

Towards Sustainable Industrial Energy Systems: An Optimization-Based Approach



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Prof. Adisa Azapagic & Prof. Robin Smith

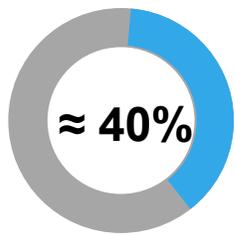


INTRODUCTION

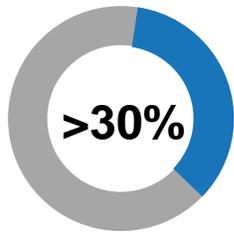


Role of Industry to achieve 'Net-Zero' targets

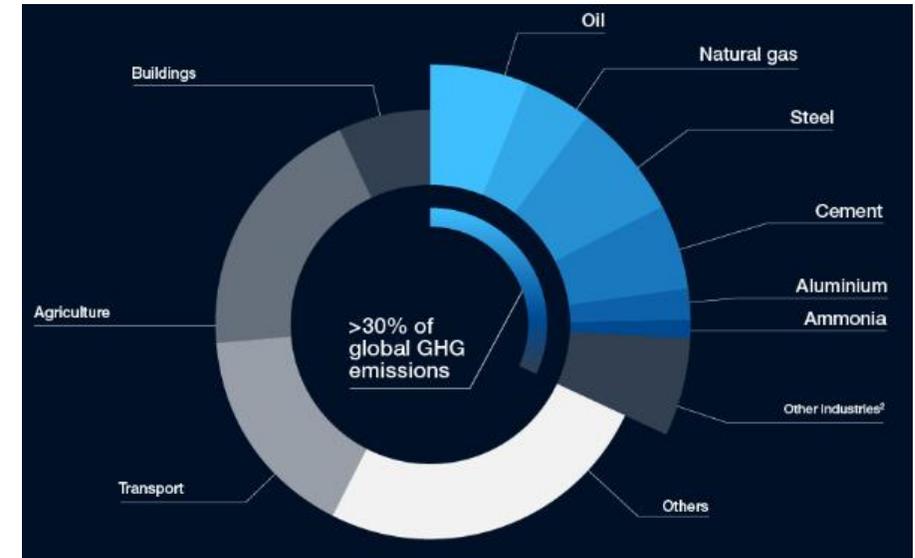
Industry play a critical role



Global energy consumption



Global greenhouse gas emissions



Production-related emissions by sector (Scope 1 and 2)

Source: IEA and World Economic Forum 2022



Towards to Industrial Decarbonisation

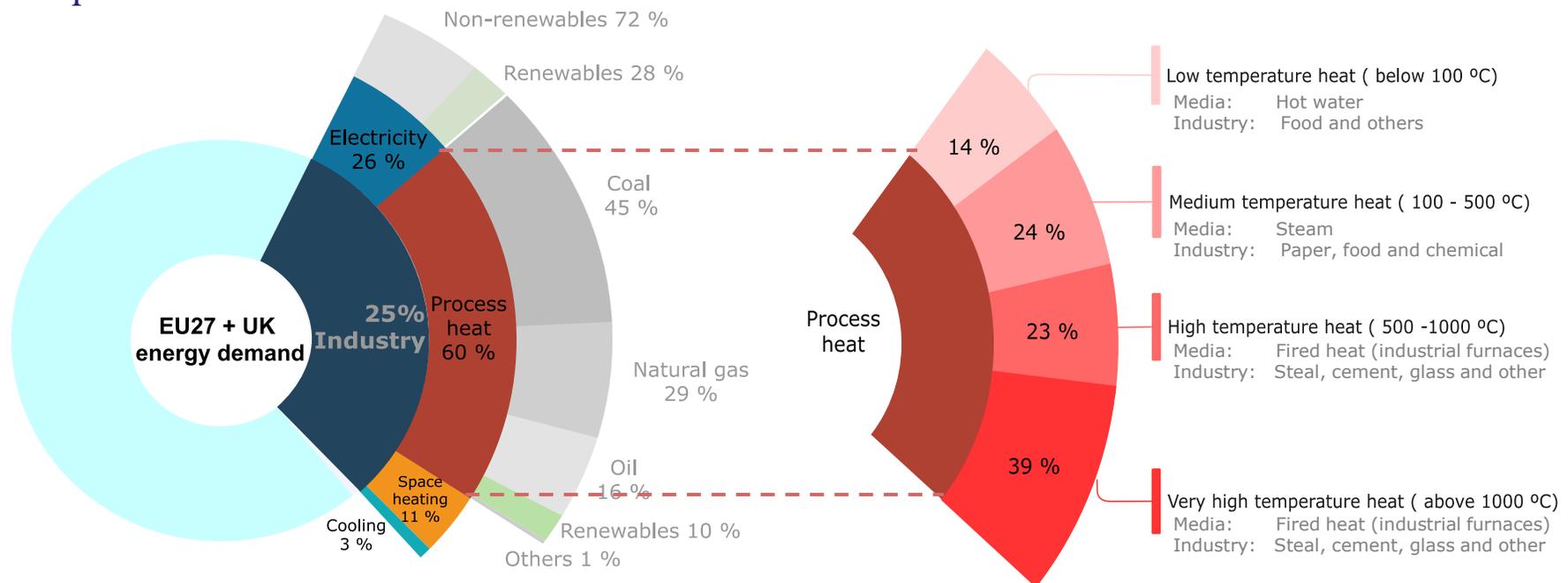


INDUSTRY

Challenges

Progress in these sectors has been limited to date.

- High heat demand
- Temperature barrier

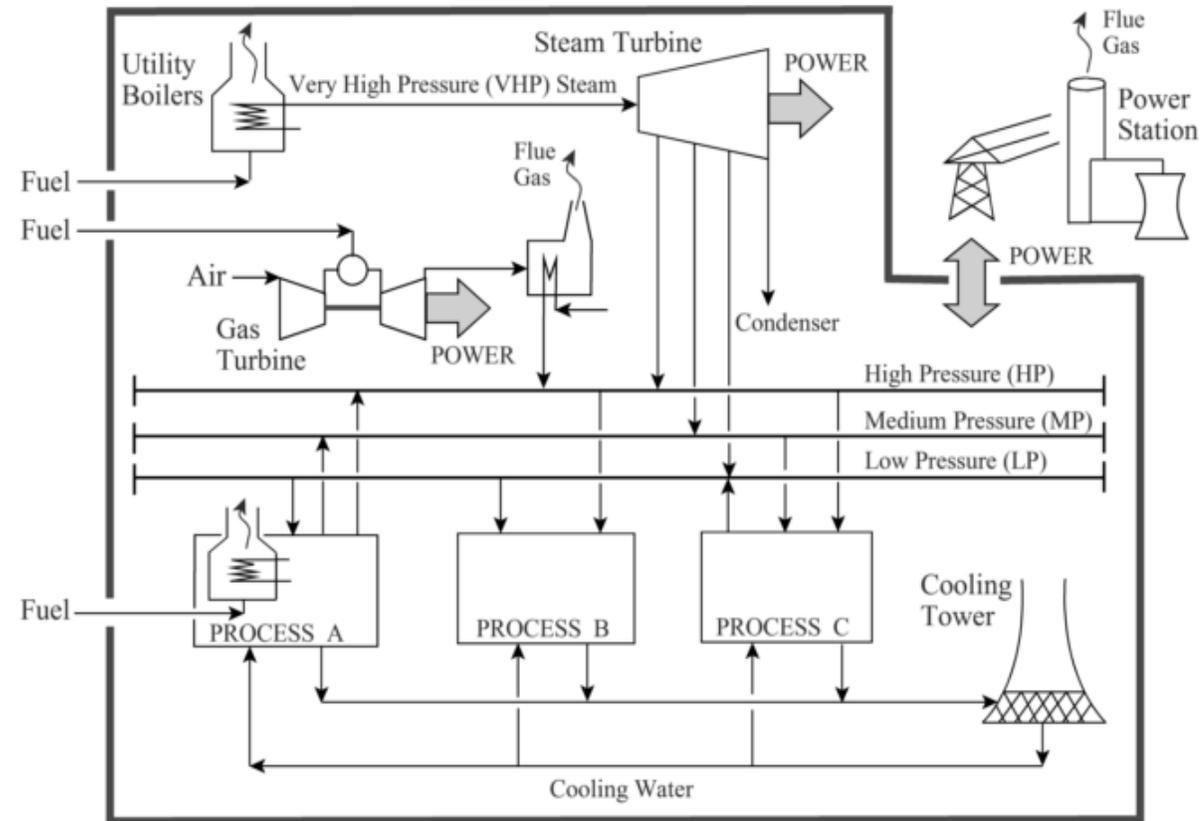


Sources:
Fraunhofer Institute (2016) Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)
Naegler et al (2015) Quantification of the European industrial heat demand by branch and temperature level. Int. J. Energy Res.



