Methodology for the technico-economic and environmental study of SMR integration

Final Conference of the TANDEM Project

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Introduction

Does it make sense to integrate SMR into Hybrid Energy Systems?

WP3 objectives:

- Propose a methodology and tools to answer this question
- Apply it to three study cases

Steps:

- Defining the study cases including architectures, input data, choice of KPIs
- Carrying out the technical, economic and environmental study
- Conducting the sensitivity analysis
- Checking the architectures and the KPIs owing to finer models

Outputs:

Deliverable 3.1: ✓
Deliverable 3.2: ✓
Deliverable 3.3: ✓
Deliverable 3.4: ✓
Deliverable 3.5: ✓

https://tandemproject.eu/resources/

Overview of the three case studies

Northern European case

Helsinki

- Finnish DH = 52 TWh of fuels
- 93% of heat is produced owing to coal, wood, CH_4, peat and waste
- Helsinki = 30% of the Finnish DH

Southern European case

Fos-sur-Mer + Dunkirk

~40%

of CO_2 industrial emissions in France

Central European case

Moravian Silesian region

- Highly industrialized region
- Large share of CO_2 production in the CR

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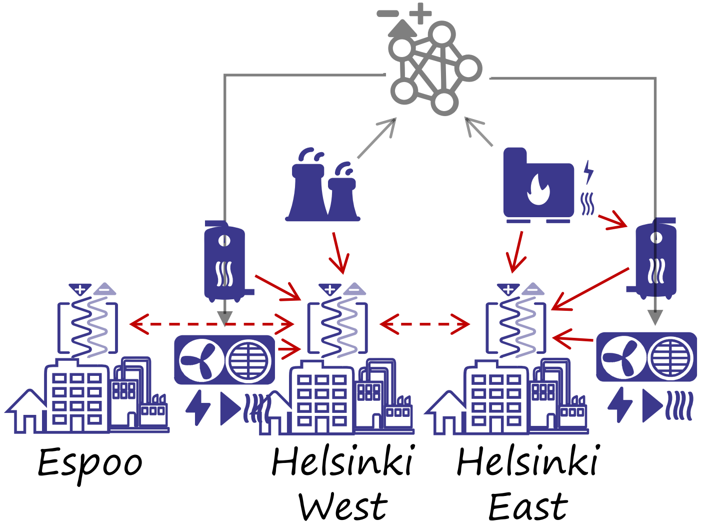
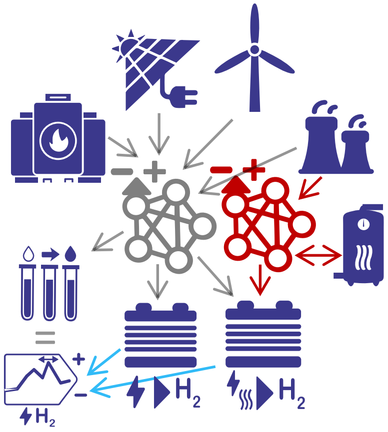
Overview of the three case studies

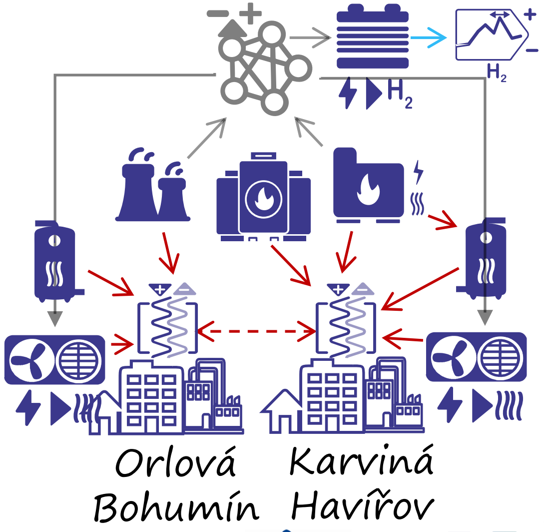
Northern European case



Southern European case



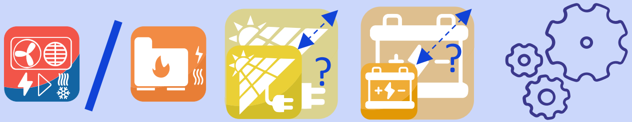
Central European case



Methodology

1. Exploration of architectures

- What combination of technologies?
- What size of each component?
- How to operate the system?



