Integrated planning of multi-energy systems

HEXAGON Workshop, Bergamo, June 20th 2024

OPTIT optimal solutions

Company Profile

Founded as Spin-off of the Alma Mater Università di Bologna (Operations Research and Management Science).

We design, develop and provide Solutions and Services based on Advanced Analytics, AI and Optimization

We integrate the talent of highly skilled Data Scientists, Business Consultants and SW Development Engineers to support our Customers and Partners in their Digital Innovation roadmap

We enable efficiency and effectiveness for medium and large enterprises in several industries (Energy, Waste, Logistics, Retail), unlocking exceptional returns on investments (ROI)

Bologna: Consultancy Services and Head Quarter

Cesena: Software Factory

New York: Commercial Office (Optit Corp HQ) optimal solutions

Our approach

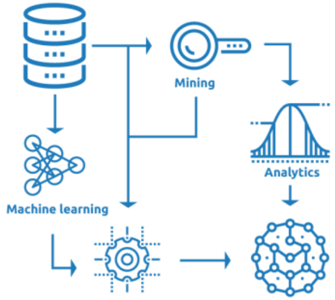
BUSINESS ISSUE

We support analysis and evaluation of the **business issue**, to focus on maximizing the **value** of our approach

DATA MANAGEMENT

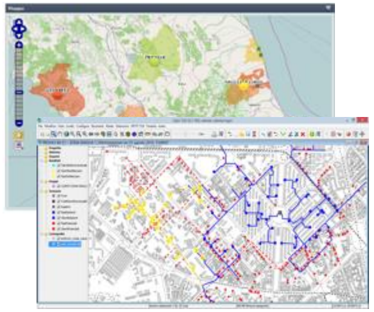
Our scientists analyze your (even big) **data** in order to extract **insights**, answer questions and develop innovative **ideas**

MODELLING, ANALYTICS AND OPTIMIZATION



We use tools and techniques of data **mining, machine & deep learning**, **optimization** to design and develop the best Digital Solution for your needs

SOLUTIONS



We develop, deploy and provide **SW tools and services**, from custom APIs to large Enterprise Applications, to ensure **optimization** is integrated in the business processes

CONSULTING & SERVICE MANAGEMENT

We manage **Software as a Service**, manage Application and Evolutionary **Maintenance**, provide AI-powered **Consulting**

Our target markets

ENERGY

CHCP Systems' Generation Management

DHC Operations and Development Optimization

DHC Network Maintenance Planning

INDUSTRY & SERVICES

Digital Innovation support (industry 4.0)

Process Workflow Digitalization

Optimized Scheduling

Customized Decision Support Services

ANALYTICS & OPTIMIZATION

Advanced & Customized Models And Algorithms

Business Intelligence

Machine Learning And Data Science

Data Mining

LOGISTICS & SUPPLY CHAIN

Distributive Logistics

Network Design

3-2d Bin Packing

Workforce Strategic Placement

Fleet Track & Tracing

WASTE

Collection Services

On Demand Logistics

Waste Supply Chain

Waste Asset Allocation

Strategic Support Services

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A comprehensive Value Proposition in the District Energy

GENERATION

DSS for Production Optimization

EBITDA **Optimization**

H/C/P demand **forecasts**

Budget Planning and What-if

Process **Automation**

DISTRIBUTION

DSS for Network development

Investment Optimization (NPV)

Decision Integration

Advanced **thermo-hydraulic model**

Partner Danfoss for real time simulation

CONSUMPTION

Advanced Analytics

Heat Consumption **patterns** & **profiling**

Users **clusters** identification

Operations enhancements

Chair — DHC+ Technology Platform

Member — AIRU; International District Energy Association

Co-founder — IrDEA Irish District Energy Association

Digital Innovation Partner — Gruppo HERA; conEdison; a2a calore e servizi; ADR Aeroporti di Roma

EU projects — upgrade DH; PlaMES; Retrofeed; Tuples

Partner — IEA DHC

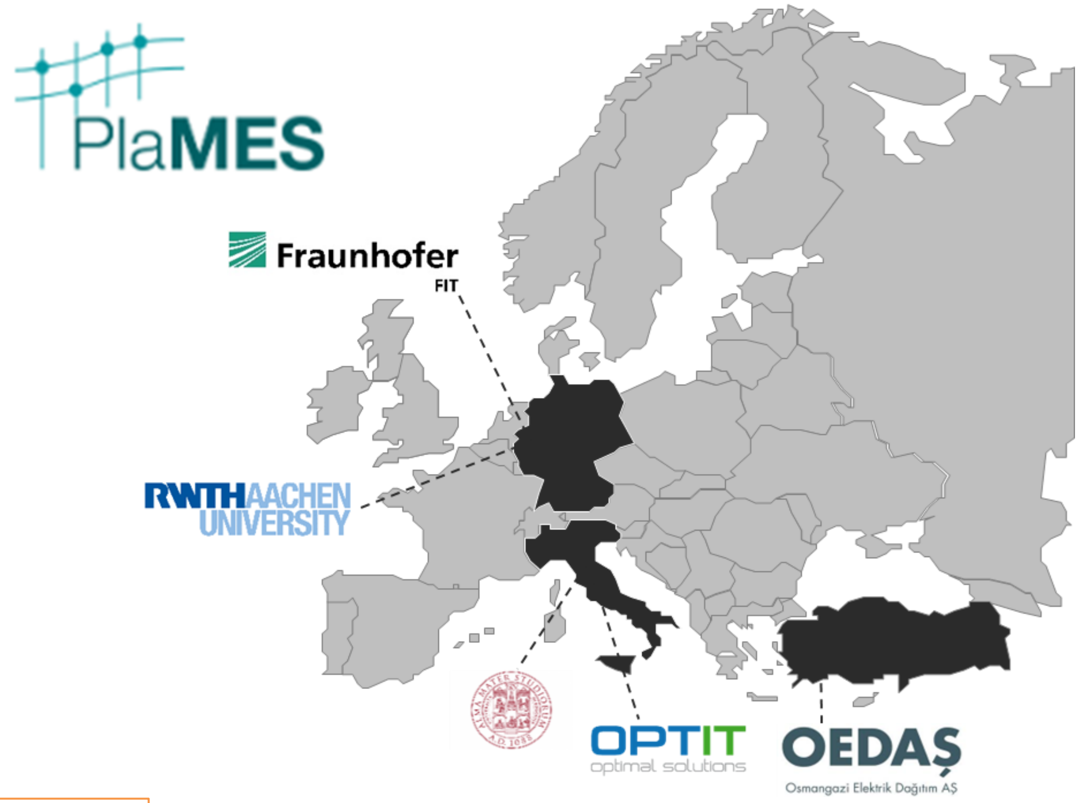
Large-scale energy planning

- Develop a **decision support tool**
- Design of the energy systems of the future, **both at generation & infrastructure levels** to achieve **decarbonization targets**
- **Integrating** the electricity, heat, gas and mobility sectors (exploiting **synergies and flexibilitie**s)
- Main Targets:
  - European and National System planners
  - System Operators (TSOs & DSOs)
  - Multi-utilities
- Looking at **2040 and beyond**

PlaMES Project (2019-2022)

Integrated Planning of Multi-Energy Systems

- Horizon 2020 project
- Design of efficient transition paths for future energy systems at both generation and grid level
- Achieve synergies and flexibility between electricity, heat, and gas
- Support system planners, regulators, national authorities, utility companies, TSOs and DSOs
- Two use cases: Germany transmission grid and Bilecik (Turkey) distribution grid



Final TRL: 5-6

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 863922.

Integrated Planning of Multi-Energy Systems

- Regional funded
- Spinoff of the PlaMES project
- Development of further supply and grid models in the sector integration context
- Improve flexibility and integrability of supply and grid models
- Development of an web application integrated with the new models

Final TRL: 7-8

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
CENTRO INTERDIPARTIMENTALE DI RICERCA INDUSTRIALE ICT

Anibal Baradei's work was funded by an Industrial Doctoral grant of University of Pisa co-funded by OPTIT s.r.l. according to MUR decree 352/2022 and University decree 22-39. The development of the software tool was funded by the POR-FESR EMILIA ROMAGNA 2021-2027, Action 1.1.1 with grant number PG/2023/190614.