Role of Utility Systems in Energy Transition

Utility system is often the largest energy consumer on process sites

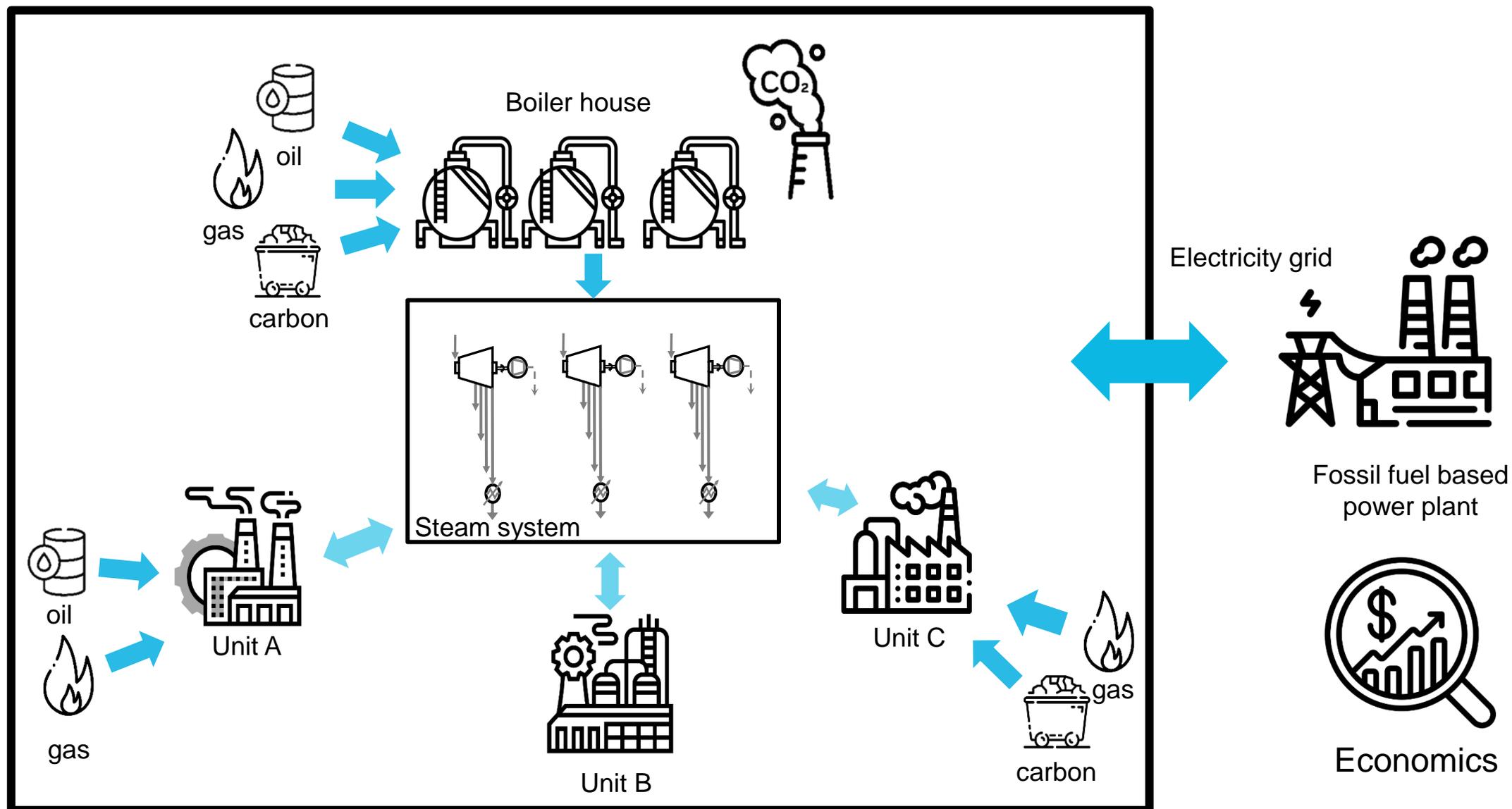


To improve the performance of such systems

... we need to model and optimize the model



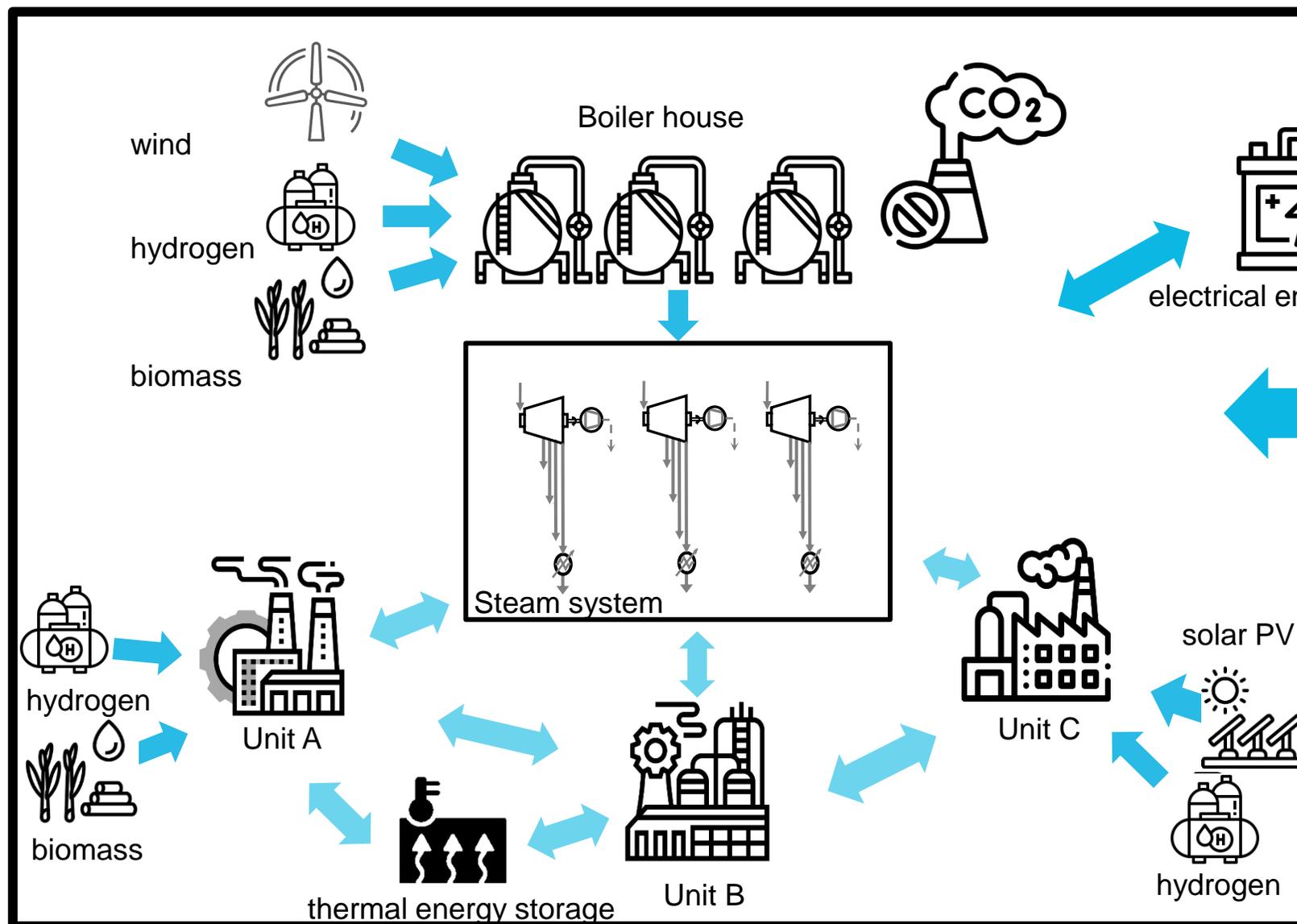
Current Industrial Energy Systems





Future Industrial Energy Systems

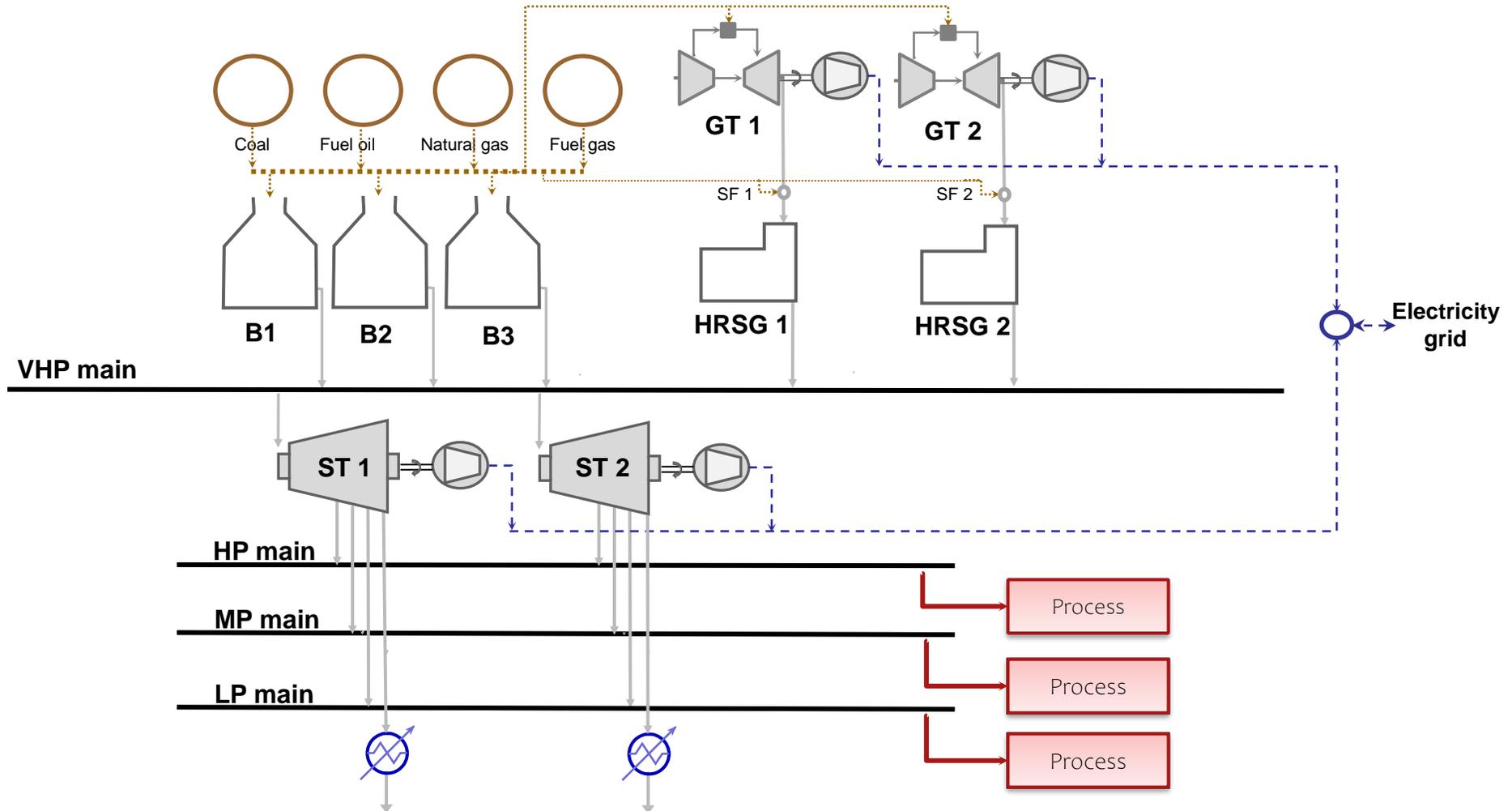
Completely different system *configuration* and *operation*