- What economic and environmental costs of the system?

KPIs

Multi objective Pareto front

2. Sensitivity studies

- How robust are design and control?
- Is optimal size compliant with uncertainties?

Uncertain parameters (CAPEX, feedstock, …)

New KPIs (resilience, …)

3. Check feasibility

- Check more precisely the feasibility of the operation under more realistic conditions
  - Perfect forsight ≠ Rolling horizon
  - MILP models ≠ DAE based models

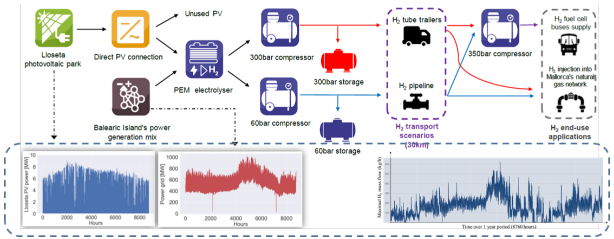
→ Soft-linking

→ Hard-linking in a co-simulation environment

Updated KPIs

Application to the Energy Hub case
1. Modeling framework

Build and solve **a MILP optimization problem** for **sizing** and **operation planning** of energy system



Objective function
NPV, Total costs, environmental impact among the 16 described in EF v3.0 (GWP100, …)

Model component constraints
Start-up, shutdown, ramps, efficiencies, …

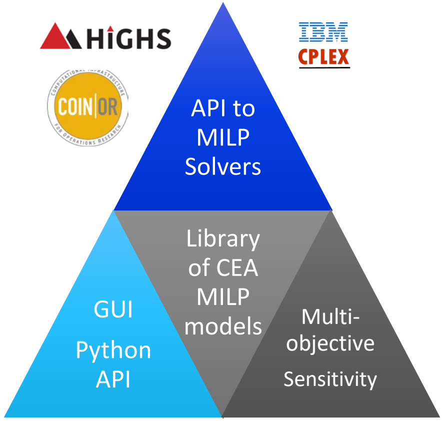
Model complex system constraints
Energy balance, yearly constraints, …

Optimal sizing & Optimal operation
KPIs (Power, energy, CO_2 emissions, …)

PERSEE → CAIRN Open by cea

Find us on GitHub:
https://github.com/CEA-Liten/CairnOpen

HiGHS
COIN-OR
IBM CPLEX



Examples of application
→ Decarbonation of various industrial sites using electricity, heat, cold.
→ Optimal control coupled with simulation tools (Dymola, DistrictLab…)
→ Optimization of ammonia production and transportation supply chain
→ Bi-objective optimization of H_2 supply chain for Balearic Islands

Strenghts
→ Optimal solution guaranted by MILP theory
→ Agnostic (all energy carriers)
→ Life Cycle Assessment & 16 impacts considered
→ Continuous Integration & Deployment

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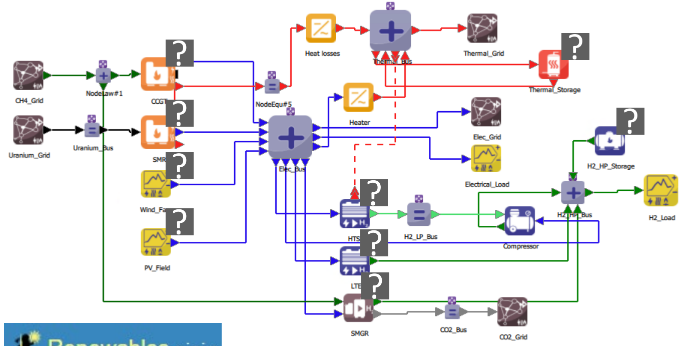
Application to the Energy Hub case
1. Exploration of architectures

2035
1 SMR

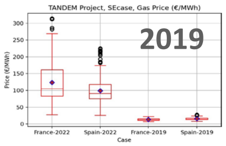
Study case definition and data collection