OptiMES Dashboard

Geographical filters

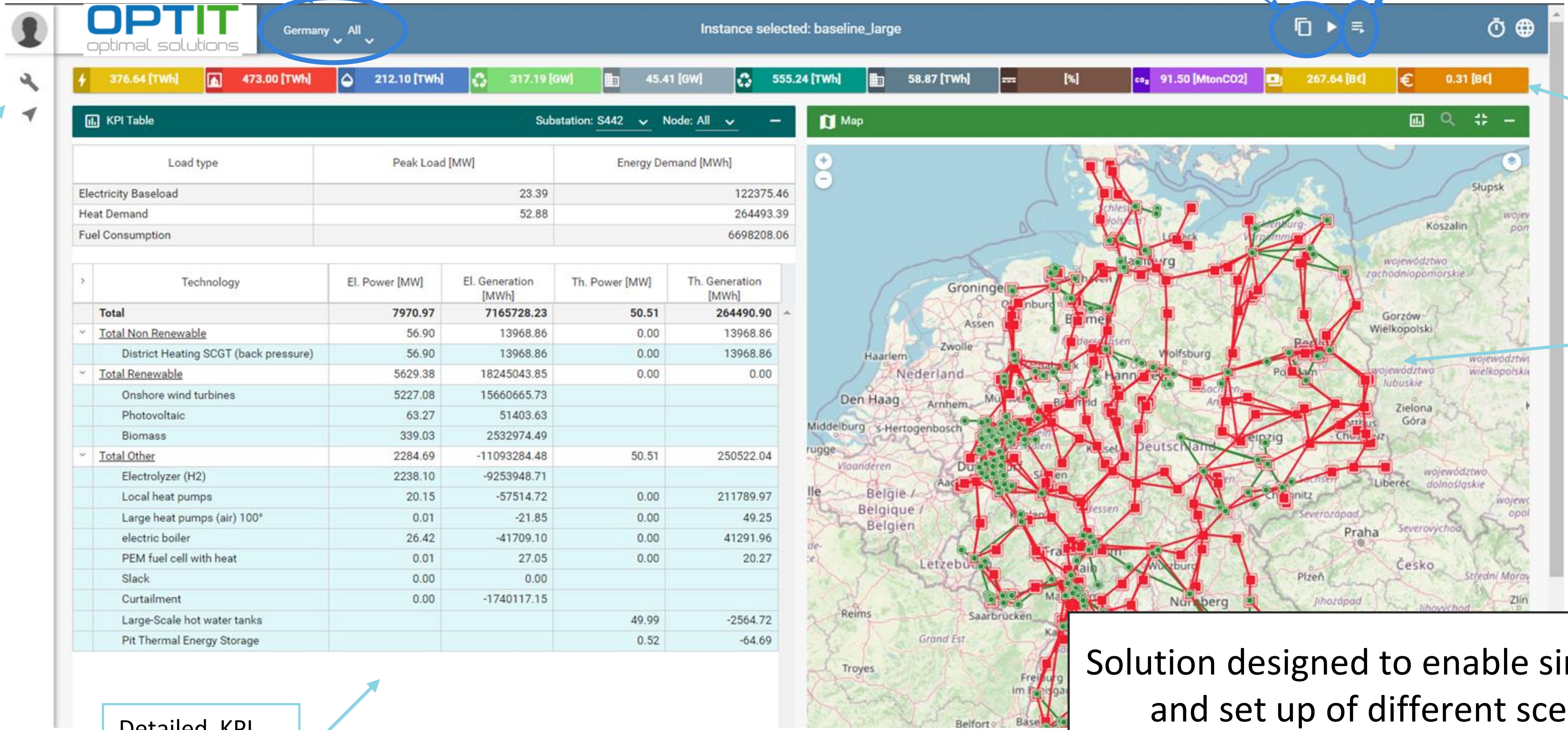
Model Management and run process

Scenario Management

Tool settings

Global scenario results KPIs

Grid map for an simplified navigation



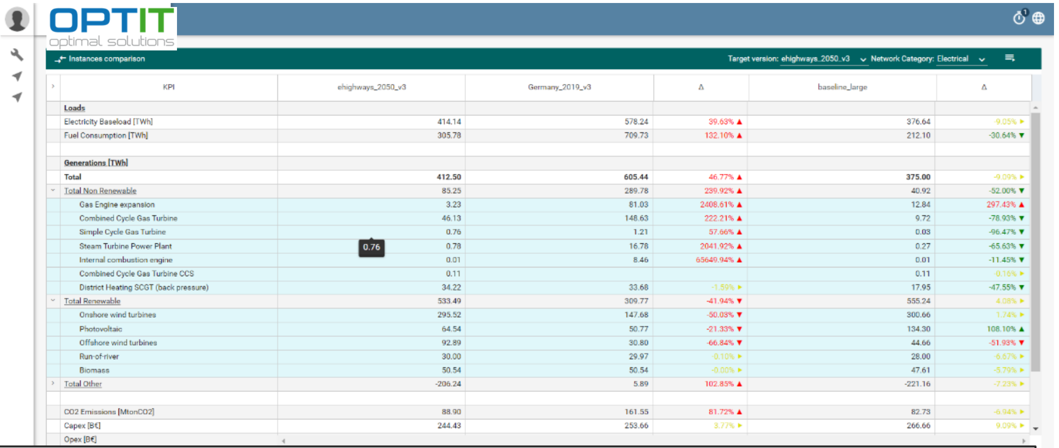
Load type	Peak Load [MW]	Energy Demand [MWh]
Electricity Baseload	23.39	122375.46
Heat Demand	52.88	264493.39
Fuel Consumption		6698208.06

Technology	El. Power [MW]	El. Generation [MWh]	Th. Power [MW]	Th. Generation [MWh]
Total	7970.97	7165728.23	50.51	264490.90
Total Non Renewable	56.90	13968.86	0.00	13968.86
District Heating SCGT (back pressure)	56.90	13968.86	0.00	13968.86
Total Renewable	5629.38	18245043.85	0.00	0.00
Onshore wind turbines	5227.08	15660665.73		
Photovoltaic	63.27	51403.63		
Biomass	339.03	2532974.49		
Total Other	2284.69	-11093284.48	50.51	250522.04
Electrolyzer (H2)	2238.10	-9253948.71		
Local heat pumps	20.15	-57514.72	0.00	211789.97
Large heat pumps (air) 100°	0.01	-21.85	0.00	49.25
electric boiler	26.42	-41709.10	0.00	41291.96
PEM fuel cell with heat	0.01	27.05	0.00	20.27
Slack	0.00	0.00		
Curtailment	0.00	-1740117.15		
Large-Scale hot water tanks			49.99	-2564.72
Pit Thermal Energy Storage			0.52	-64.69

Detailed KPI Panel of single node

Solution designed to enable simple navigation and set up of different scenarios, with extensive drill down capabilities

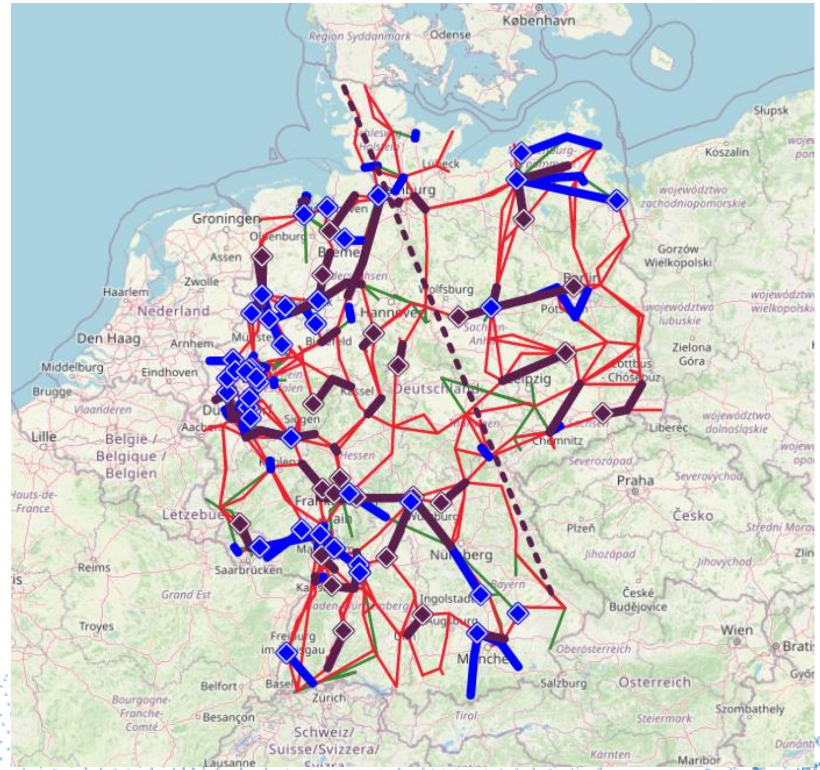
Generation of long-term and Large-scale decarbonization scenarios considering multi energy carriers like electricity, heat and fuels (CH_4, H_2, biomass etc.).