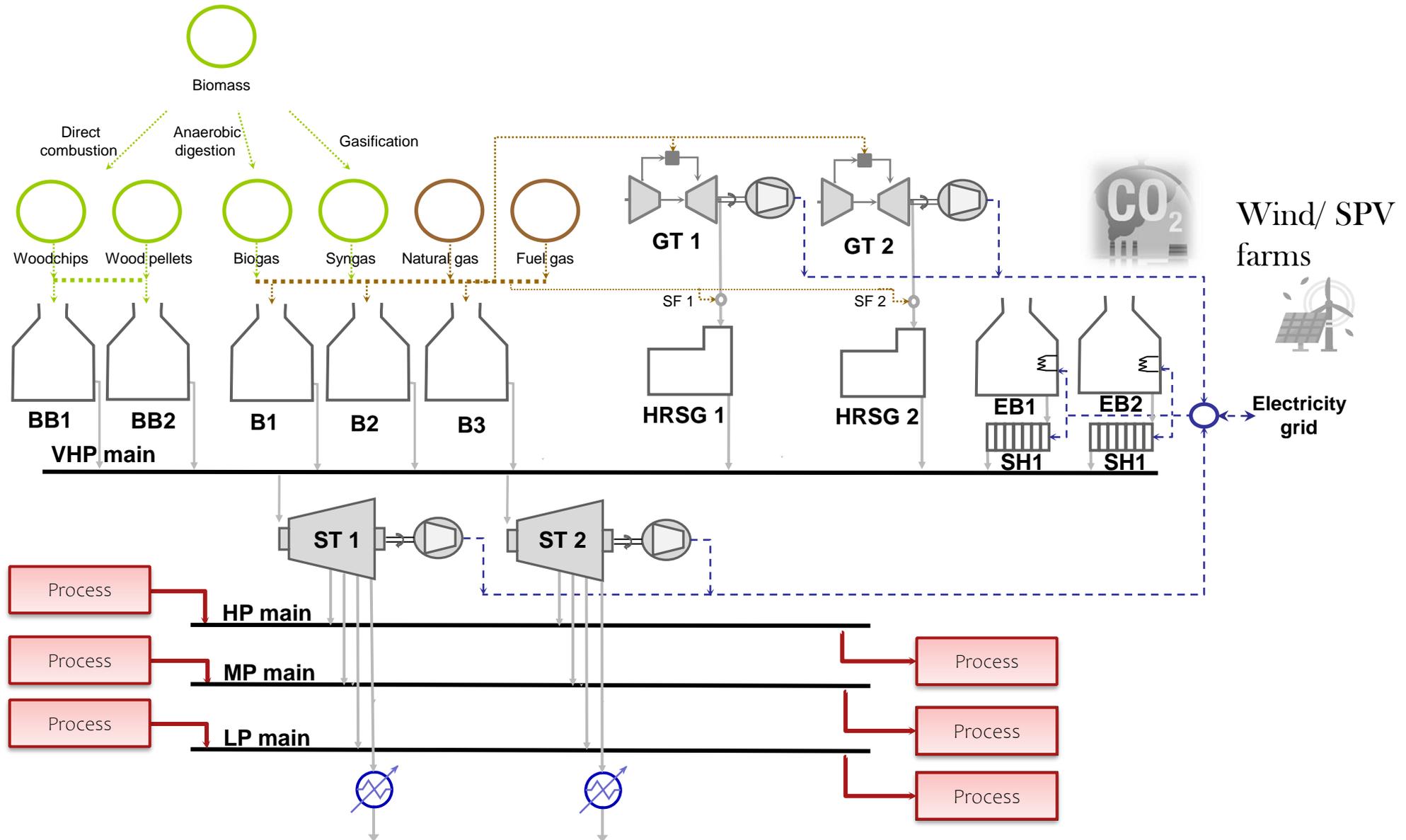


Economics



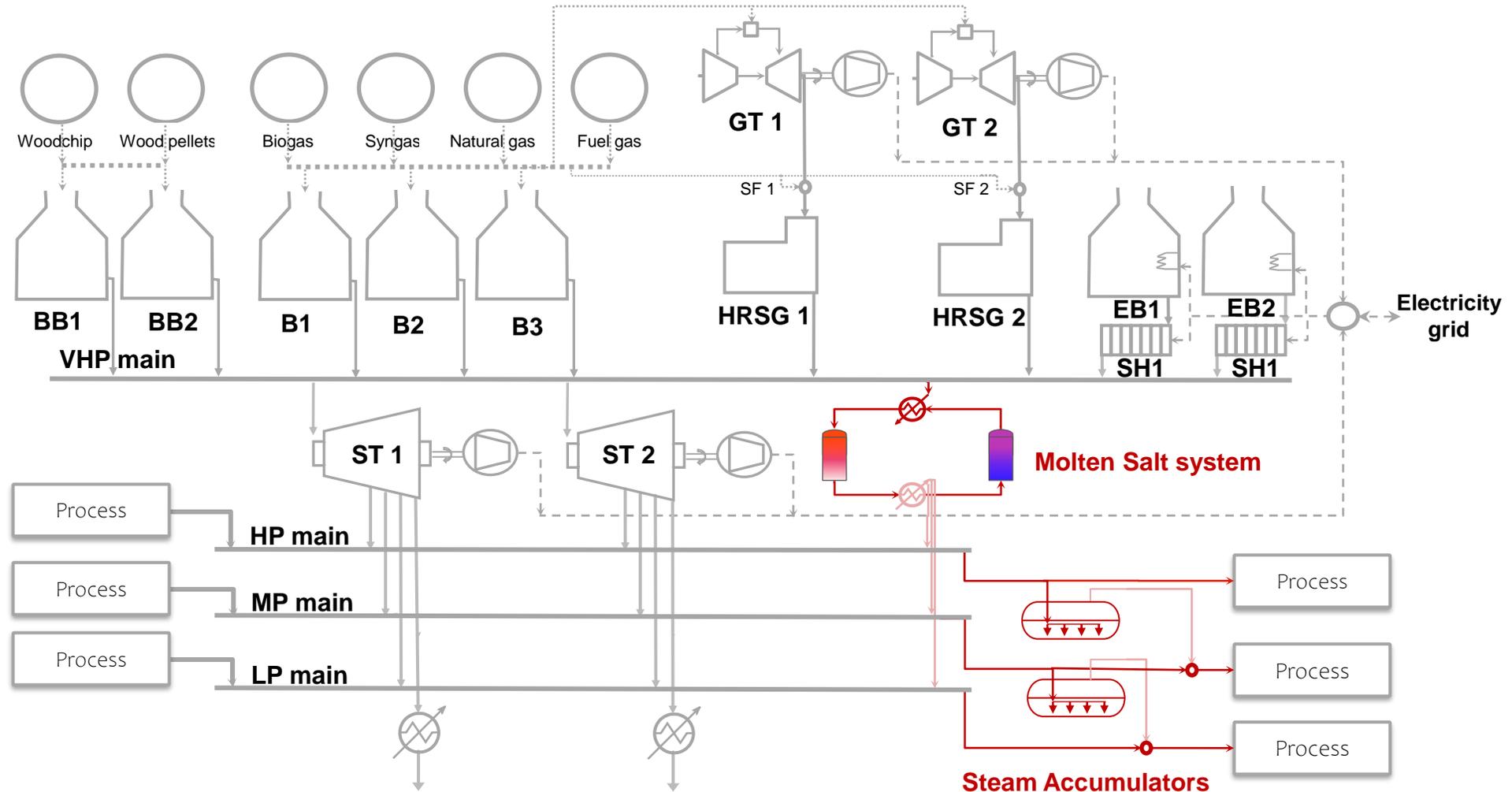
Environment





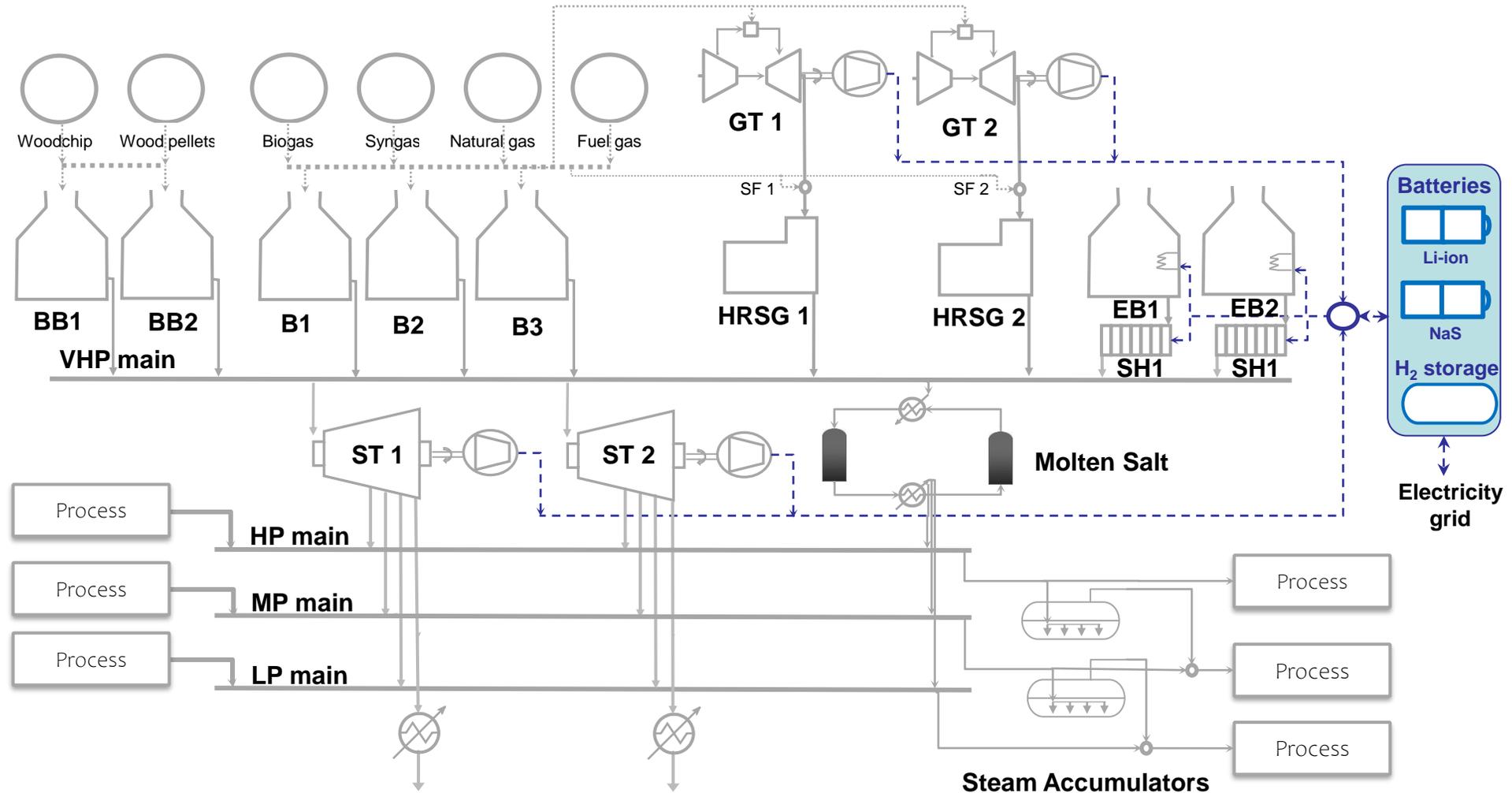


Thermal Energy Storage



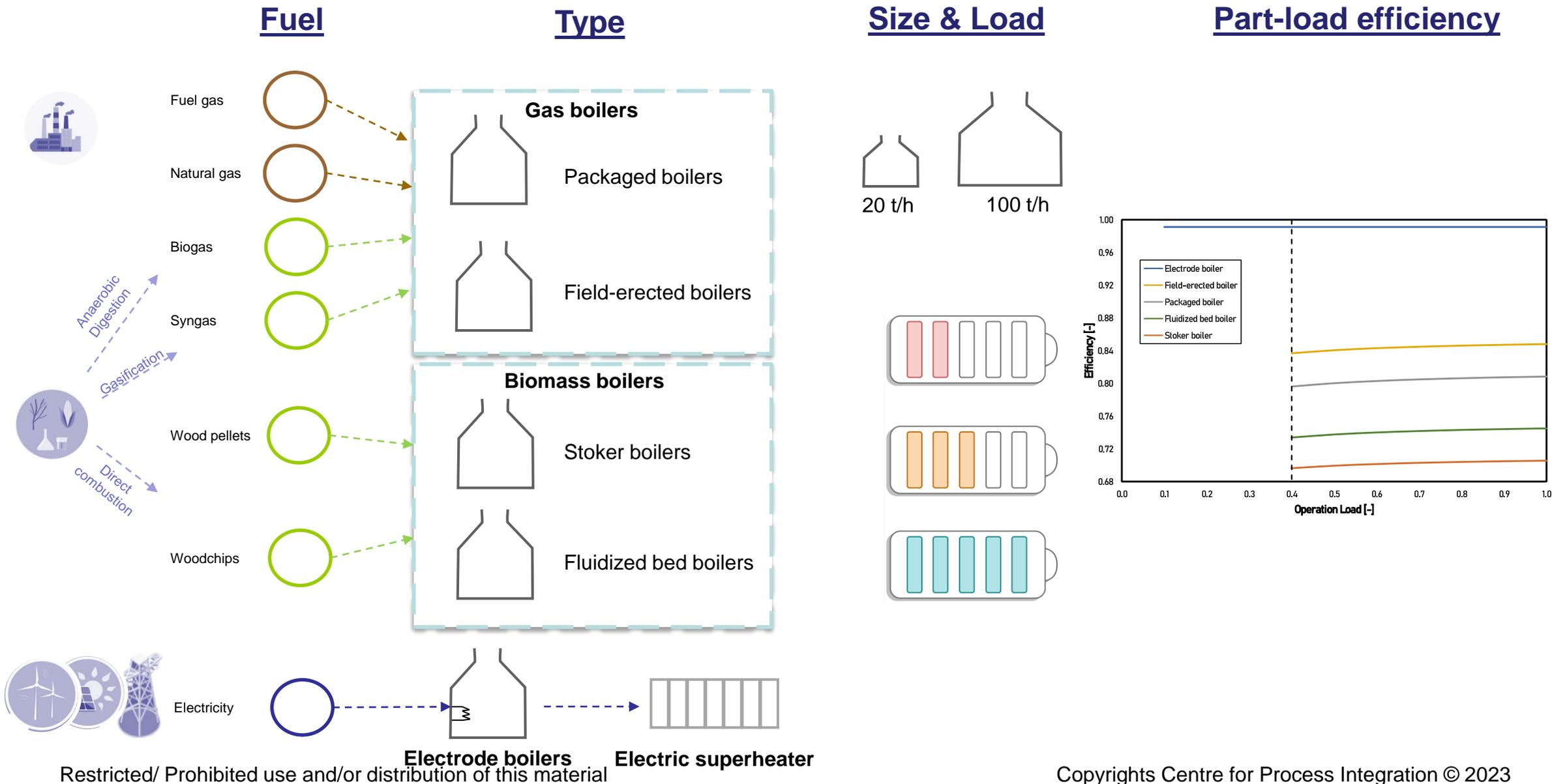


Electrical Energy Storage





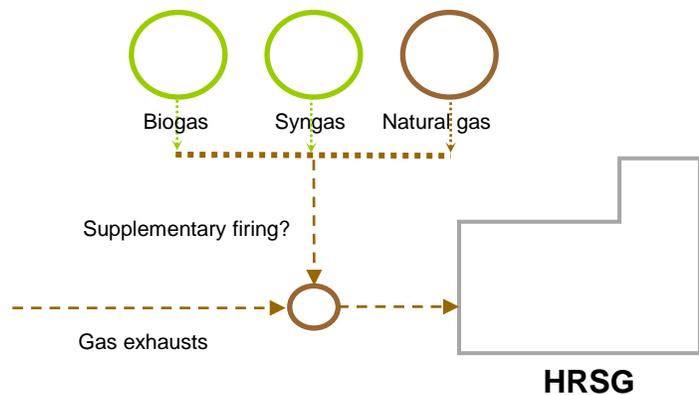
Energy Decarbonisation challenges



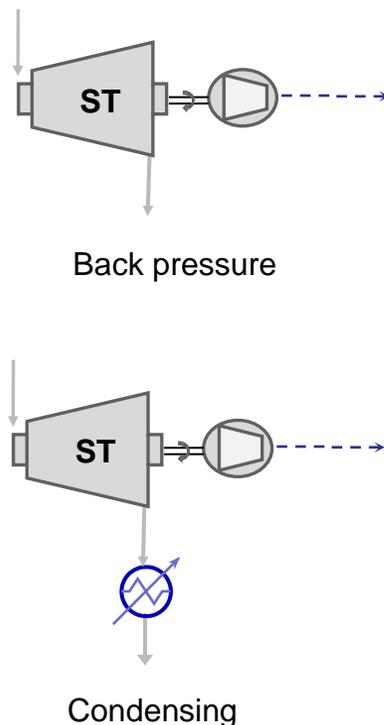


Energy Decarbonisation challenges

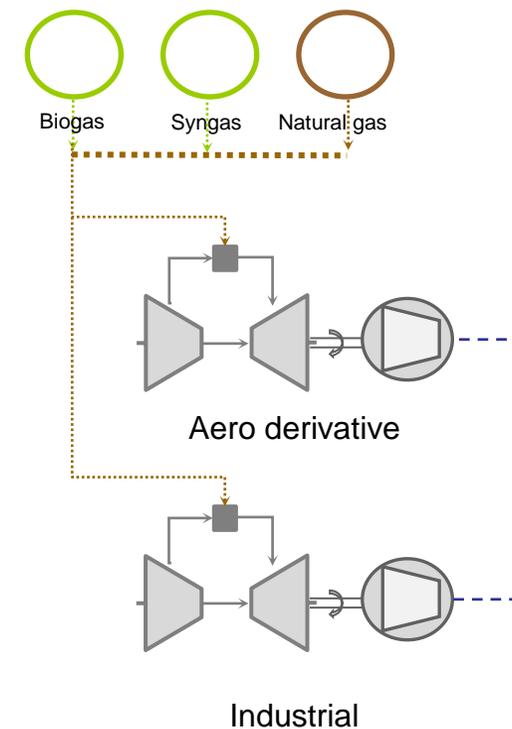
Heat recovery steam generators



Steam turbines



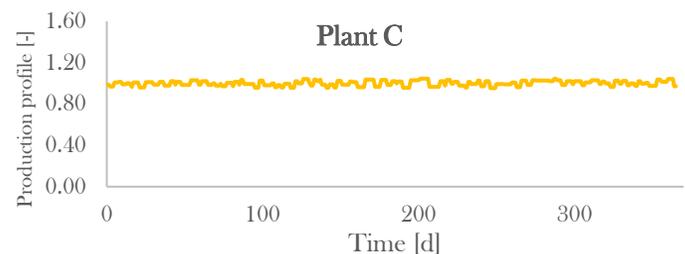
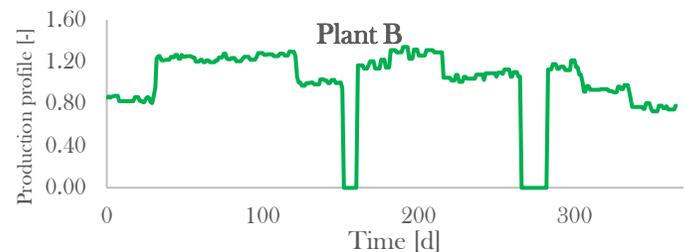
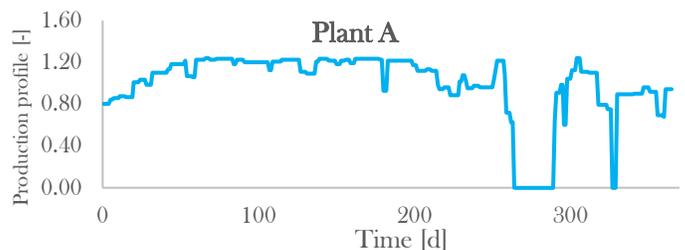
Gas turbines



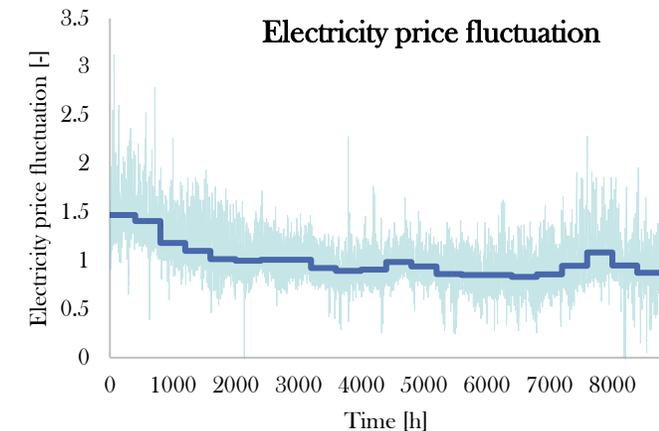
