OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

FINAL WEBINAR SERIES

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Optimal mix of flexibility in long-term scenarios

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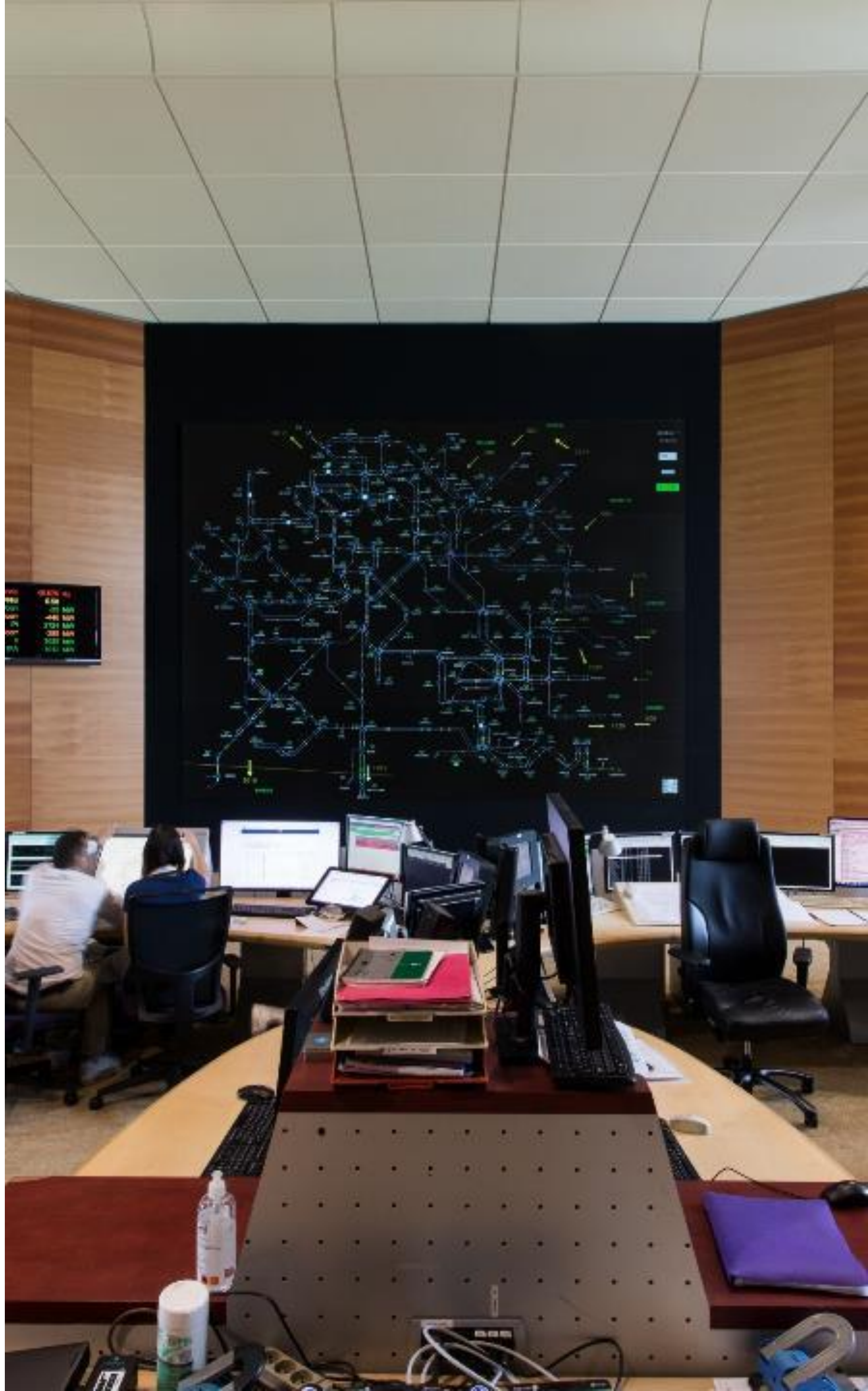
Agenda

1. **OSMOSE in a nutshell**
2. Enhanced modeling to capture flexibility
3. Evolving flexibility in European long-term scenarios
4. Integration of Innovative Flexibility Options in the context of Planning, Operation and Stability



The OSMOSE project

- ✓ H2020 EU funded
- ✓ 28M€ budget
- ✓ 33 partners
- ✓ Leaders: **RTE**, REE, TERNA, ELES, CEA, TUB
- ✓ 01/2018 – 04/2022