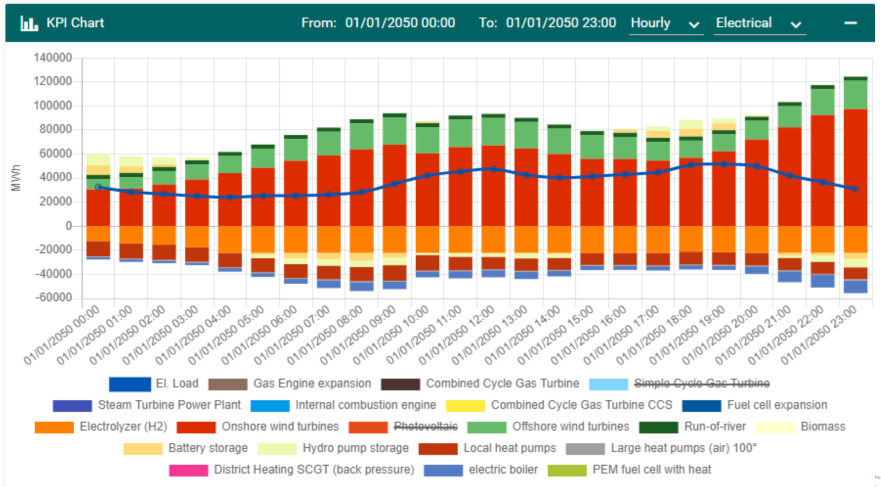


KPI	ehighways_2050_v3	Germany_2019_v3	Δ	baseline_large	Δ
Loads					
Electricity Baseload [TWh]	414.14	578.24	39.63% ▲	376.64	-9.05% ►
Fuel Consumption [TWh]	305.78	709.73	132.10% ▲	212.10	-30.64% ▼
Generations [TWh]					
Total	**412.50**	**605.44**	46.77% ▲	**375.00**	-9.09% ►
Total Non Renewable	85.25	289.78	239.92% ▲	40.92	-52.00% ▼
Gas Engine expansion	3.23	81.03	2408.61% ▲	12.84	297.43% ▲
Combined Cycle Gas Turbine	46.13	148.63	222.21% ▲	9.72	-78.93% ▼
Simple Cycle Gas Turbine	0.76	1.21	57.66% ▲	0.03	-96.47% ▼
Steam Turbine Power Plant	0.78	16.78	2041.92% ▲	0.27	-65.63% ▼
Internal combustion engine	0.01	8.46	65649.94% ▲	0.01	-11.45% ▼
Combined Cycle Gas Turbine CCS	0.11			0.11	0.16% ►
District Heating SCGT (back pressure)	34.22	33.68	-1.59% ►	17.95	-47.55% ▼
Total Renewable	533.49	309.77	-41.94% ▼	555.24	4.08% ►
Onshore wind turbines	295.52	147.68	-50.03% ▼	300.66	1.74% ►
Photovoltaic	64.54	50.77	-21.33% ▼	134.30	108.10% ▲
Offshore wind turbines	92.89	30.80	-66.84% ▼	44.66	-51.93% ▼
Run-of-river	30.00	29.97	-0.10% ►	28.00	-6.67% ►
Biomass	50.54	50.54	-0.00% ►	47.61	-5.79% ►
Total Other	-206.24	5.89	102.85% ▲	-221.16	-7.23% ►
CO2 Emissions [MtonCO2]	88.90	161.55	81.72% ▲	82.73	-6.94% ►
Capex [B€]	244.43	253.66	3.77% ►	266.66	9.09% ►
Opex [B€]					

Comparison of multiple scenarios (volumes and costs) for heat and electricity systems

Thematic maps and graphic features highlight results interpretation





MULTI-ENERGY GENERATION AND NETWORK EXPANSION OPTIMIZER

Baradei Anibal

OBJECTIVE

Create an optimization model for large-scale, high-level decision making towards system decarbonization.

Energy systems are comprised of a multitude of interdependent systems that can be:

- Linear (rarely)
- Non-linear
- Deterministic
- Stochastic
- Chaotic

SCOPE

Scope and model fidelity, the“short blanket” problem:

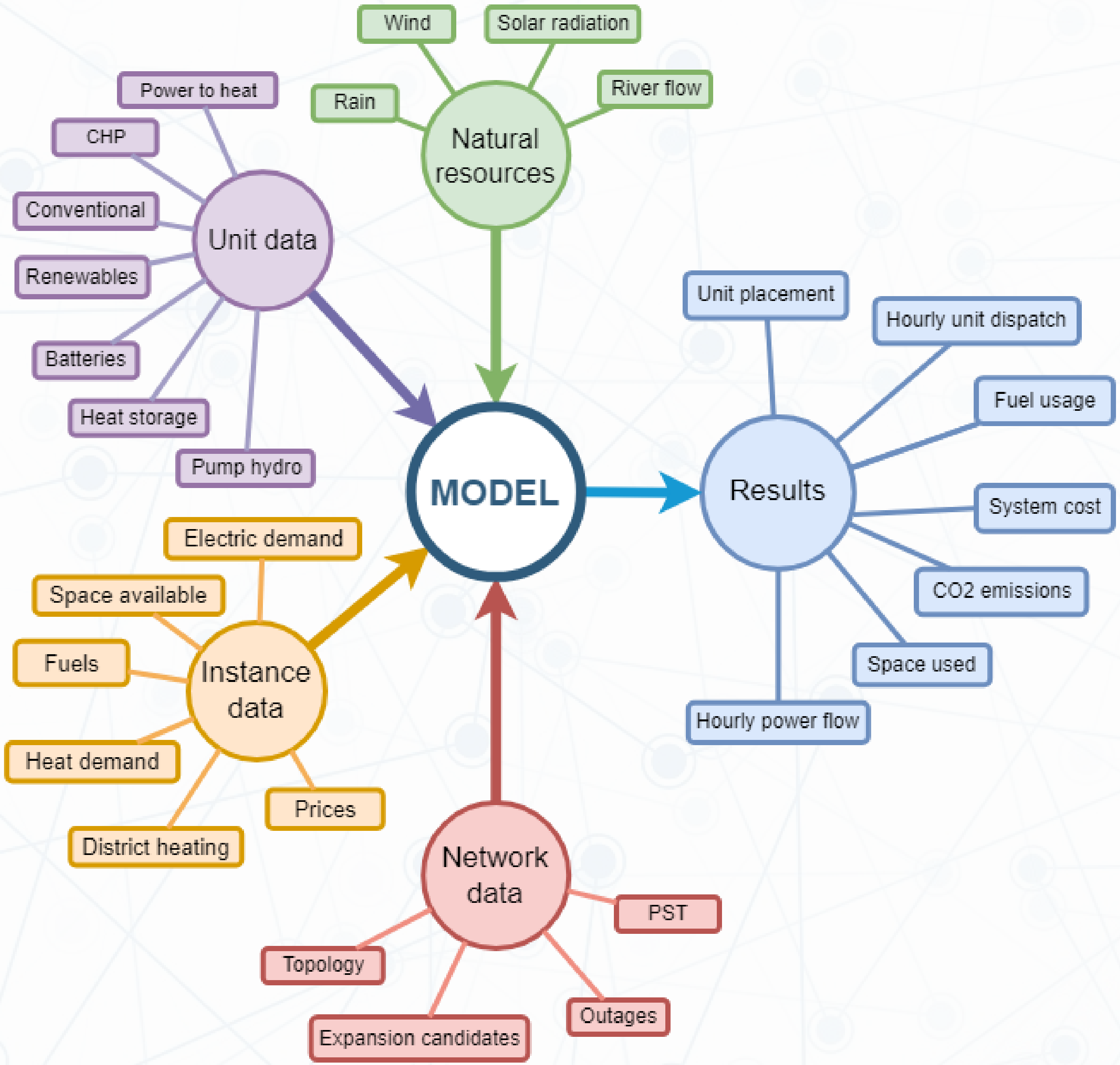
- High model fidelity
  - Non-linear formulations
  - Small timesteps (minutes/hours)
- Small scope
  - Less integrated systems
  - Short time period
  - Reduced geographical area

- Low model fidelity
  - Linear formulations
  - Large timesteps (hours/months)
- Large scope
  - More integrated systems
  - Long time period
  - Large geographical area

What is the right balance?