Renewables.ninja

European Commission

PVGIS



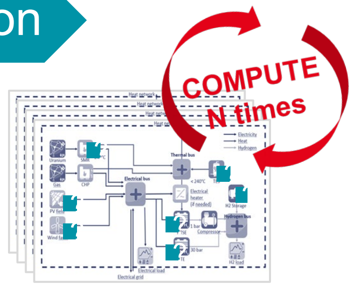
8,26tH2/h

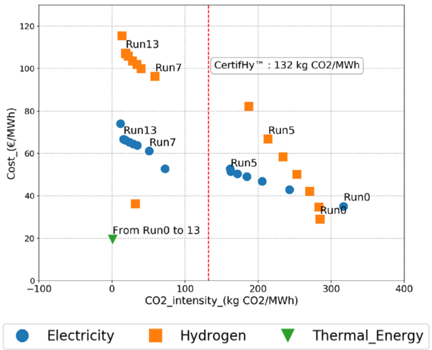
72.3 ktons of H_2/year
657 GWhe

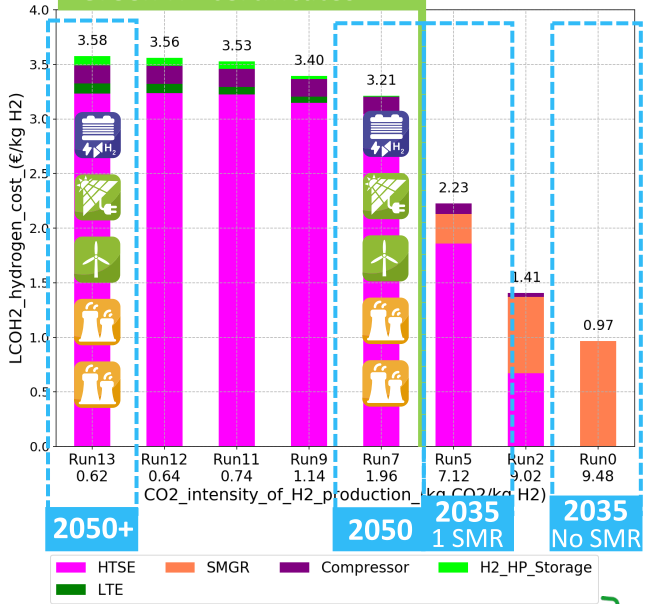
20 years

5%

$€_{2023}$







Conduct study and results analysis

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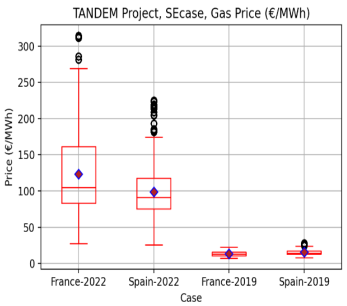
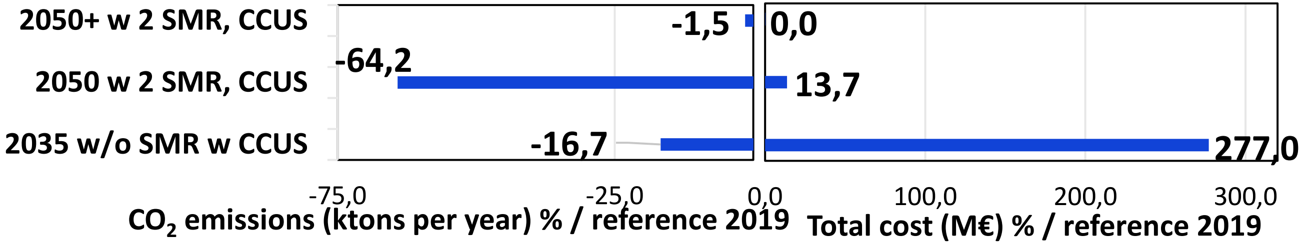
https://tandemproject.eu/wp-content/uploads/2024/06/D3_2_presentation_of_dynamic_techno_economic_analysis_for_each_case_study_V1.pdf

