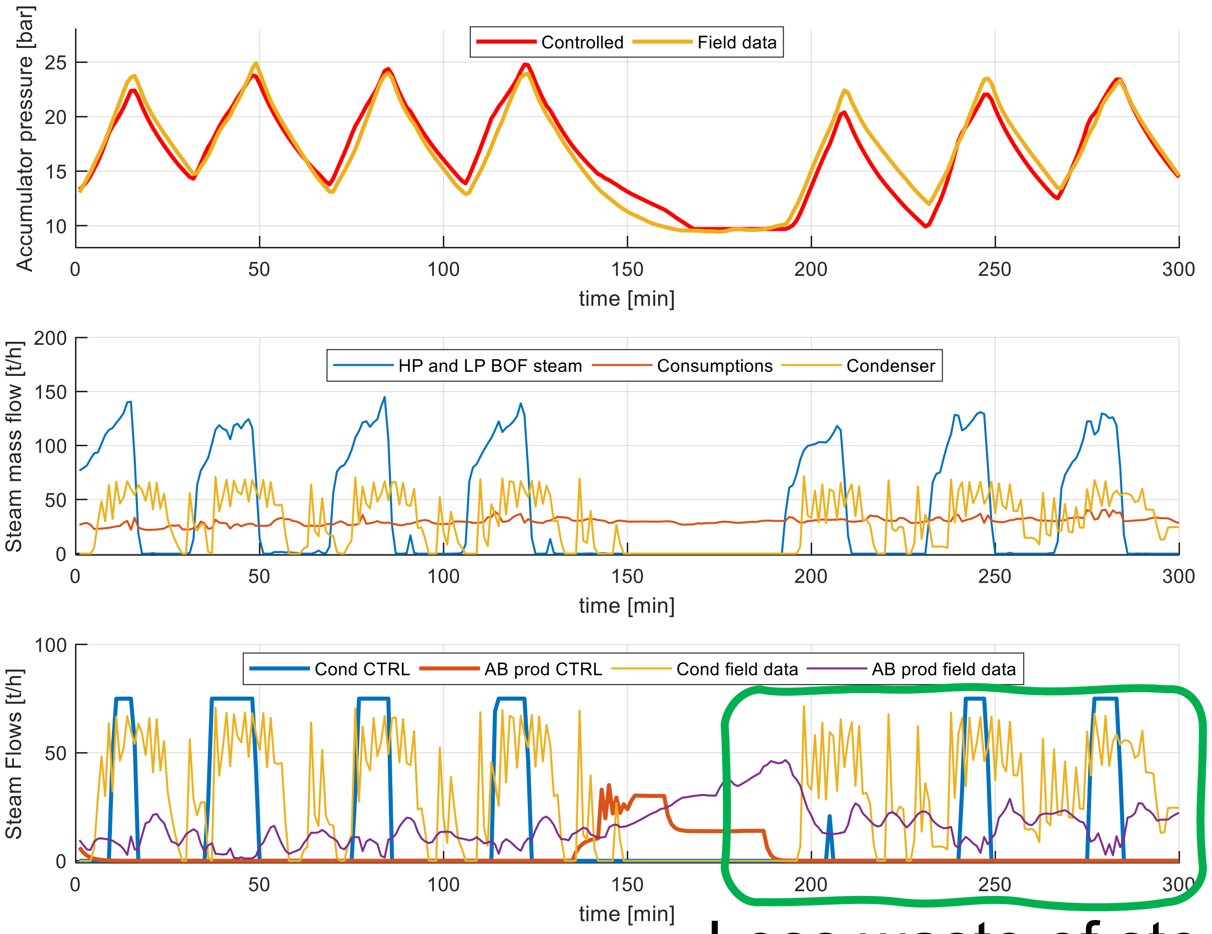
Dispatch Controller application:
Offline simulation example