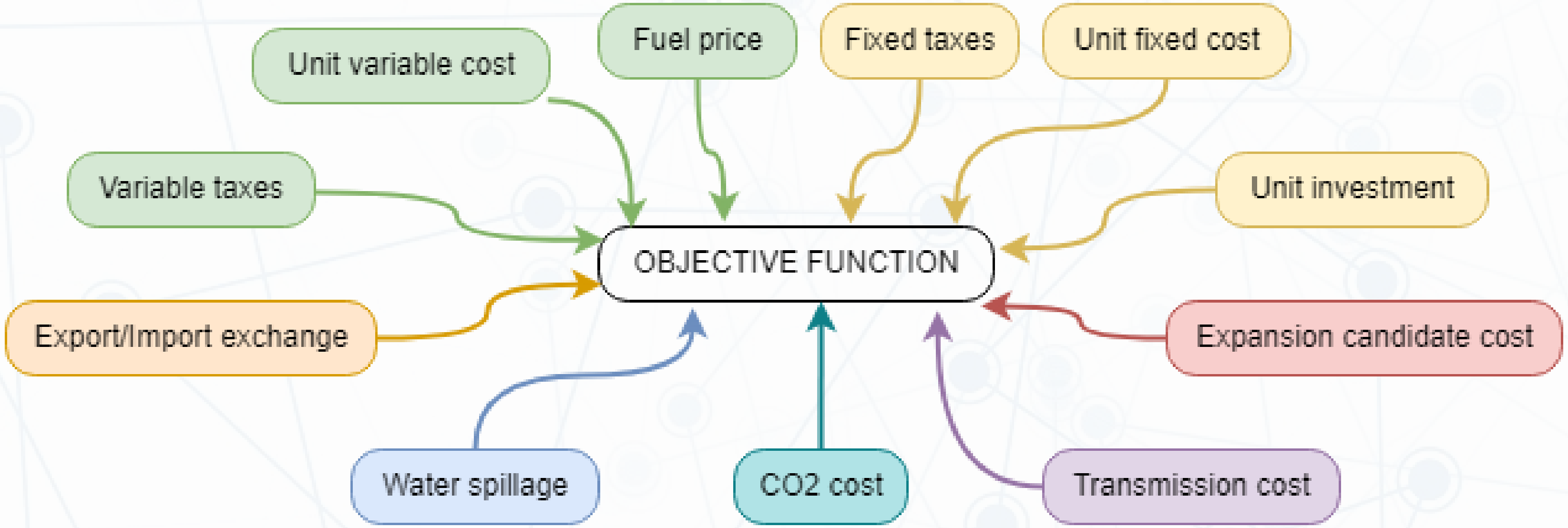
PROBLEM STATEMENT

Modeled as a mixed integer linear program (MILP).



OBJECTIVE FUNCTION

Minimization of the system cost

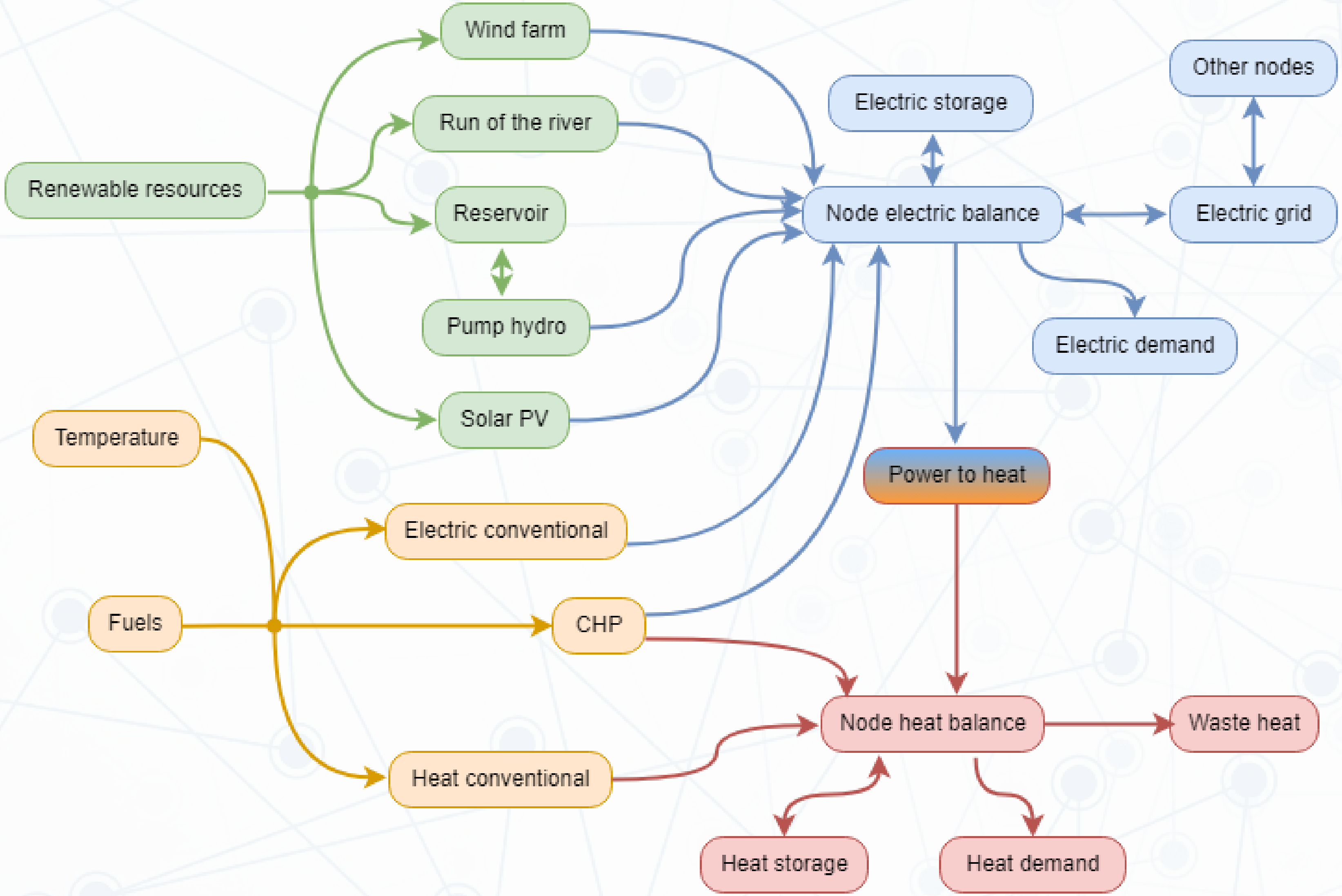


Variable and fixed cost of each unit represent maintenance and other necessities needed for operation. Fixed ones are yearly.

- Modular
  - Further additions
  - Applying changes
  - Selecting necessary parts for each instance
- Computationally lightweight
  - For planning standards
  - Depends on size
  - Minutes to few days
- As accurate as feasibly possible
  - Reach the best accuracy obtainable using linear models
  - Depends on data quality

FEATURES

- Direct Current Power Flow (DCPF)
  - Angle formulation
- Hourly resolution
- Generation expansion
  - Optimal placement of units
  - Linear implementation
- Network expansion
  - Uses binary variables
  - All elements can be declared
- Fuel constraints
  - Multiples fuels can be defined
- Space constraints
  - Geographical limitation per node
- Simplified district heating
  - Affects a defined percentage of the residential demand at each node
- Temperature variable efficiency and output
- Outages
  - Elements can be defined as “open” for a set time