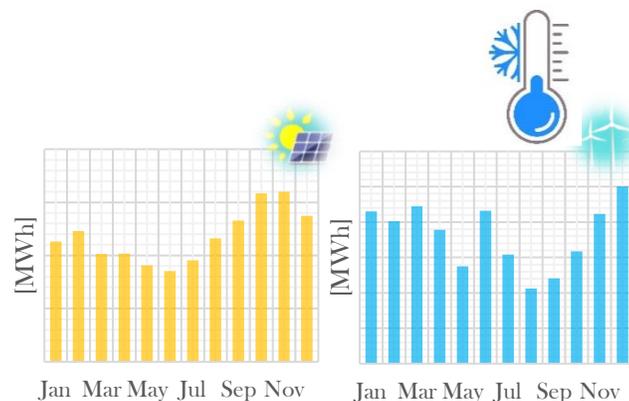
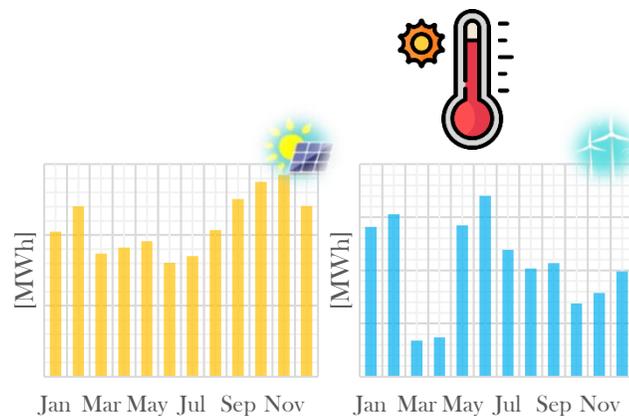


Energy Decarbonisation challenges

Energy demand variation



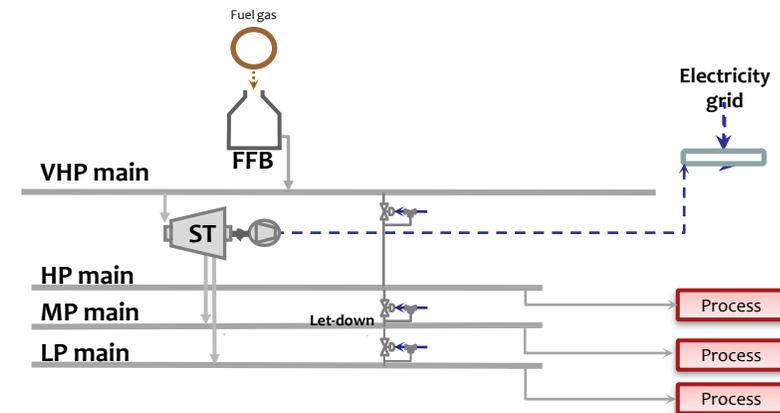
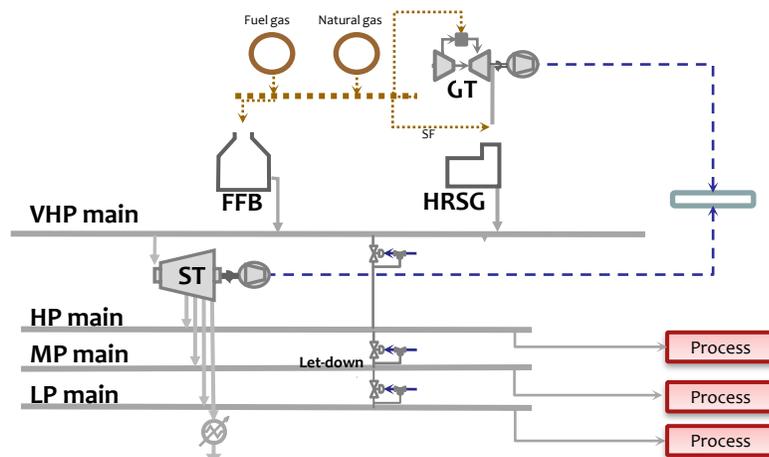
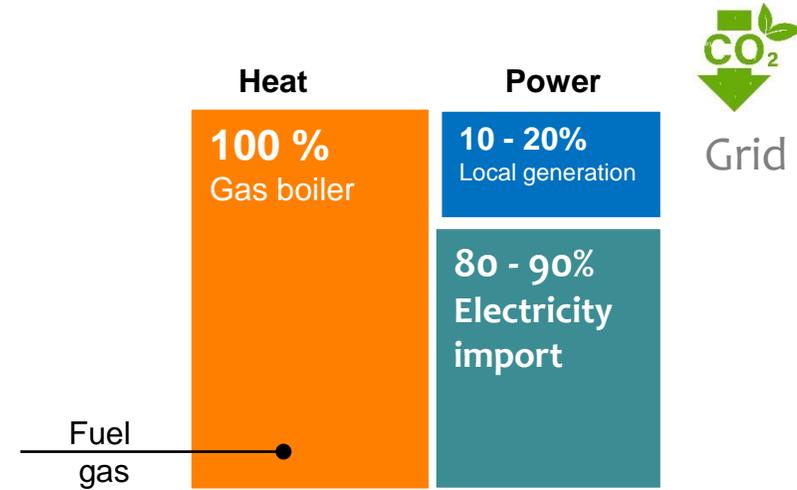
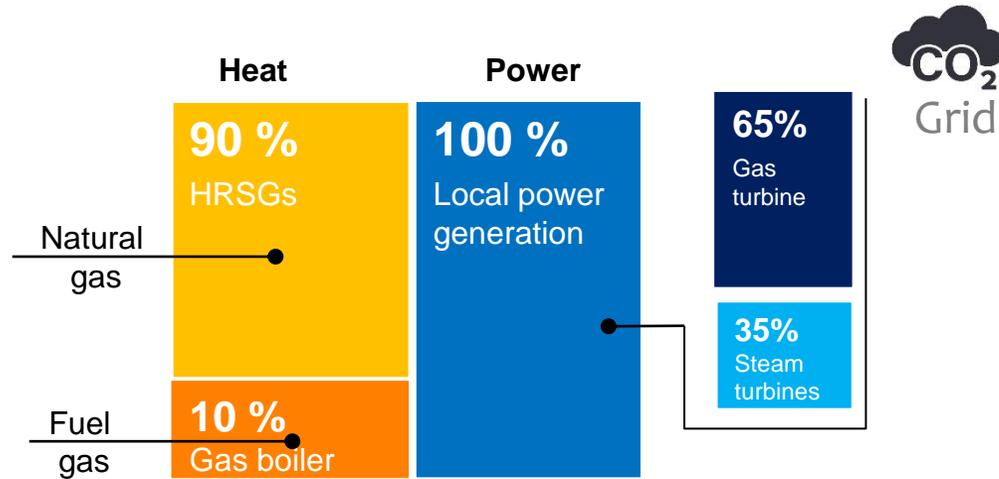
Energy supply/price variation





Energy Decarbonisation challenges

Environmental factor





Energy Decarbonisation challenges

There is no silver bullet

Depends on several aspects:

- Technologies/sources available
- Variability of the energy demand and supply across the time
- Site thermal and power demand
- Utility prices (Power tariffs)
- Sources environmental factor