Application to the Energy Hub case
2. Sensitivity studies

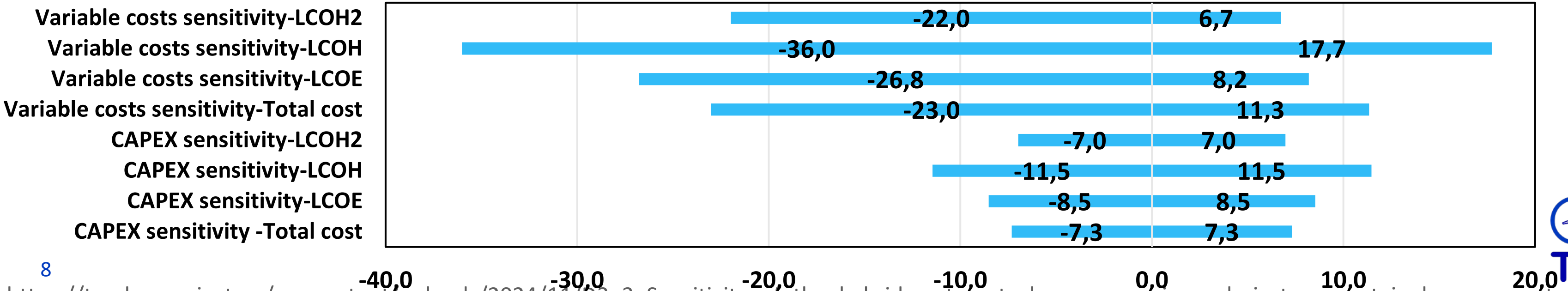
- **Sensitivity to CH4 price**





→ **The less dependent to natural gas the system is, the more robust the results are in terms of LCOE and $LCOH_2$**

- **SMR main parameters (CAPEX, variable costs, …)**



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https://tandemproject.eu/wp-content/uploads/2024/11/D3_3_Sensitivity_of_the_hybrid_system_techno_economic_analysis_to_uncertain_key_parameters_V1_V1.pdf

Application to the Energy Hub case
3. Check feasibility

- **Soft-linking:**

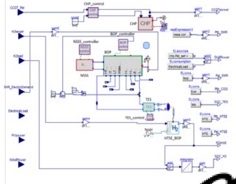
1) Make consistent the DAEs models and the MILP models

2) Check that the operation is feasible over 1 week, 1 year with a relevant timestep

→ Showed that a stronger coupling is relevant in this case

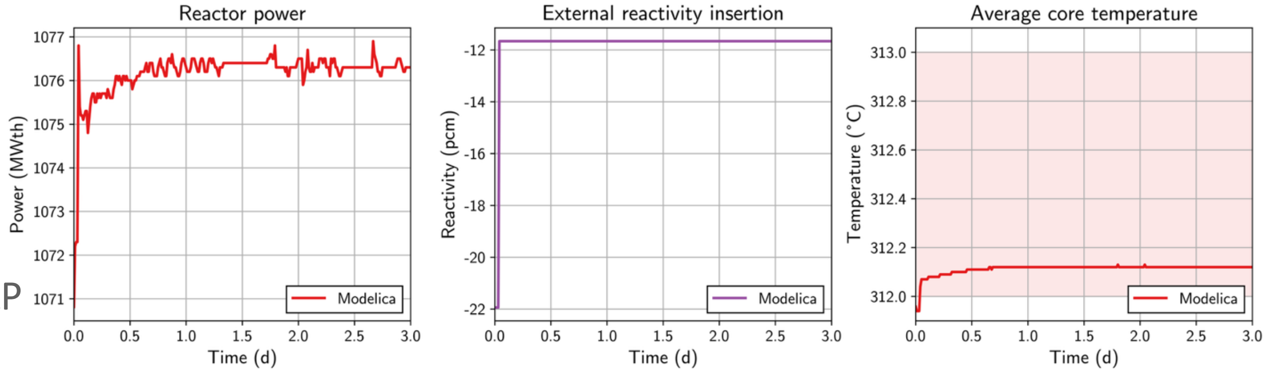
- **Hard-linking:**

Directly operate the DAEs models using setpoints provided by the MILP models that take into account return states from the DAEs models



Application to the Energy Hub case
3. Check feasibility

- **Results**
  - Allows to access to finer technical results
  - Identify possible mismatches between MILP models and DAEs models
  - See the impacts of non perfect foresight of the future



Variable	Unit	Hard-linked	Soft-linked
CCGT electrical energy	GWhel	398	371
Discounted emissions	ktons	4064	3820
Discounted Net OPEX	bm€	1.05	1.07
Total costs	bm€	3.668	3.689

Updated KPIs

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https://tandemproject.eu/wp-content/uploads/2025/06/D3_4_assessment_of_the_control_and_flexibility_constraints_on_system_components_by_thehybrid_system_simulator_coupled_with_an_optimizer.pdf

Application to one District Heating case
1. Modelling framework

- Generic energy network optimization tool
- Can model a large range of energy system features, including but not limited to
  - Generation, storages, transmission, and conversion between energy carriers,
  - operation and investments,
  - Energy, emissions, materials, and costs,
  - forecasts and reserves,
  - hydro power reservoirs, cascades, and delays,
- Designed to be highly adaptable in different dimensions: temporal, spatial, technology representation and market design.