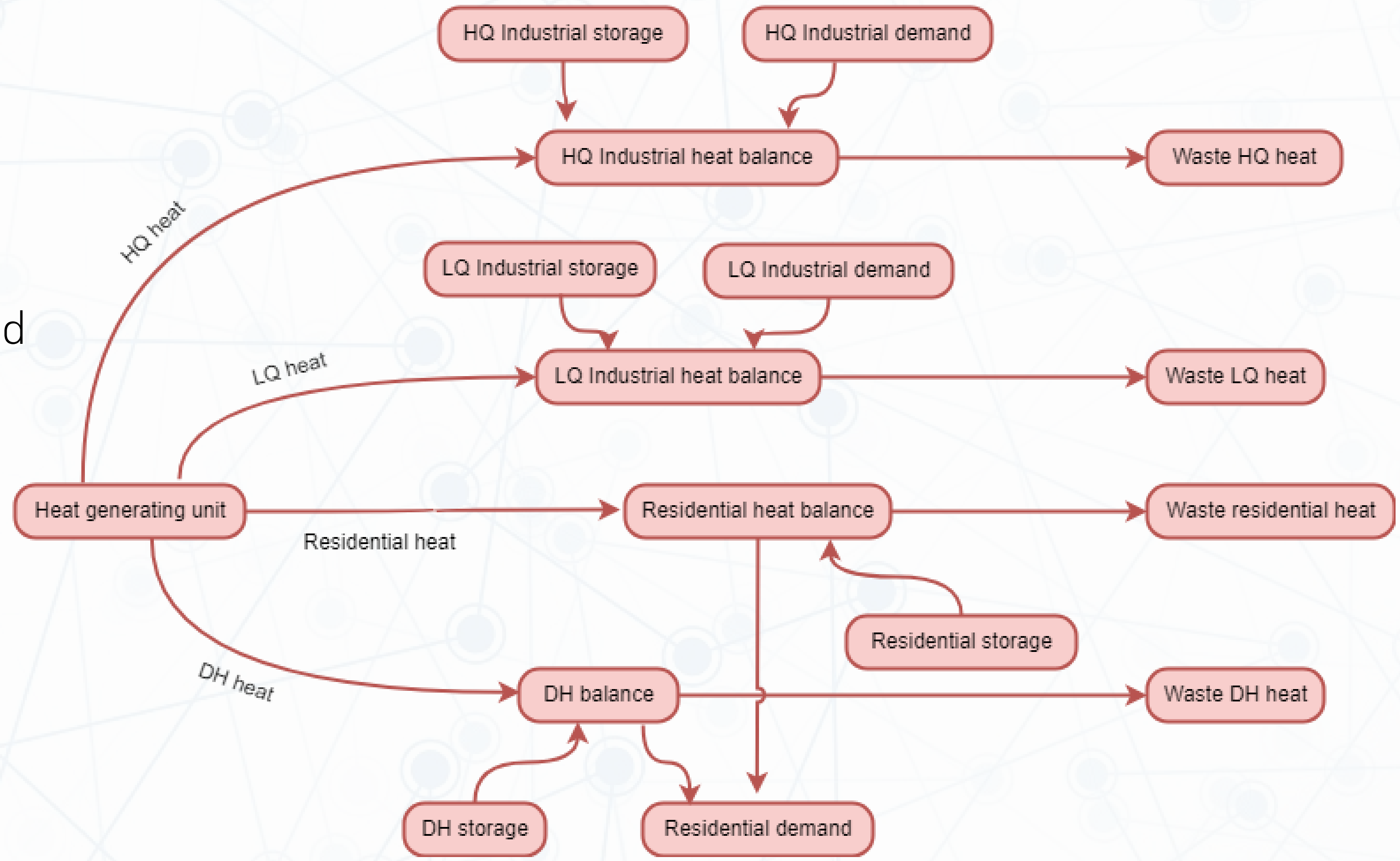
NODE OVERVIEW

- RED: Heat
- ORANGE: Fuels
- BLUE: Electricity
- GREEN: Natural resources

HEAT BALANCE

Each heat generating unit can have any mix of heat categories.

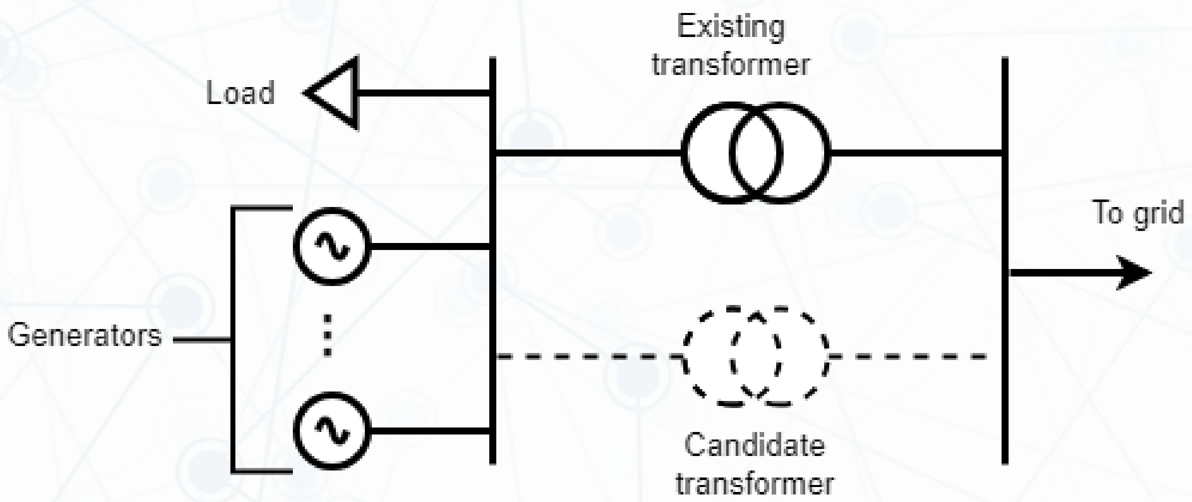
District heating can supply a defined maximum percentage of the residential heat demand



ELECTRIC BALANCE

The result of adding all the generating unit outputs and the load in each node gives the current exchange with the grid.

That exchange is limited by the substation transformer. It can be designed as candidate for expansion.



$$x_{n,t} = \sum_{i \in Iel} g_{n,i,t} - L_{n,t}$$

$$-ST_n < x_{n,t} < ST_n$$

$$-ST_n(1 + un_n) < x_{n,t} < ST_n(1 + un_n)$$

GRID ELEMENTS

The model has the following elements modeled:

- Lines
- Transformers
- Phase shifting transformers
- High voltage DC lines

All models are based on the DCPF formulation, the following is an example of the line (and transformer) model:

$$f_{l,t} = B_l(a_{N,t} - a_{Q,t})$$
$$-FLOW_l^{max} < f_{l,t} < FLOW_l^{max}$$

All elements can be designed as “candidate”, which means a binary variable is created to model the creation of the element and associated cost of installation:

$$-M(1 - u_l) < f_{l,t} - B_l(a_{N,t} - a_{Q,t}) < M(1 - u_l)$$
$$-u_l \cdot FLOW_l^{max} < f_{l,t} < FLOW_l^{max} \cdot u_l$$

Each generation and storage unit is linearly scaled by the model to reach the optimal configuration.

The linearized parameters are modeled using real unit data, and many different machines can be defined under each category (Conventional, Renewable, etc)

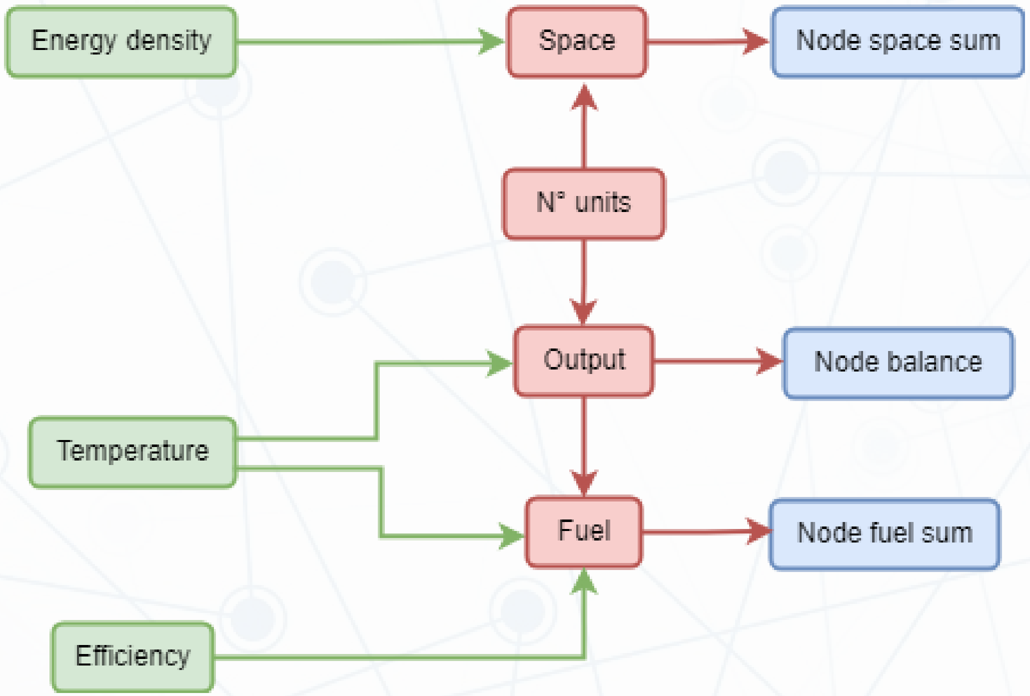
All the elements that refer to units are scaled by the number constructed, costs, space used, etc.

$$0 \leq g_{n,i,t} \leq P_i^{max} \cdot y_{n,i} \qquad 0 \leq soc_{n,i,t} \leq CAP_i \cdot y_{n,i}$$

GENERATION EXPANSION

CONVENTIONAL MODEL

Considered as units that burn fuel to generate electricity or heat.
Temperature affects the efficiency and total available output power.