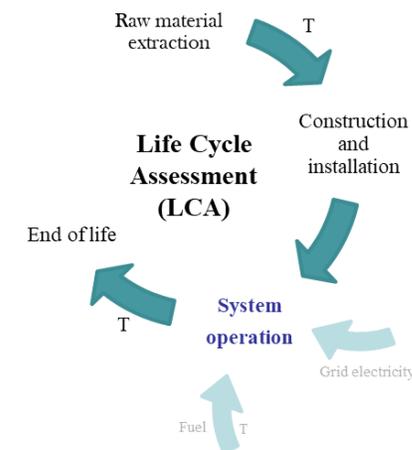
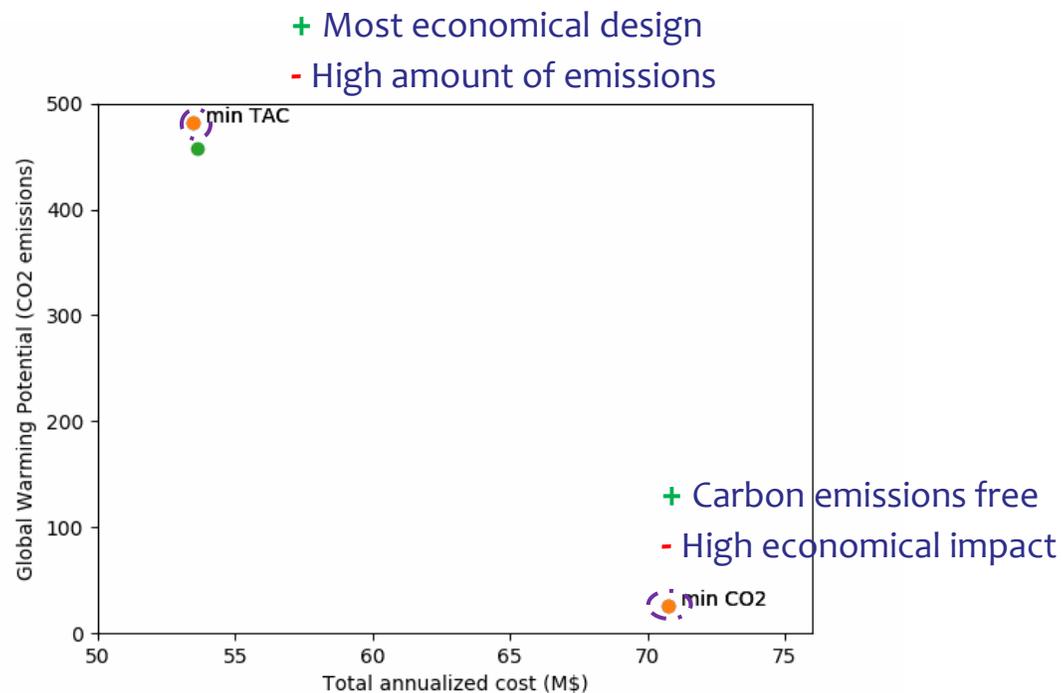


Challenges of Industrial Decarbonisation

Previously, the design was based on **Economics** of the site.

BUT...

Other aspects as **environmental impact** are also important.

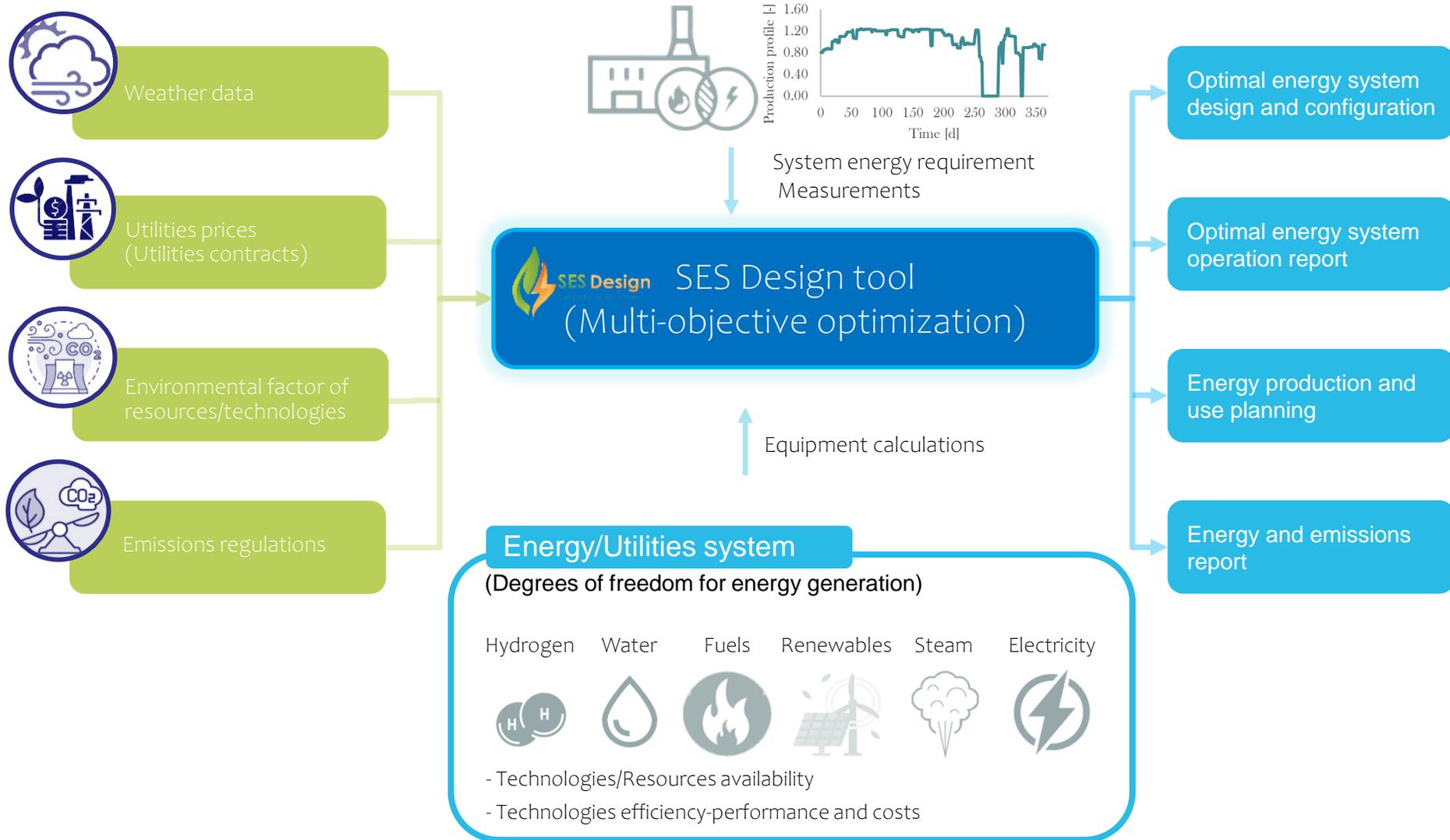


LCA is an essential tool to understand the true CO₂ abatement provided.

Multi-objective optimization
to analyse the *trade-off* between
**environmental and techno-
economics aspects.**



How to successfully integrate environmental objectives?