Backbone

Examples of application

- Multi-sector studies: power, district heating, transport, buildings, and industry,
- Electricity distribution grids,
- Building thermodynamic properties and heating
- Multi-objective optimization
- Biomass supply model
- Power To X and carbon economy
- Life Cycle Assessment emissions
- **Studying SMR integration to District heating and power grids**

Backbone is open-source and can be downloaded from https://gitlab.vtt.fi/backbone/backbone/

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Application to one District Heating case
2. Method

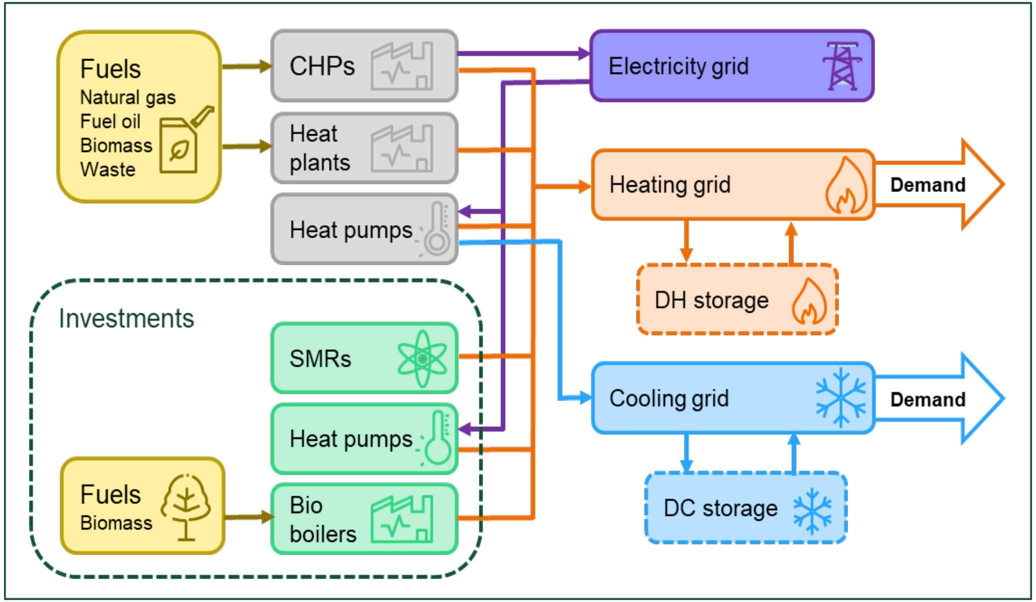
Figure shows a simplified structure of a city-level District heating (DH) and district cooling (DC) energy system model

Model can be used to study

- Analysis of the current systems
- Estimating the development
- Studying policies and new technologies
- **Comparing investment options**

In this project, we model

- 2030's system of Helsinki + Espoo + Vantaa
- No SMR (baseline), E-SMR, LDR-50



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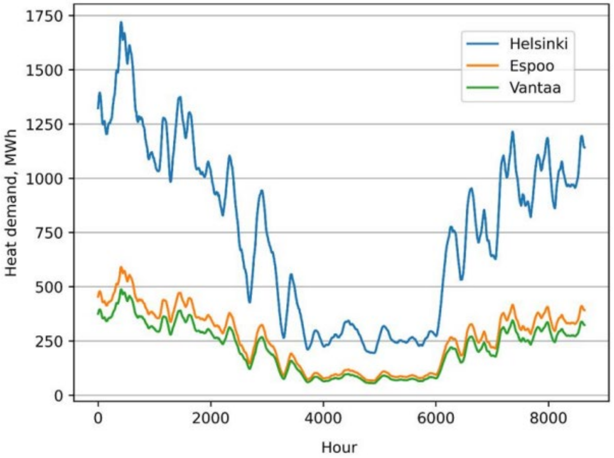
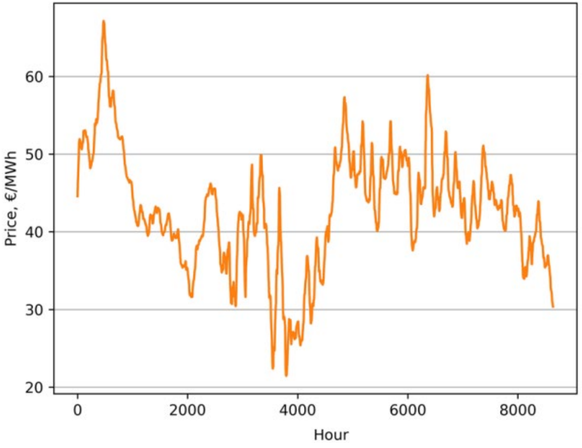
Application to one District Heating case
3. Case study system