Less waste of steam → Less use of auxiliary boilers

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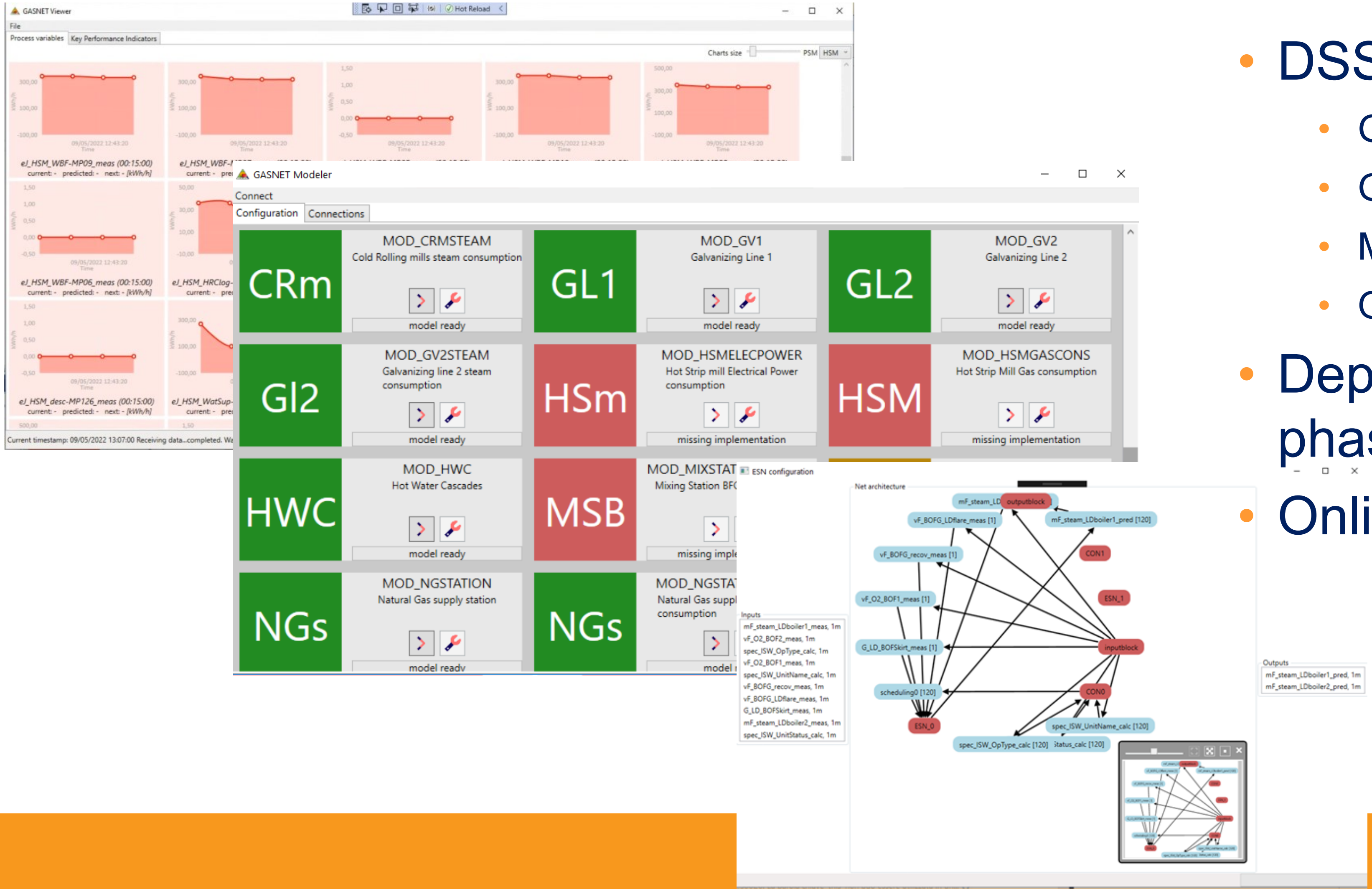
DSS application

From simulations to online tests



- DSS composed of several tools
  - GUIs for Control trends
  - GUI for KPIs
  - Modelling tools
  - Offline gas network optimization tools
- Deployment in the finalization phase
- Online tests in 2 month

Discussion and conclusions

PROS

ML models are effective at predicting future energy flows (POG, electricity, steam)

Real-time control through MILP

Plantwide control allows an intelligent exploitation of POGs

Easy prototyping (matlab/python)

CONS and issues

Complex industrial implementation through open-source libraries (Google Or-tools, Tensor flow / custom algorithms for ML models)

Non-Open-source optimization libraries are expensive (CPLEX, Gurobi, etc.)

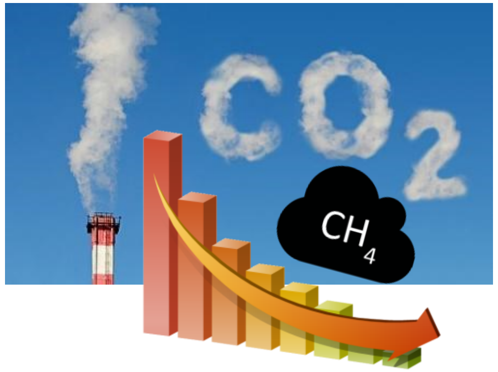
Custom DSS requires a long engineering phase

DSS + operators vs **Automatic control**: control action must be applied ASAP

Discussion and conclusions

Future works:

- Deployment and online test of the control/supervision software in the plant
- Sensitivity of control approach to energy media prices
- Study MIQP approach (reference tracking) for Low-level controllers
- ML physical based approaches for disturbance modelling



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Thank you!

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