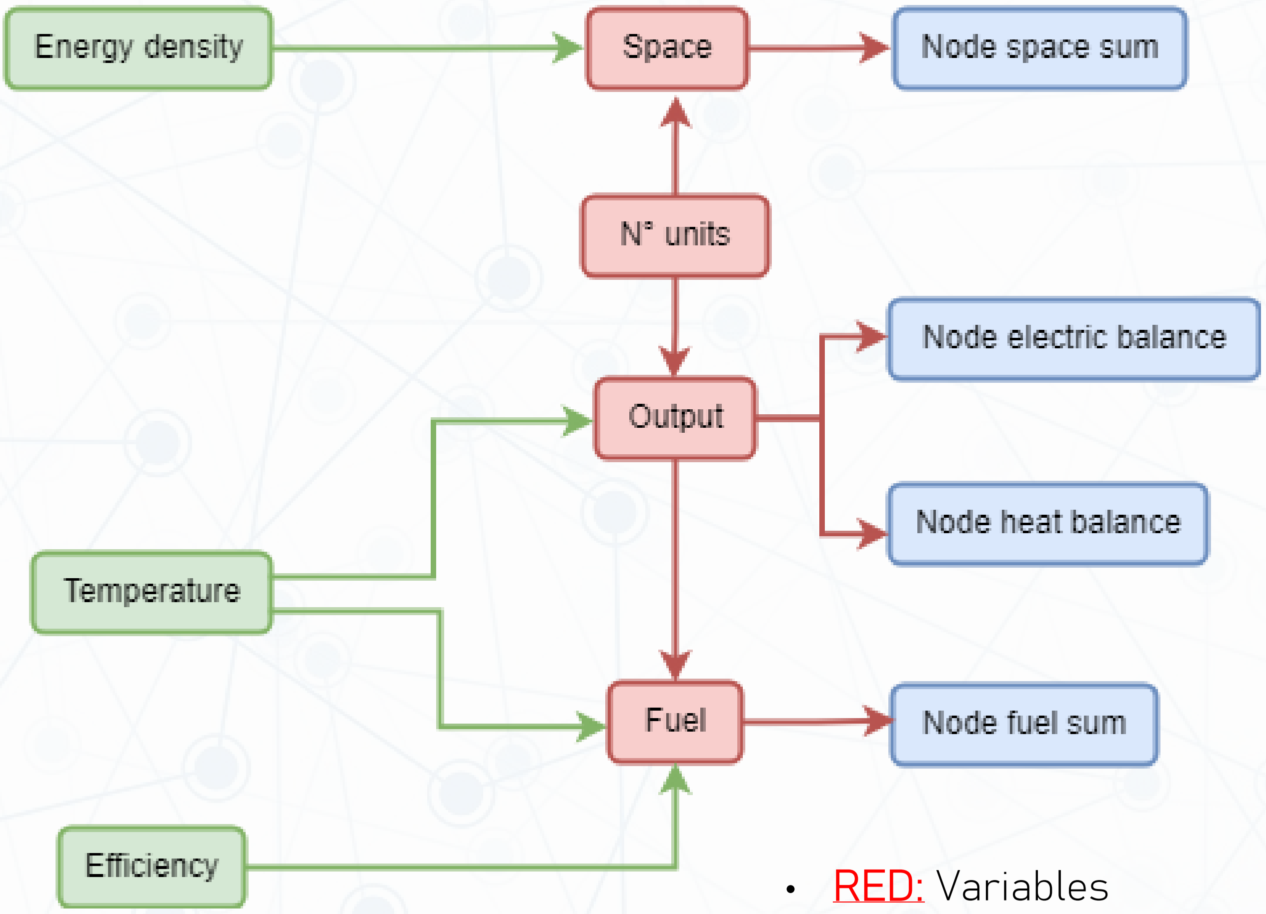


- RED: Variables
- BLUE: Constraints
- GREEN: Parameters

COMBINED HEAT AND POWER

This units produce electric and heat simultaneously. Each output is set at the same setpoint, but maximum output can be individually defined, defined by:

$$g_{n,i,t} \cdot \frac{H_i^{max}}{P_i^{max}}$$



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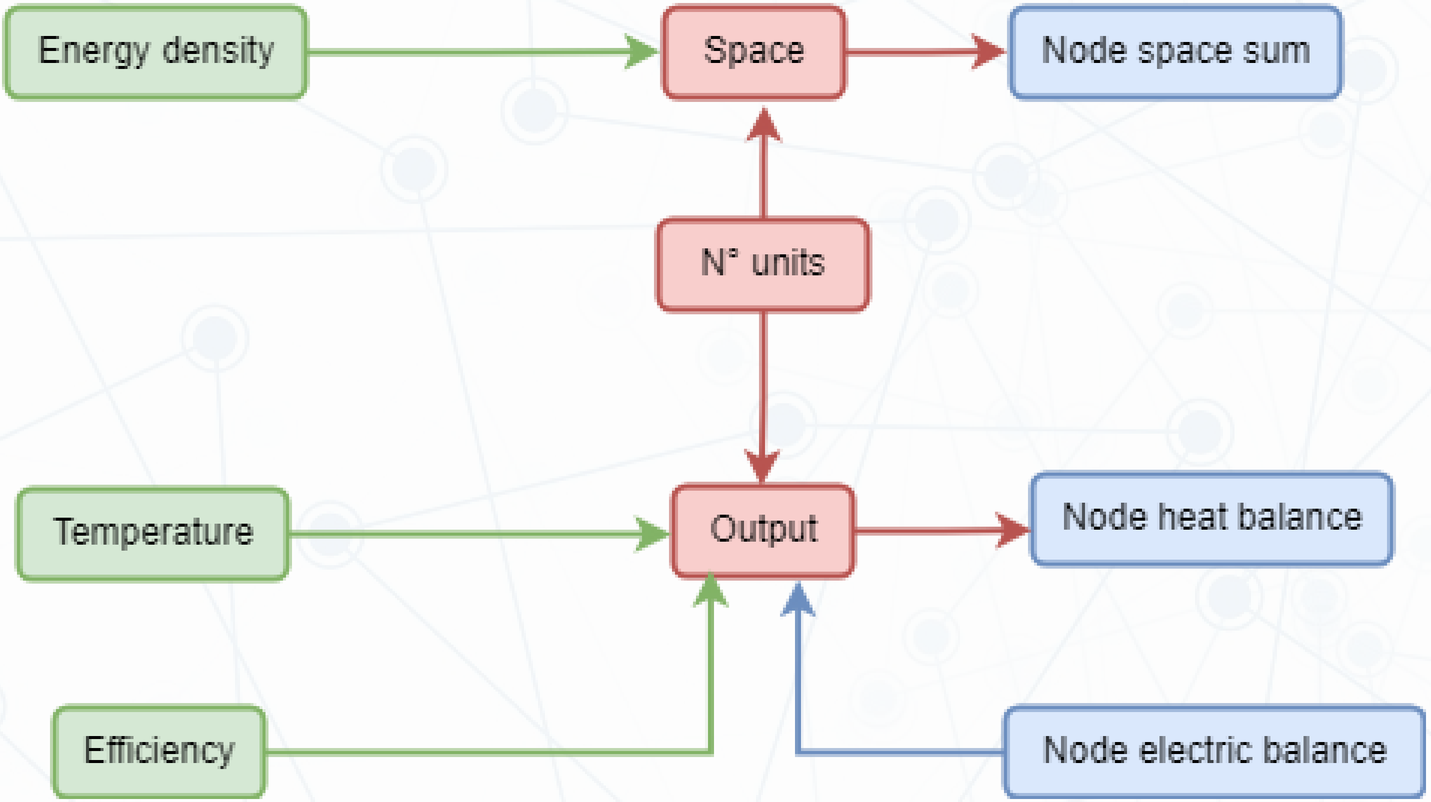
POWER TO HEAT