OSMOSE objectives

- **Improve the understanding of future needs and sources of flexibility** required to achieve the decarbonization of Europe
    - ✓ Modelling and quantification of flexibility in European Long-term scenarios

- Foster the **implementation** of innovative flexible solutions
    - ✓ Large scale demonstrators led by Transmission System Operators (TSOs)
    - ✓ Advanced tools for Battery Energy Storage System operators and power System Operators

Work structure

Simulations of long-term scenarios

- ✓Identify future needs and sources of flexibility
- ✓Develop new tools and methods for flexibility assessment

WP1 Optimal mix of flexibilities

WP2 Market designs and regulations

WP7 Scaling-up and replication

4 Demonstrators

- ✓Foster the participation of new flexibility providers
- ✓Demonstrate new flexibility services and multi-services capabilities

WP3 Grid forming by multi-services hybrid storage

WP4 Multi-services by different storage and FACTS devices

WP5 Multi-services by coordinated grid devices, large demand-response and RES

WP6 Near real-time cross-border energy market

Objectives of “Optimal Mix of Flexibilities”

To identify an (cost-)optimal mix of flexibilities for the European power system and to establish a broad understanding of drivers for the deployment of flexibility options.

- Methodology compatible with European energy mixes with high VRES share
- PoC using scenarios over 2030 to 2050
- Holistic vision of flexibility, integrating any available lever

Research questions

- Select a workable definition of flexibility (not only a buzz-word)
- Set up a methodology
  - taking into account all relevant temporal and geographical scales
  - transparent, replicable, and tractable on real data
  - preferably based on existing and recognised open-source tool(s) with additional own developments

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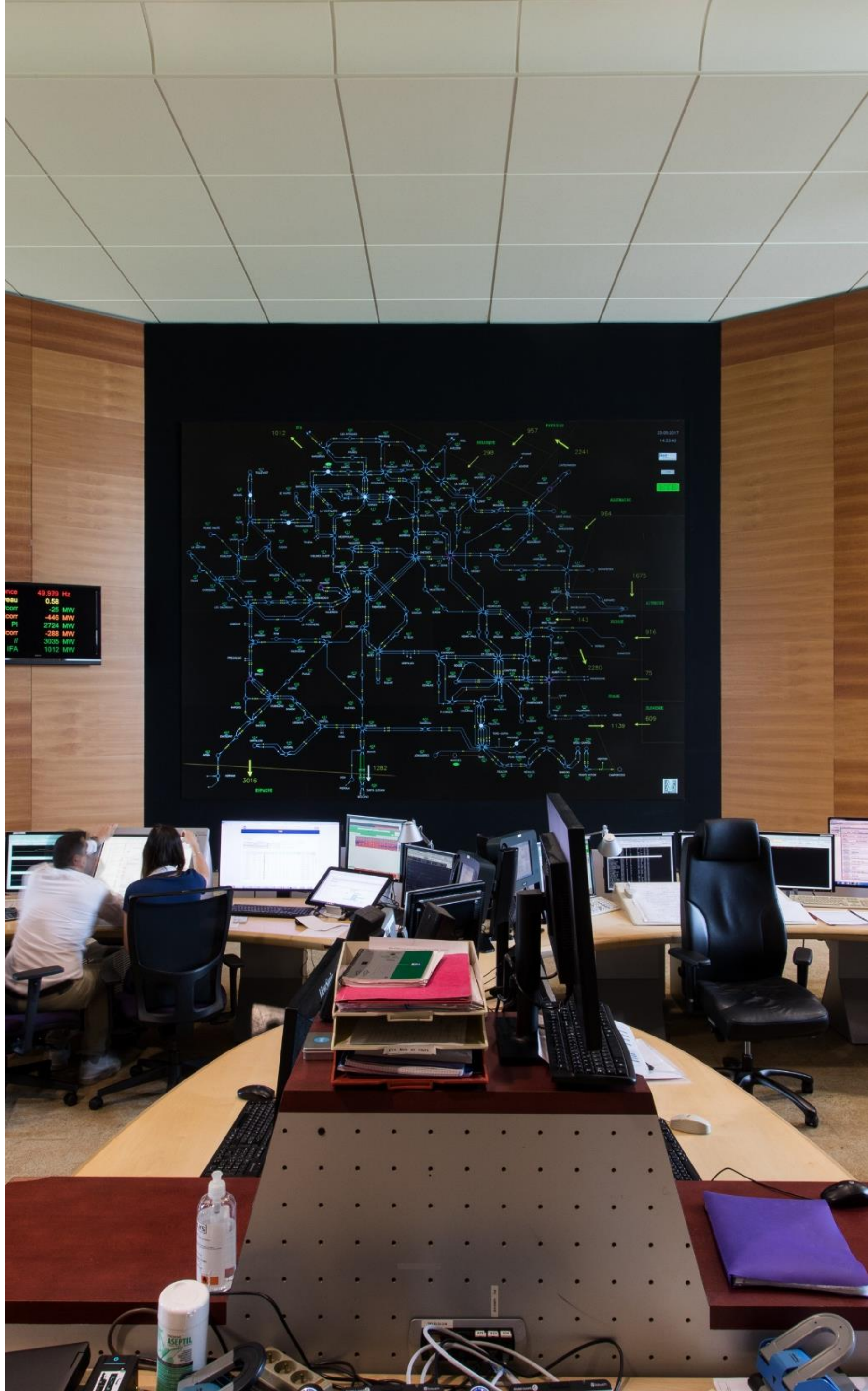