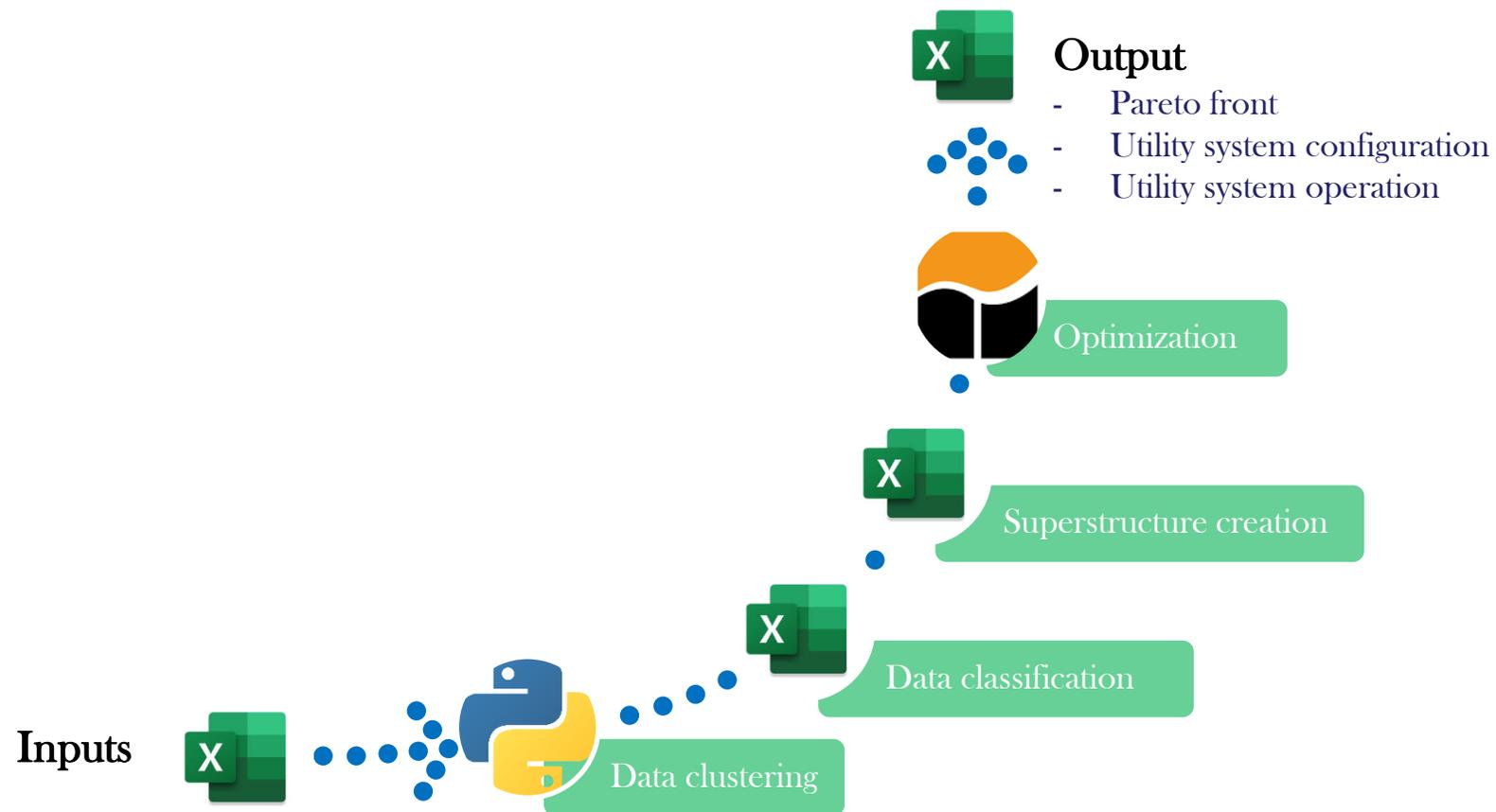




APPROACH



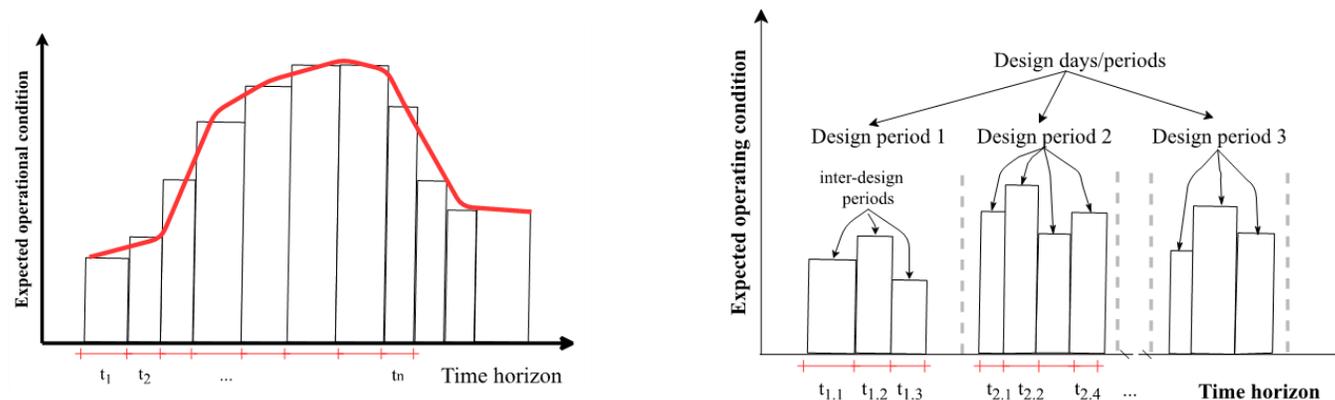
Methodology





Methodology

Multi-period approach



various scenarios to represent
different operating conditions

Inputs

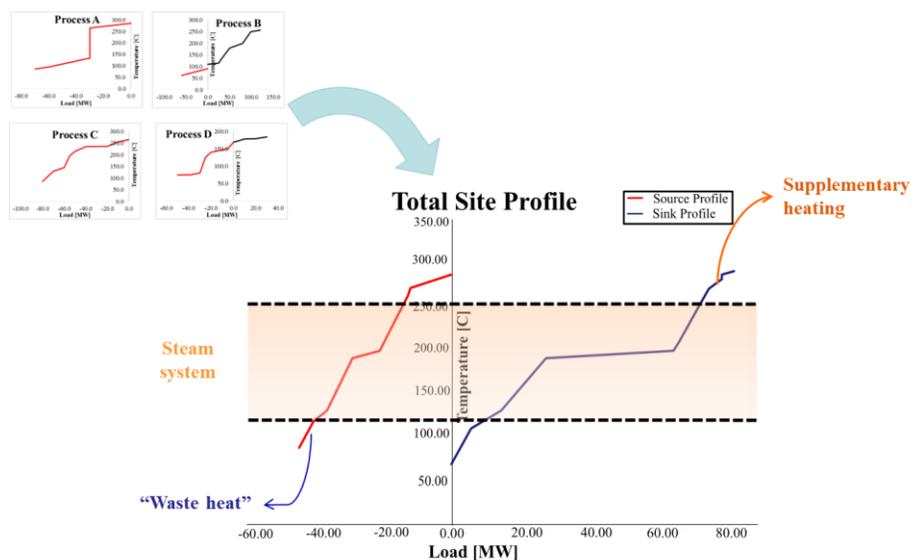


Data clustering

- Stream data
- Production profiles
- Power demand
- Market prices
- Technology data



Methodology



Inputs



Data clustering

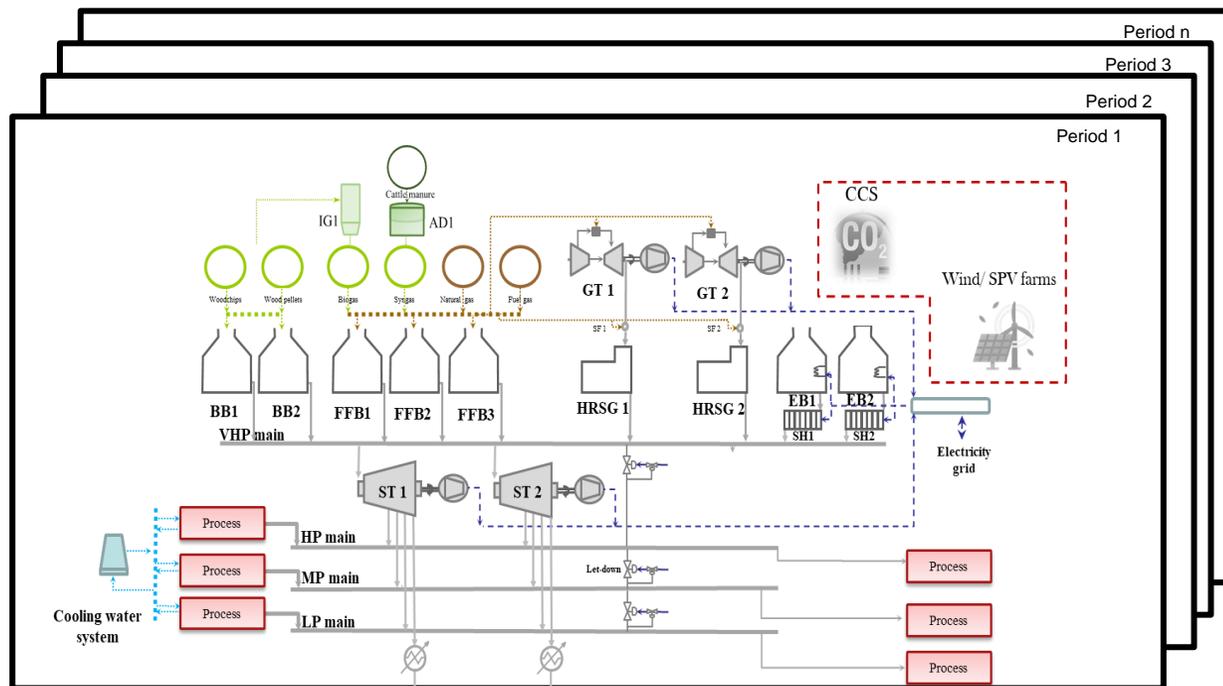


Data classification

- Stream data
- Production profiles
- Power demand
- Market prices
- Technology data



Methodology



Inputs

- Production profiles
- Energy demand
- Market prices
- Technology data



Data clustering



Data classification

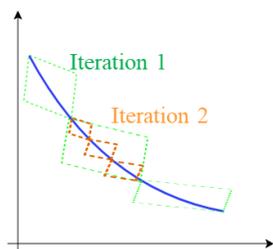


Superstructure creation



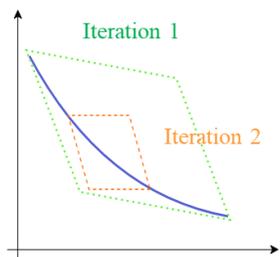
Methodology

Energy balance terms
(bilinear)



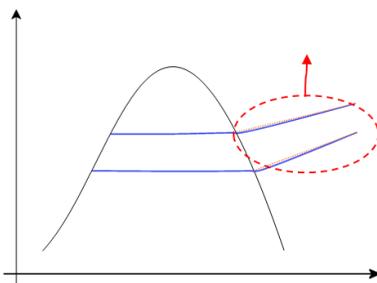
MILP linearization
Gounaris et al. (2009)

Equipment performance
(bilinear)



LP linearization
McCormick (1976)

Steam properties
(convex nonlinear)



Assuming pressure as a parameter
Error up to 2%*
* P_{range} : 0.1-120 bar
 T_{range} : Tsat-570 °C

Costs and emissions
(nonlinear)



Piecewise affine approximations

Inputs

- Stream data
- Production profiles
- Power demand
- Market prices
- Technology data