Helsinki has up to 10x district heating demand in Winter compared to Summer baseload



Finland has one of the cheapest electricity prices (grid price, producer income) in Europe



Helsinki, Espoo, and Vantaa already have decarbonization plans based on heat pumps, biomass, heat storages, and electric boilers.

<u>SMRs need to be profitable additional investments</u>

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Application to one District Heating case
4. Results

Both investment candidates (E-SMR, LDR-50) had similar results on following:

- Technically feasible options for district heating grids
- Reduce a major share of remaining fossil fuels
- Replace other generation capacity and thus e.g. reduce the consumption of electricity and biomass
- Diversify production portfolio, which is important from the energy and economic security reasons

But differed in following aspects:

- E-SMR significantly improved the electricity balance of the cities
- E-SMR investment costs were too high, and it was relatively far from being a profitable investment for a district heating operator in Finland.
- LDR50 investment costs were more acceptable, and the investment still seemed profitable despite other ongoing low-carbon investments by the cities.

https://tandemproject.eu/wp-content/uploads/2024/06/D3_2_presentation_of_dynamic_techno_economic_analysis_for_each_case_study_V1.pdf

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Application to one District Heating case
5. Sensitivity studies, LDR-50

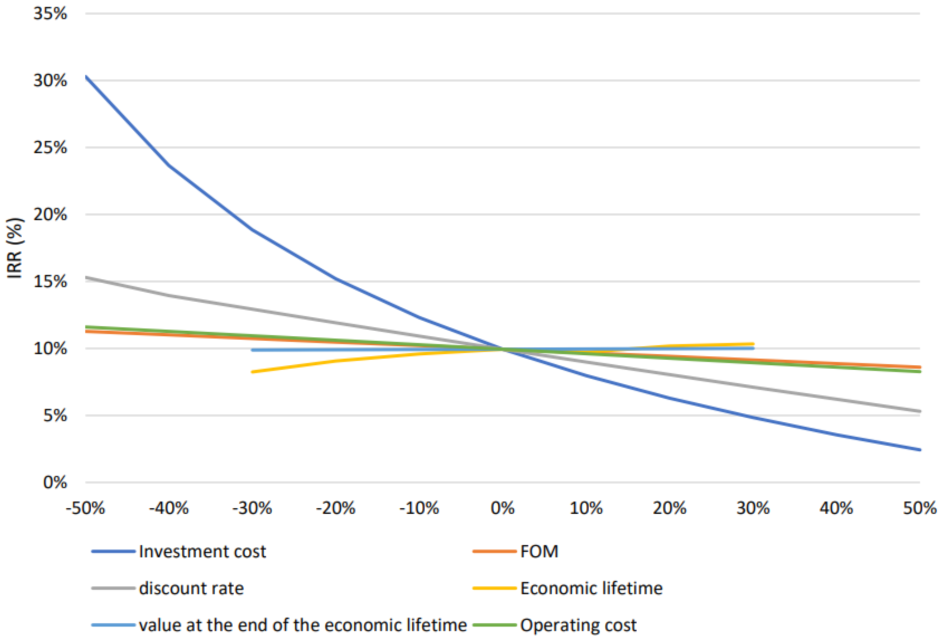

Figure 7: Sensitivity analyses related to LDR-50 economic assumptions.