Introduction to capacity expansion models

Case study structure:
- Technologies
- Investment period
- …

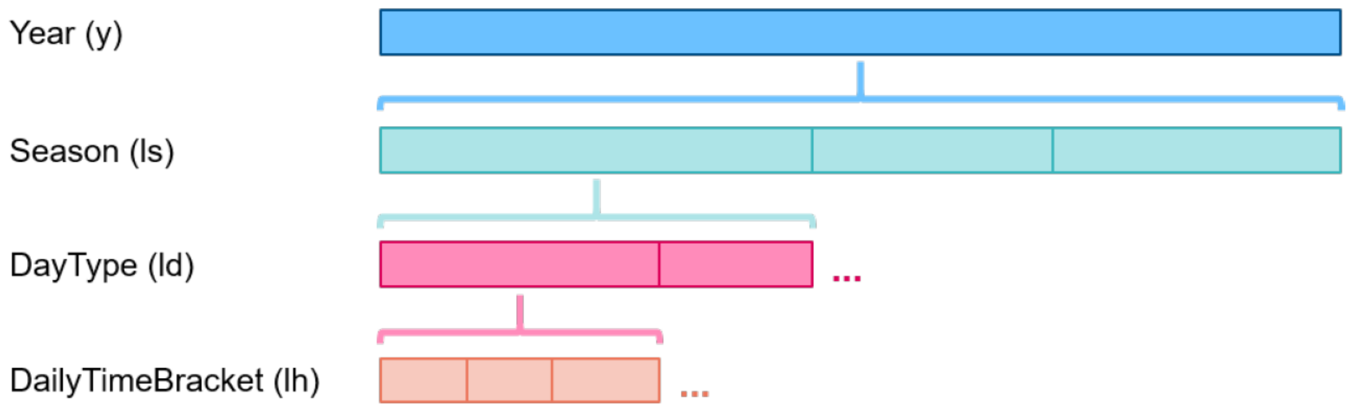
Parameter values:
- Costs
- Technology potentials
- …

Minimisation TOTEX

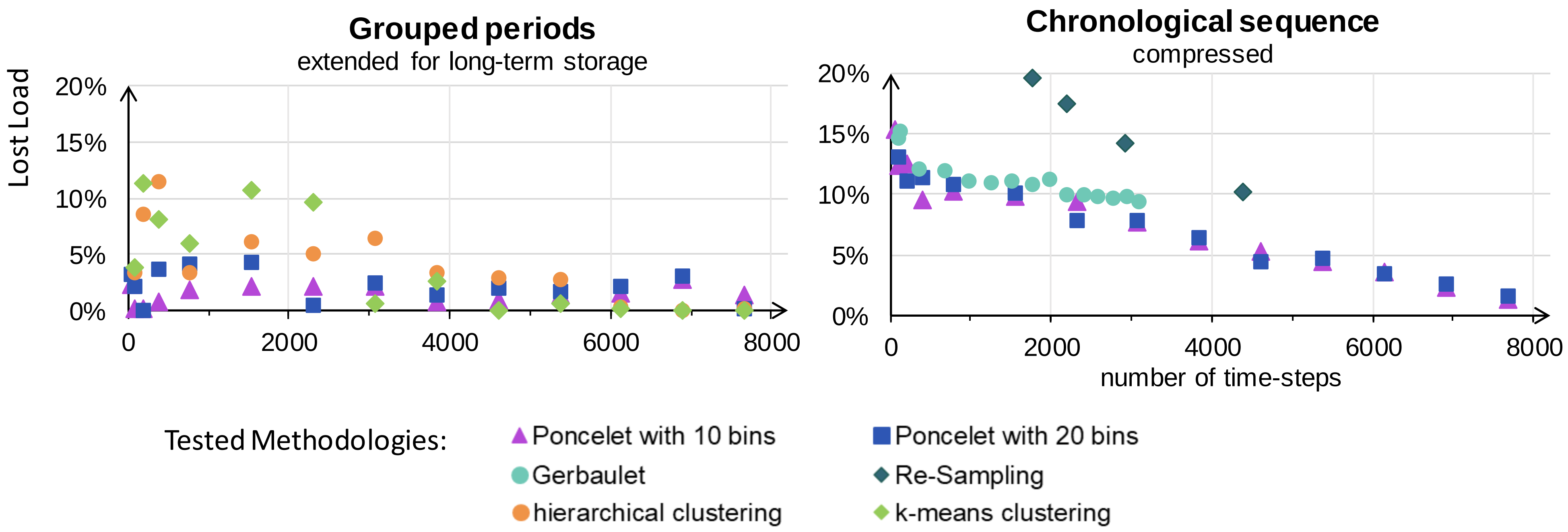
Investment pathway for each technology on each node.