Data clustering



Data classification



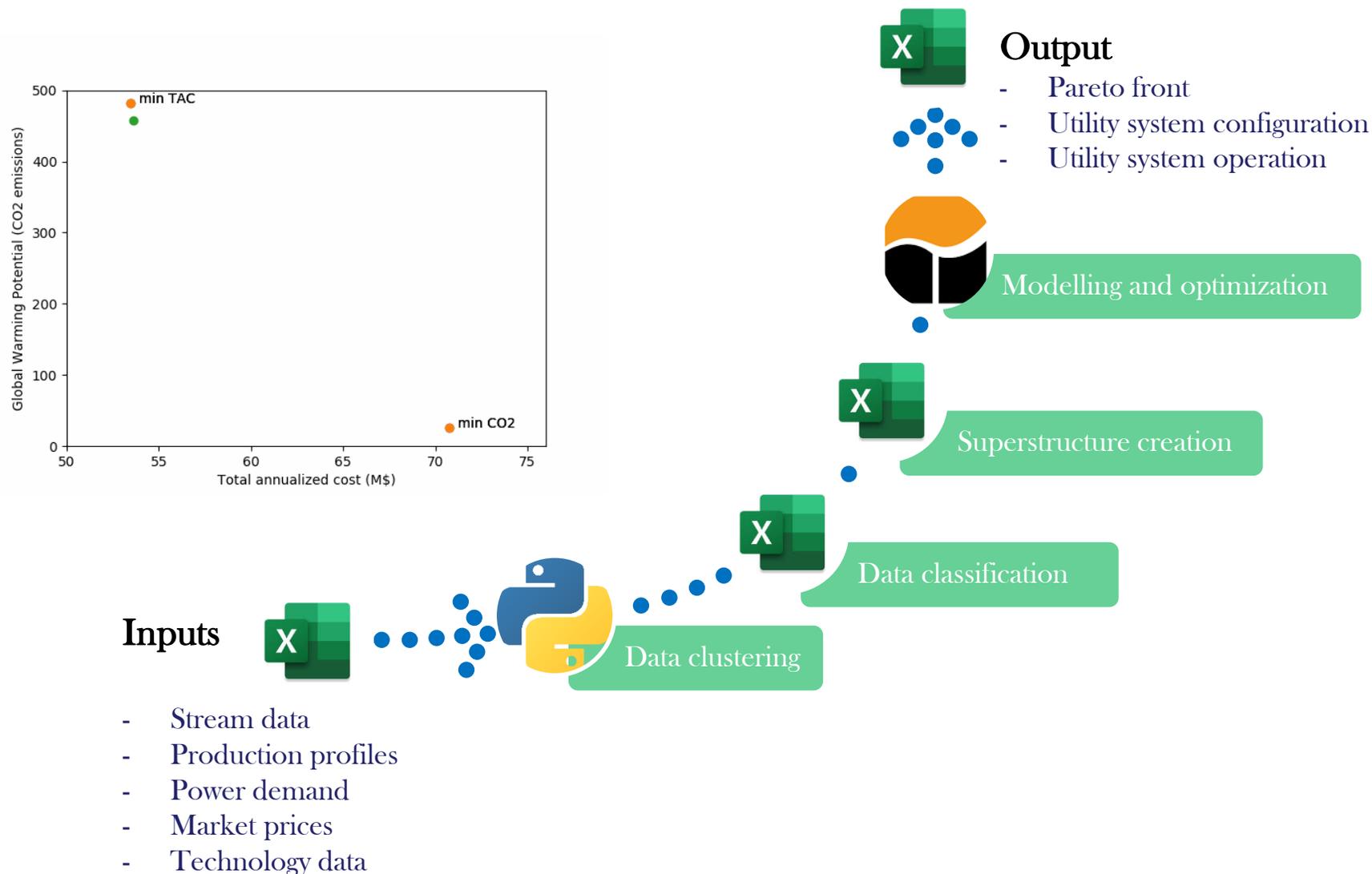
Superstructure creation



Modelling and optimization



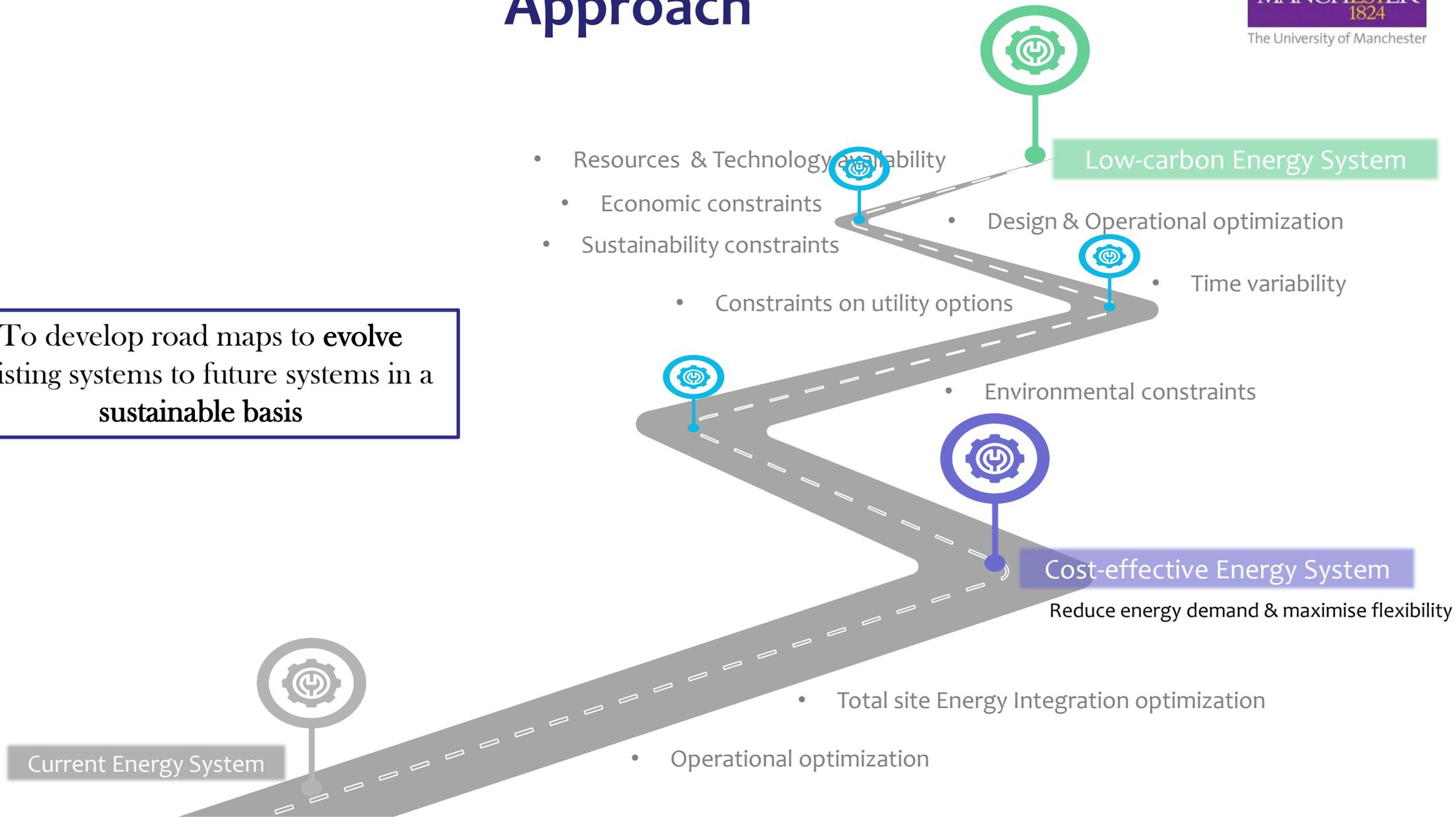
Methodology





Approach

To develop road maps to **evolve** existing systems to future systems in a **sustainable basis**



- Resources & Technology availability
- Economic constraints
- Sustainability constraints

• Design & Operational optimization

• Time variability

• Constraints on utility options

• Environmental constraints

Cost-effective Energy System

Reduce energy demand & maximise flexibility

• Total site Energy Integration optimization

• Operational optimization

Current Energy System



CASE STUDY



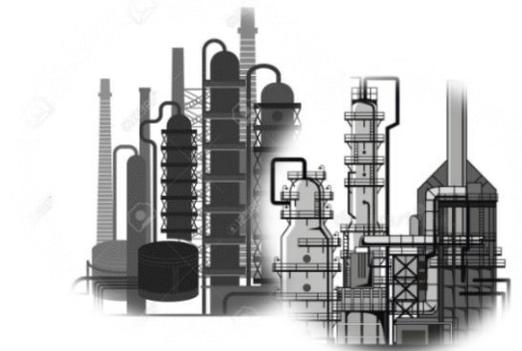
Case Study

Background

- Design of the utility system for a medium-size complex site
- Analysis of the **economic and environmental implications** of various technology/source alternatives

Objective

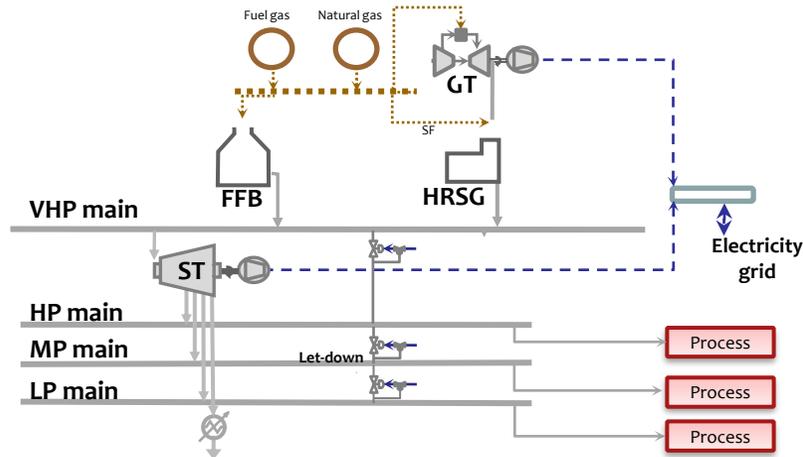
- Reduce environmental impact by **design and operational optimization of the utility system** at minimum costs



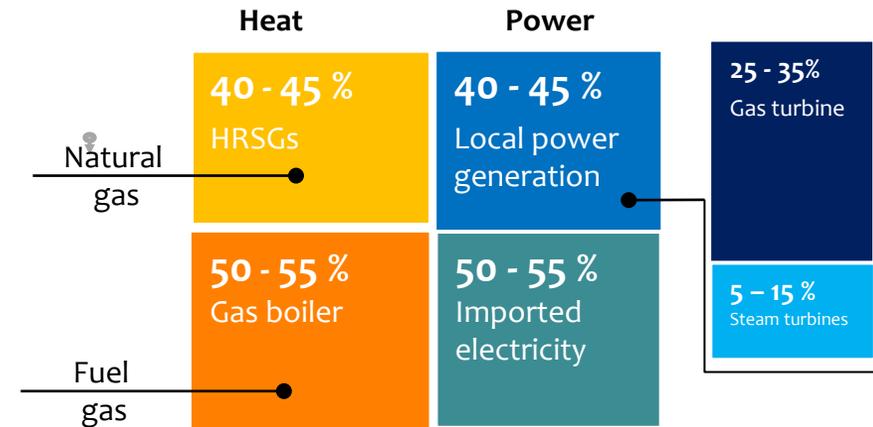


Case Study

Current utility system:

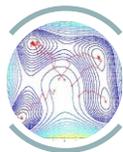


Energy strategy:



Explored options:

Operational optimization



CCS



Renewables



Heat electrification



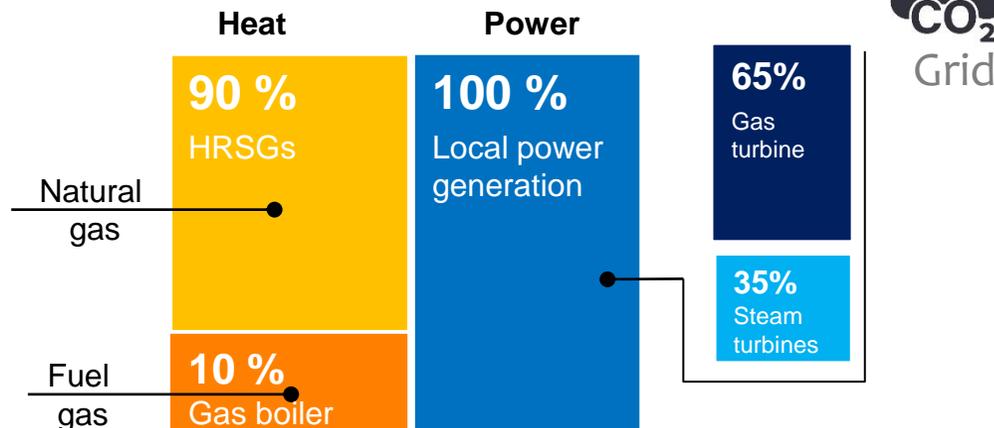
Biomass and waste



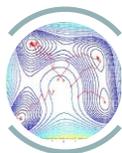


Case Study

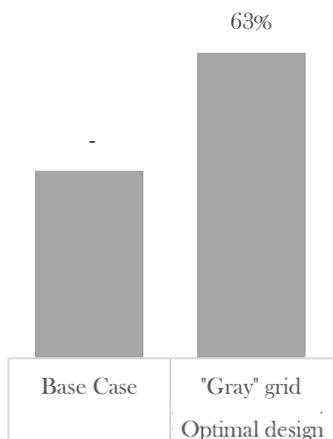
Energy strategy:



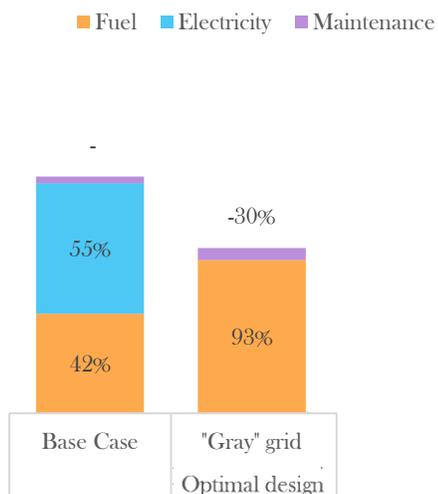
Operational optimization



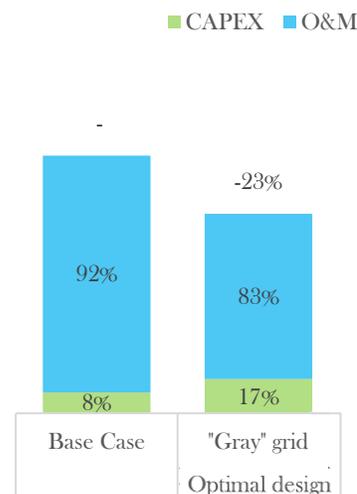
CAPEX [m\$/year]



O&M [m\$/year]



Total costs [m\$/year]



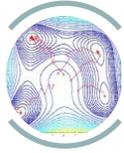
Emissions [ktCO₂/year]



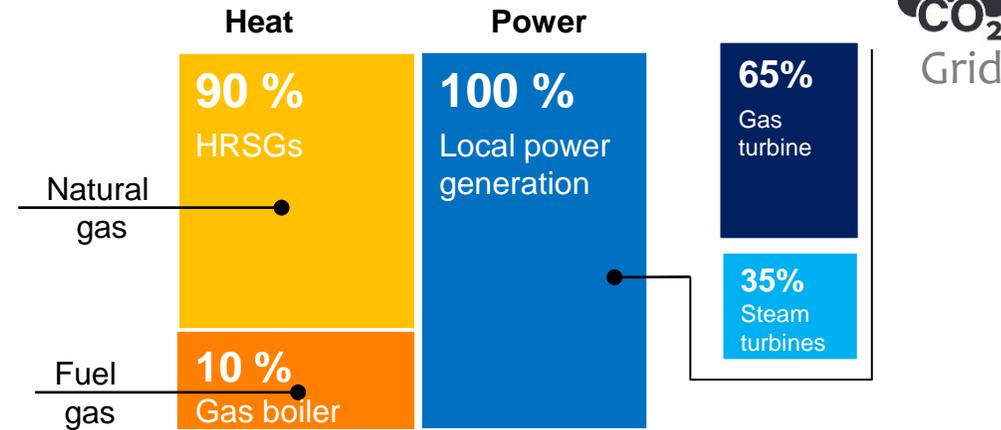


Case Study

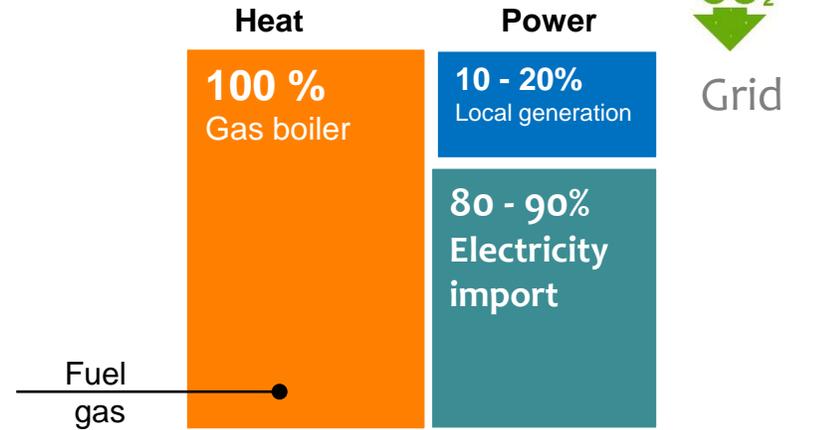
Operational optimization



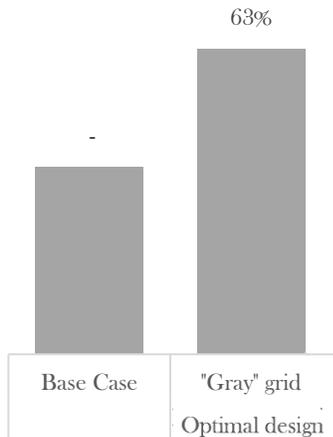
Energy strategy:



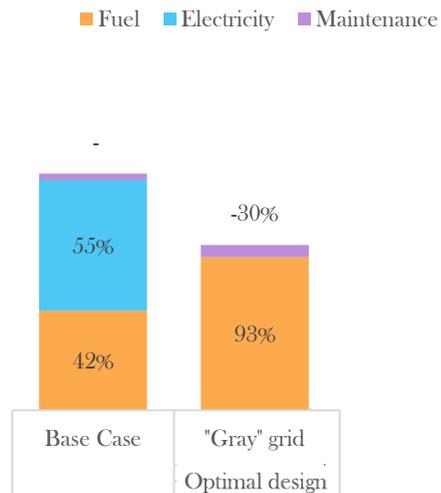
Energy strategy:



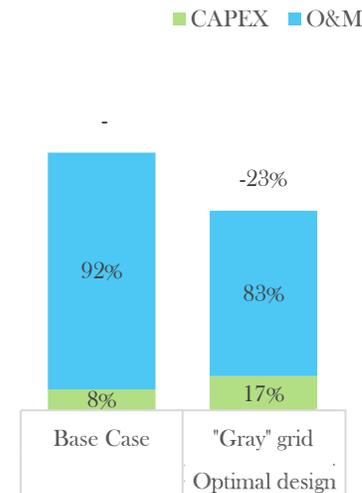
CAPEX [m\$/year]



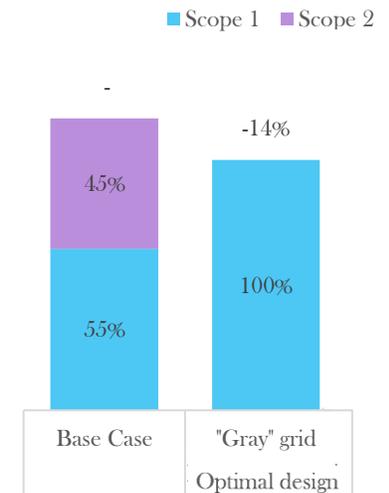
O&M [m\$/year]



Total costs [m\$/year]



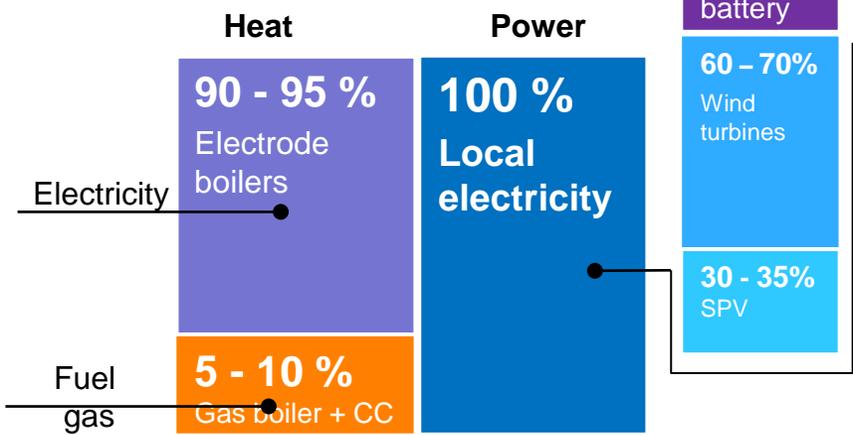
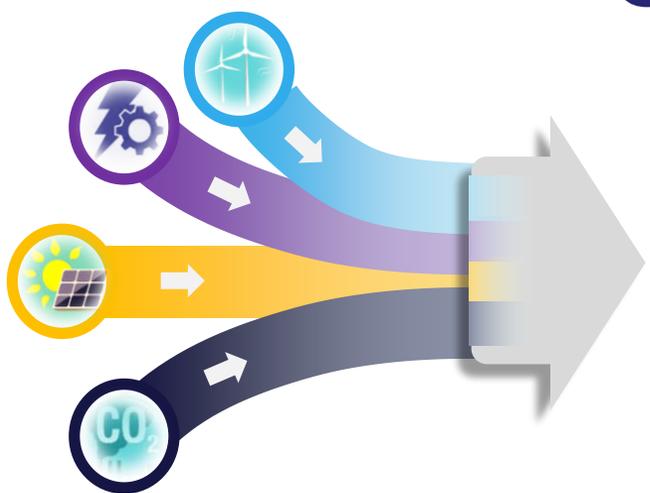
Emissions [ktCO₂/year]



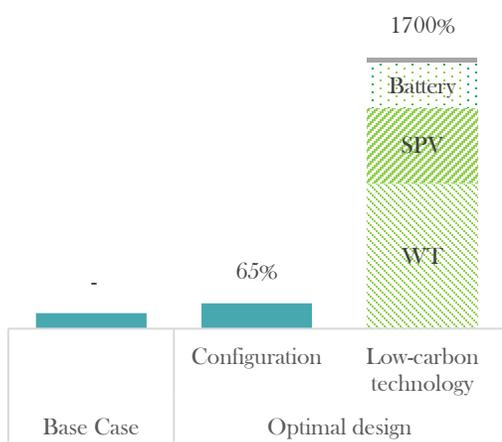


Case Study

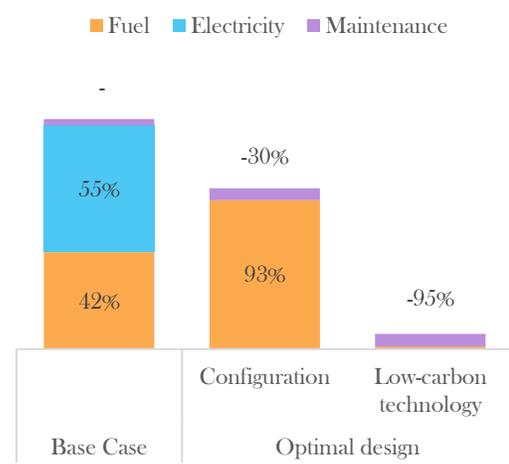
Energy strategy:



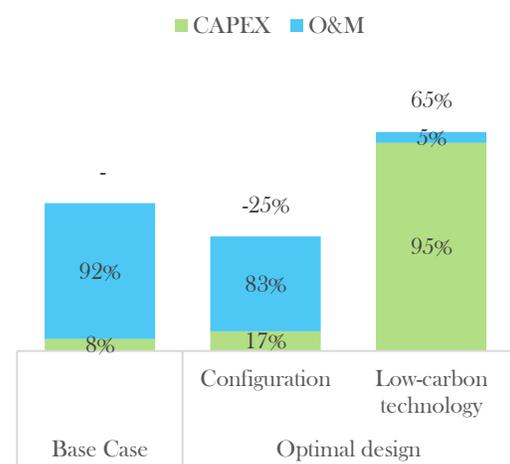
CAPEX [m\$/year]



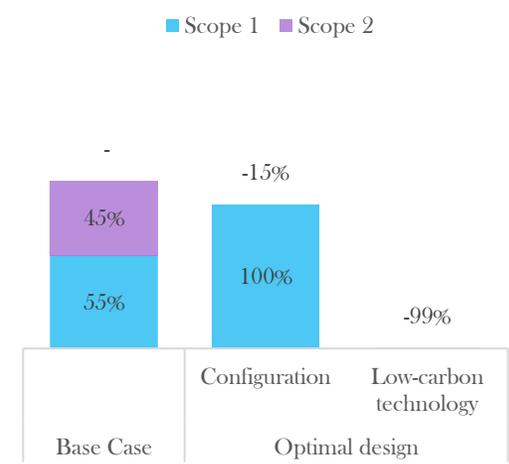
O&M [m\$/year]



Total costs [m\$/year]



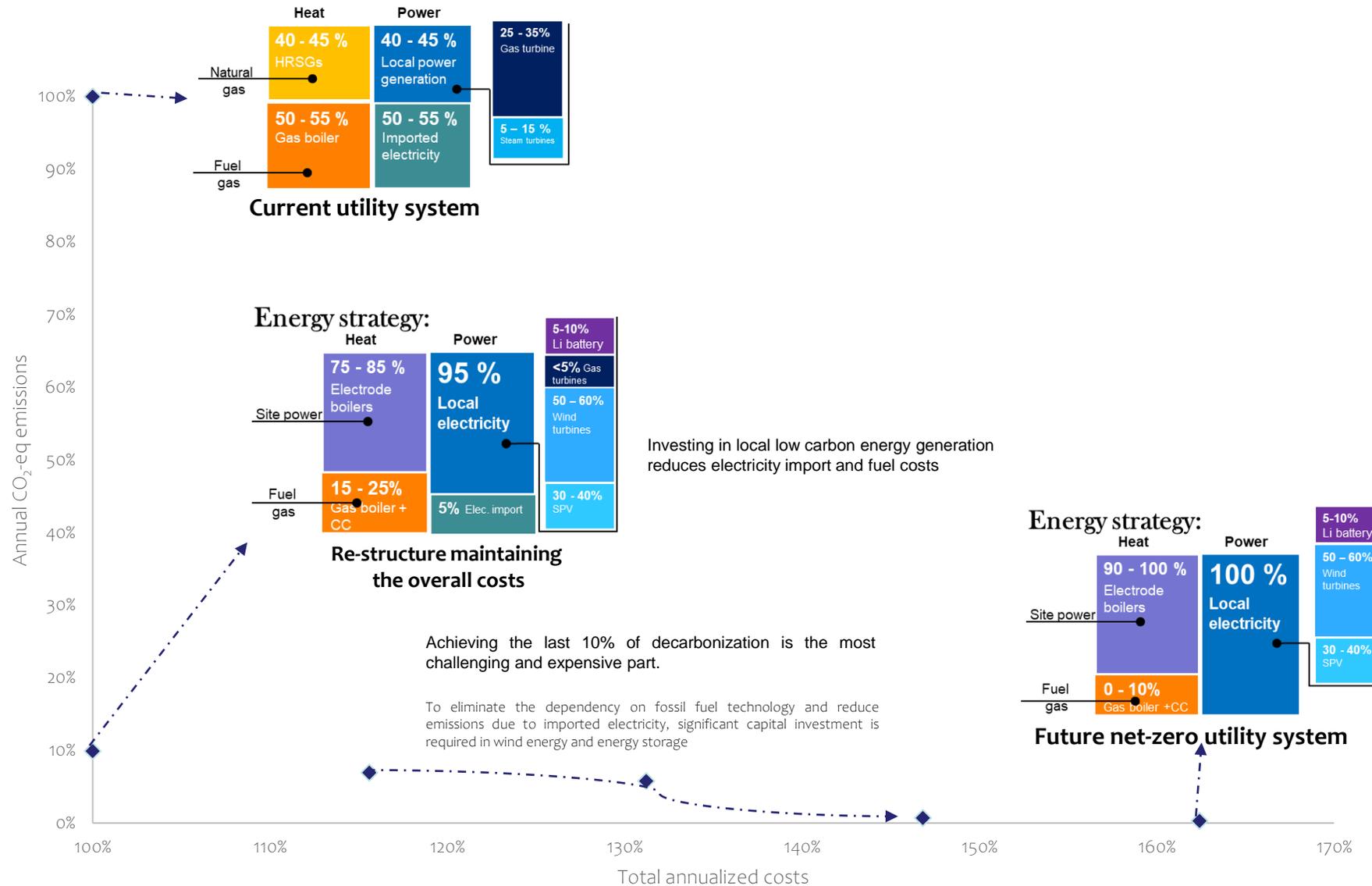
Emissions [ktCO₂/year]



We know our goal, but how we achieve it?



Case Study – Financial Roadmap





CONCLUSIONS



Conclusions

- Energy efficiency plays a key role in industrial energy transition, but further paradigm change in the way the systems are design and operated is required.
- There is **NO “one solution fits all”**. Optimal design will depend on several factors, as location, energy carbon intensity, energy price fluctuations, sources & technology availability.
- The strategy for developing the road map to industrial net-zero energy systems requires the use of decision support tools to identify the most cost-effective design that meets sustainability goals.





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תודה
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Ďakujeme Vielen Dank Paldies
Kiitos Täname teid 谢谢
Thank You Tak
感謝您 Obrigado Teşekkür Ederiz
Σας ευχαριστούμε 감사합니다
Bedankt Děkujeme vám
ありがとうございます
Tack