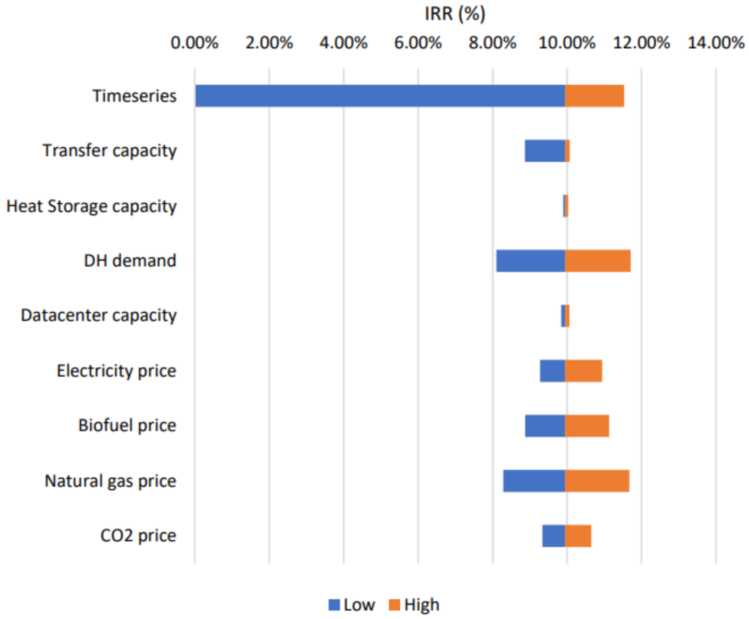

Figure 11: Sensitivity analyses to technological and economic factors for LDR-50.

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Application to one District Heating case
5. Sensitivity studies, E-SMR

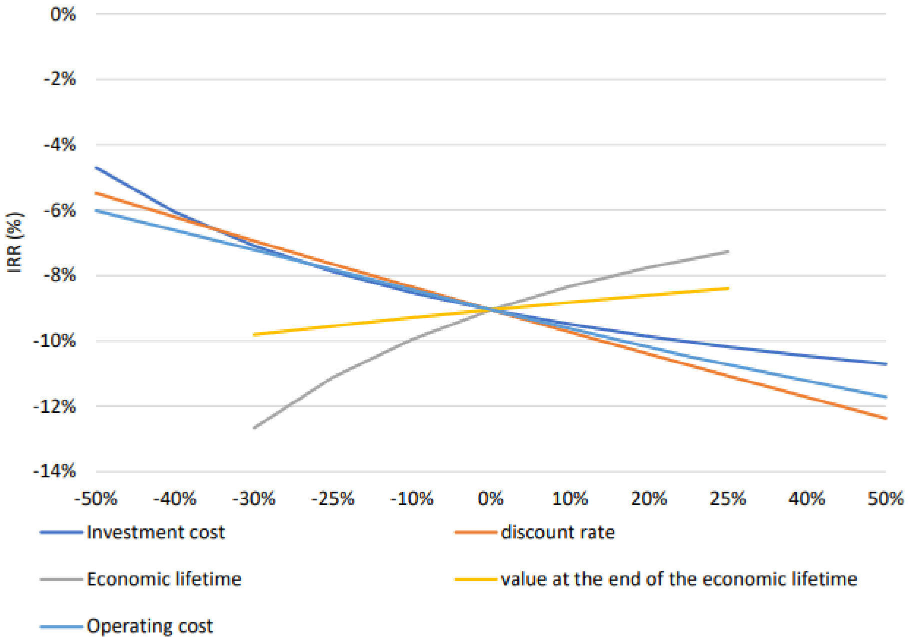

Figure 6: Sensitivity analyses related to E-SMR economic assumptions.

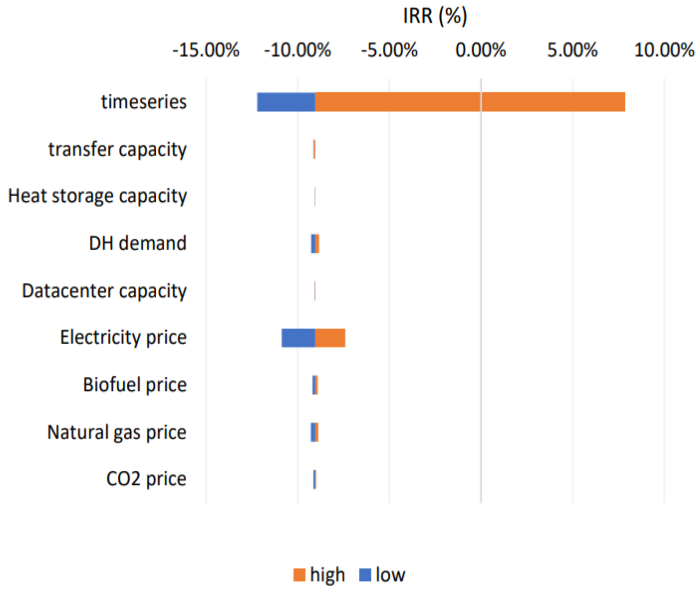

Figure 12: Sensitivity analyses to technological and economic factors of E-SMR.