This technology consumes electric power to generate heat. The link between each is defined by the efficiency:



$$g_{n,i,t} = -\frac{h_{n,i,t}}{EF_i}$$

- RED: Variables
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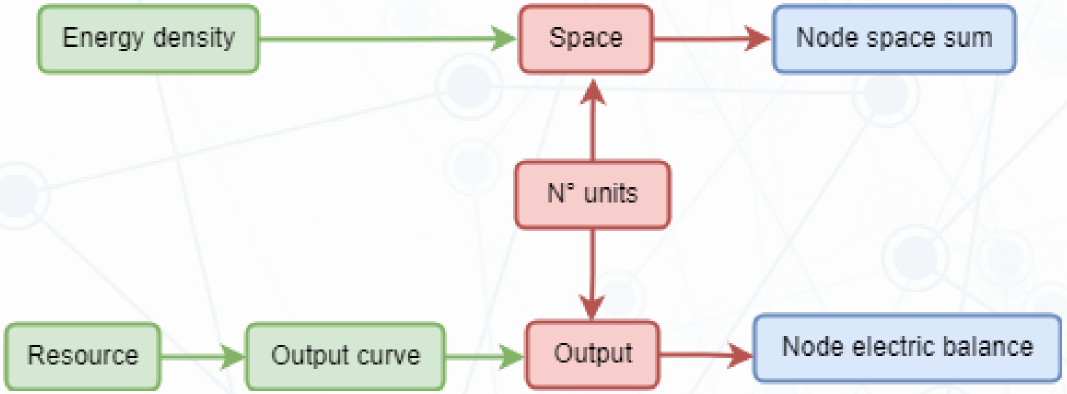
RENEWABLES

This technologies have outputs that depend on the availability of their respective resource, hour by hour. The wind speed, river volumetric flow and solar irradiance is provided for each node and time. The relation between the resource and each output is unique to each technology:



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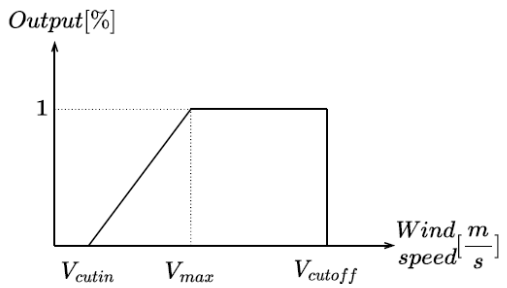
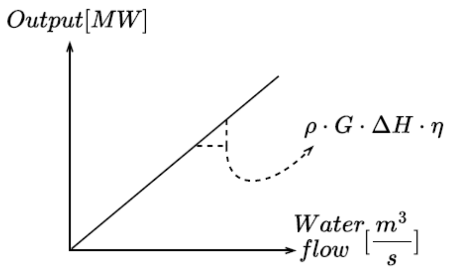
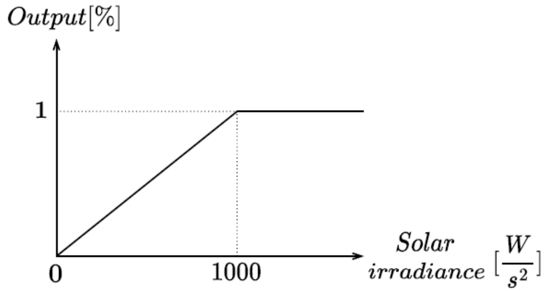
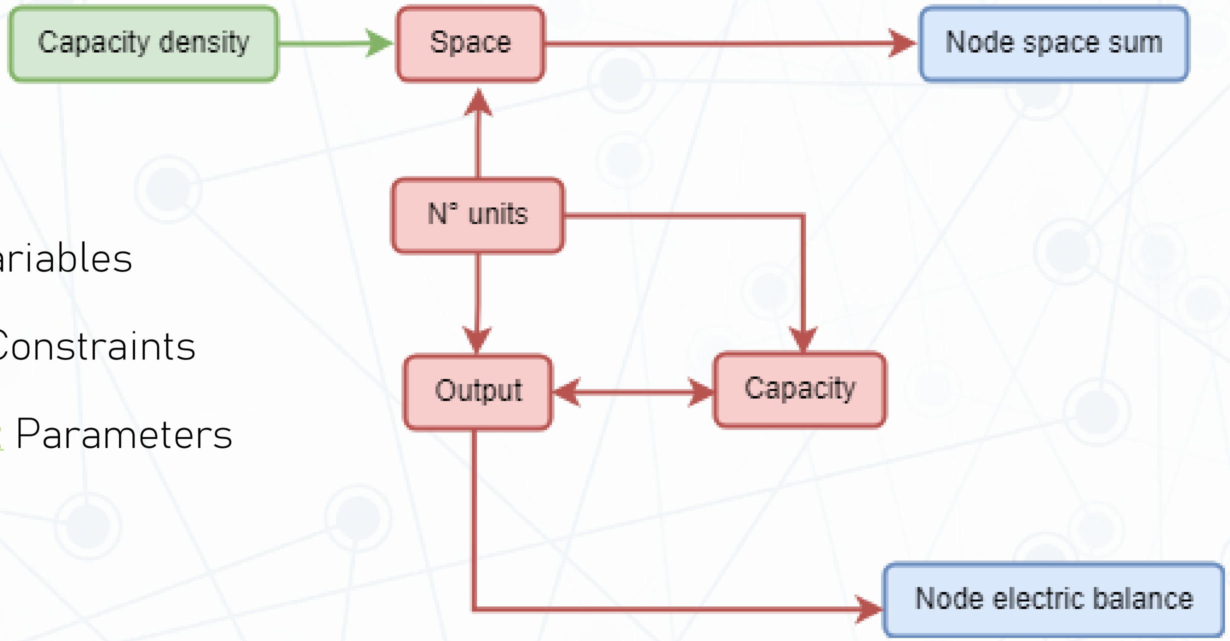






STORAGE

This units can charge or discharge its energy reserve by consuming or outputting power. There are three categories, electric, heat (one for each heat type) and pump hydro. Both the rated output and the capacity are scaled by the number of units.

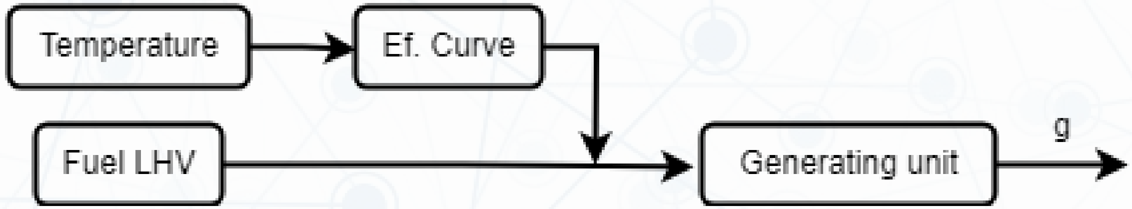


- RED: Variables
- BLUE: Constraints
- GREEN: Parameters

Initial and final storage level can be defined, and their values affect the simulation results.

FUEL

Given the output of the generating unit, the temperature-dependent efficiency and the lower heating value of the fuel, the hourly consumption is calculated with:



$$ci_{n,i,fuel,t} = \frac{g_{n,i,t}}{EF^{th}(TEMP) \cdot LHV_{fuel}}$$

Each node has an hourly fuel constraint per fuel.

SPACE

With the number of machines built and their respective power density, the total space used is calculated.

$$TSP_{n,i} = P_i^{max} \cdot S_i \cdot y_{n,i}$$

$$TS_n = \sum_i TSP_{n,i}$$

All space used by all elements must be within the available terrain in each node

$$0 \leq TS_n \leq S_n^{av}$$

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There are two sources of CO_2 in the model:

- Fuel, each has a defined emission per kg/m3 burnt
- Installation of any unit, each has a defined emission per MW installed

Multiple fuel types and their emission per unit burnt can be defined to study environmental impact.

The CO_2 tax price can be calculated with all the emissions in the system and the tax price.