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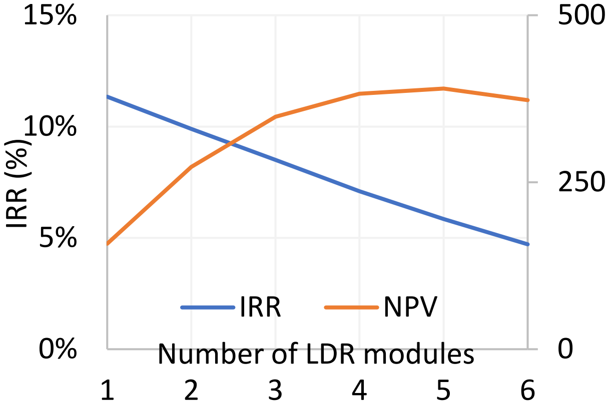
Conclusion

Northern European case

From a DH operator's viewpoint

LDR50 suits more



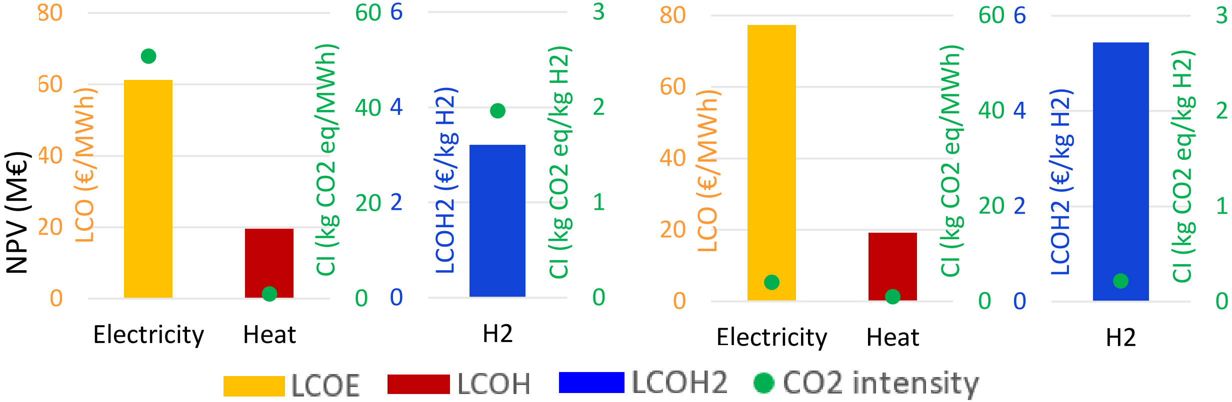
Technical characteristics of SMR must be in line with the addressed market

Southern European case

Central European case

From the viewpoint of a design office commissioned for decarbonisation studies

2050 results → showed the interest of integrating E-SMR into HES



- Mean SPOT price = 97 €/MWh_e (France, 2023)
- Mean CO_2 intensity = 56 kg CO_2 eq/MWh_e (France, 2023)
- Mean $LCOH_2$ in 2022 = 6 €/kg H_2 (Europe, 2022)[1]

[1]European Hydrogen Observatory, «The European hydrogen market landscape», 2022

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Conclusion & Perspectives

- The 3 study cases of TANDEM **showed the interest of integrate SMR into HES** even if the technical and economic characteristics must be in line with the addressed market

- TANDEM provided **open source** tools & methodologies to study the integration of SMR into HES
- TANDEM provided **public** deliverables & data and assumptions for 3 study cases
- Some points could thus be **studied further**:
    - Conduct other sensitivity studies
    - Play with the flexible operation of the E-SMR
    - In terms of methodologies, define and use new KPIs to account for the flexibility offered by controllable energy sources such as SMR

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