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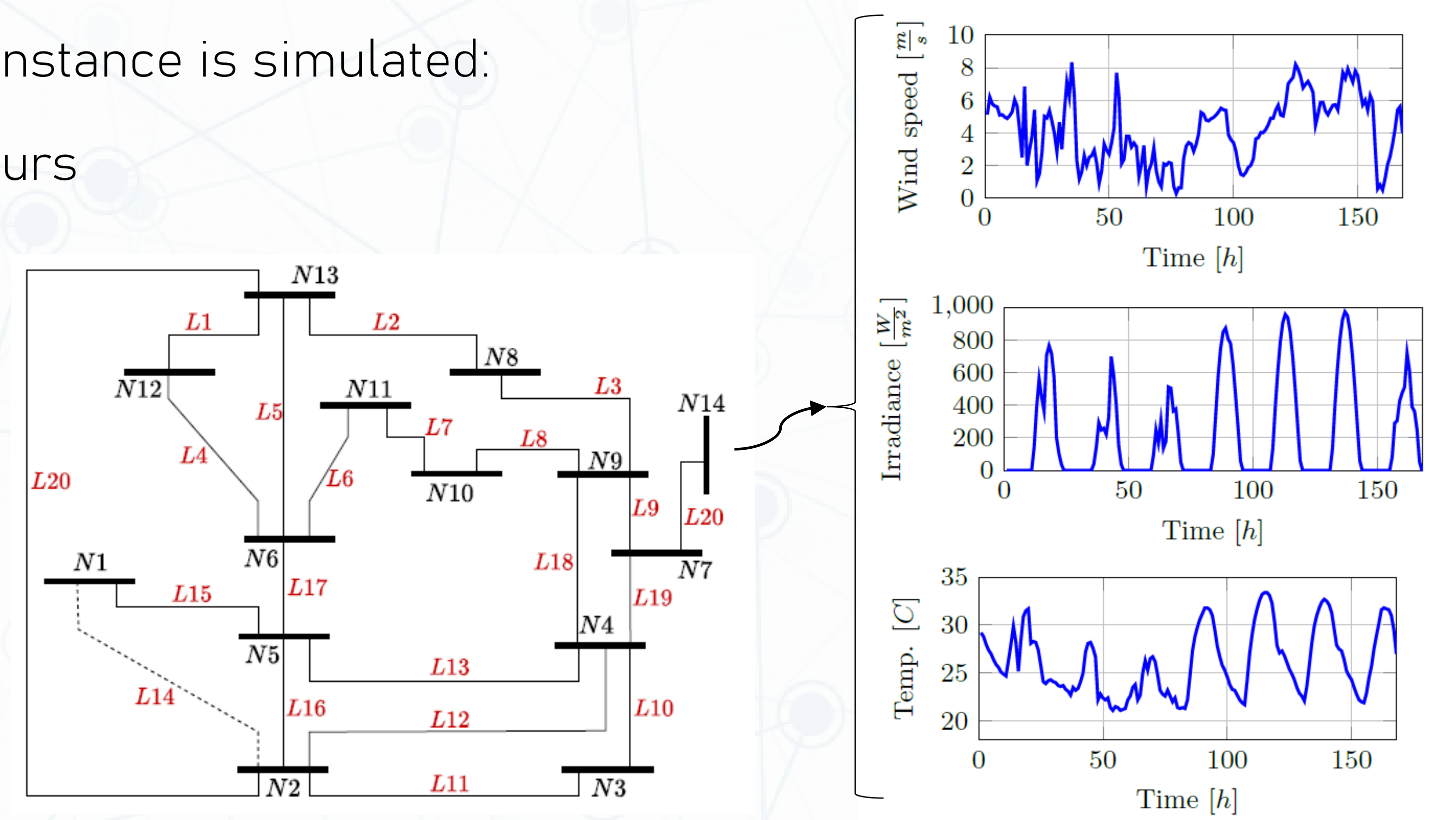
TEST CASE

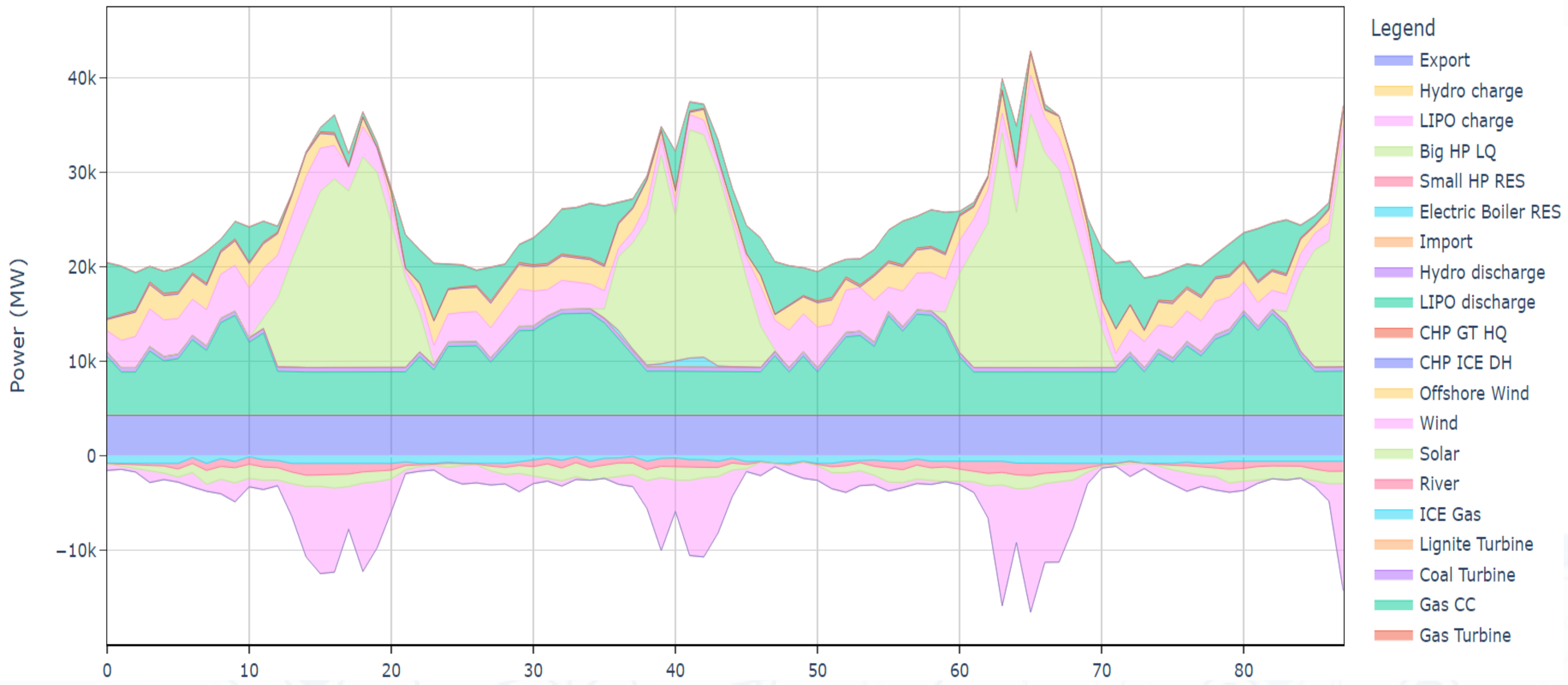
To showcase the model, the following instance is simulated:

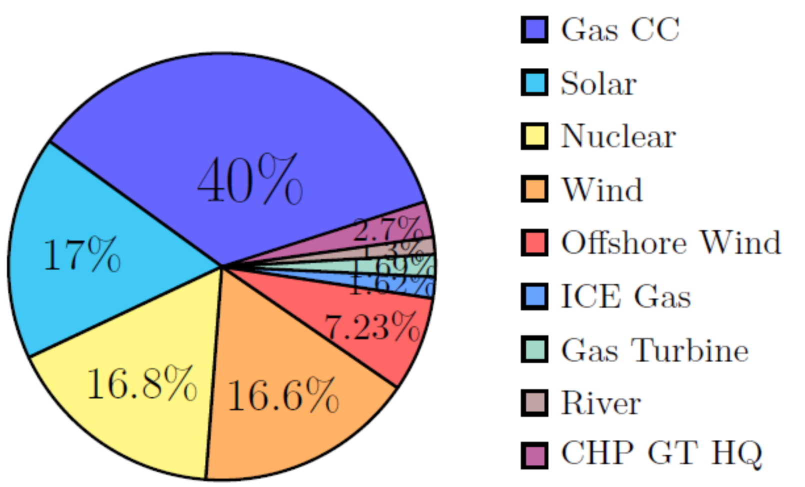
- Simulated time: 150 days or 3600 hours
- 14 nodes
- 21 lines
- 5,175,221 variables
- 23 different technologies
- Virtual data based on real cases
- Solved with Gurobi



RESULTS

The simulation time was 20 minutes, and the total system cost is 12.6 billion euros.





SCALABILITY TEST

This test is performed to check solve times at very large instances. Note that these are extreme cases with no clustering or simplifications:

N	I	T	u	Solve (h)	Variables
14	23	3600	0	0.42	5,175,221
14	23	8760	0	1.02	9,233,433
42	23	3600	0	2.21	11,377,177
42	13	8760	0	6.01	17,012,593
42	23	8760	0	10.0	27,682,777
42	13	8760	1	35.3	17,012,593

CONCLUSION

From the test results the following conclusions were drawn:

- The model gives reasonable and coherent results for all the instances
- Solve times are acceptable given the problem size
- Small changes in the parameters have proportionally small impact on the objective function, but may have different unit configuration in some nodes
- Instance size in terms of nodes and technologies can be increased with a time tradeoff, reducing considered time, clustering or representative days.

Next planned steps

- Finalize the **OptiMES** web application and its adaptation to the latest version of the model
- **OptiMES** will be validated by the end of this year…
  - on the **Germany** use case from the Plames project
  - on a **Ireland** use case that will be provided by Prof. Paul Dean (University College Cork)
- 2025: Start the **commercial campaign**

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