Total costs, emissions...

To keep the optimisation computable, those models use time slices:

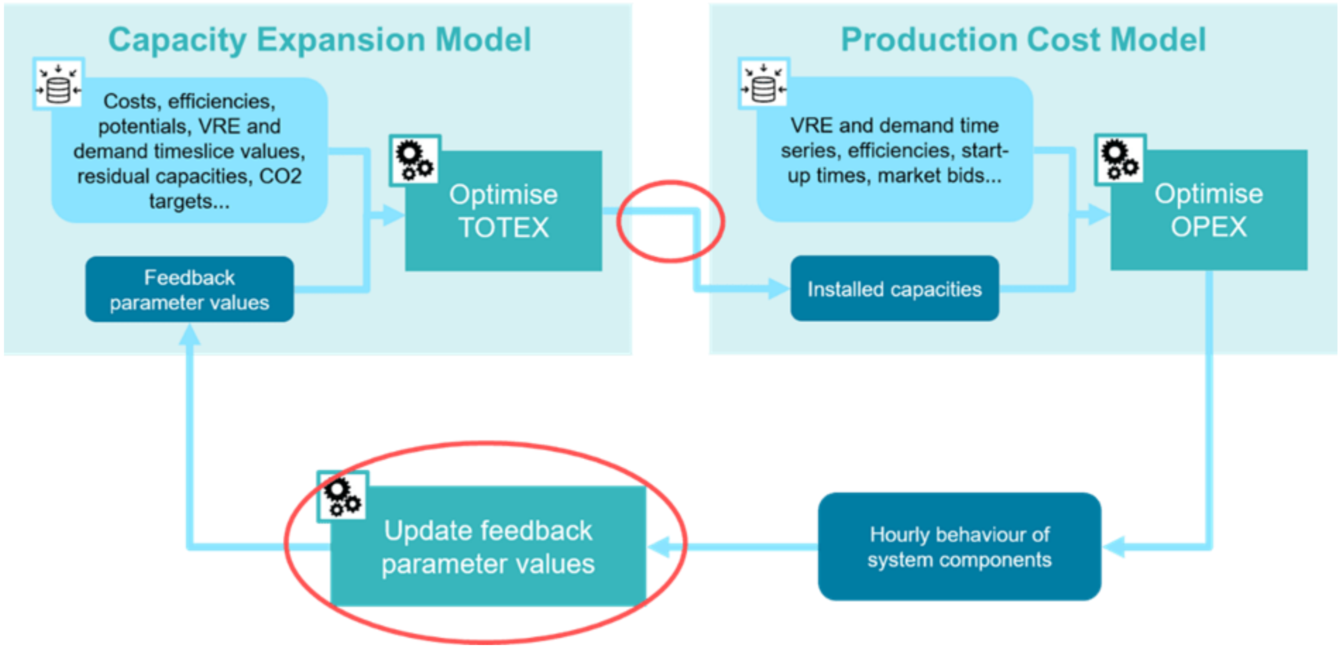


Short-comings of reduced time-series in planning models



At low temporal resolution and high shares of variable renewables all methods for time-series reduction exhibit significant shares of lost load in the power sector (corresponding publication in Energy)

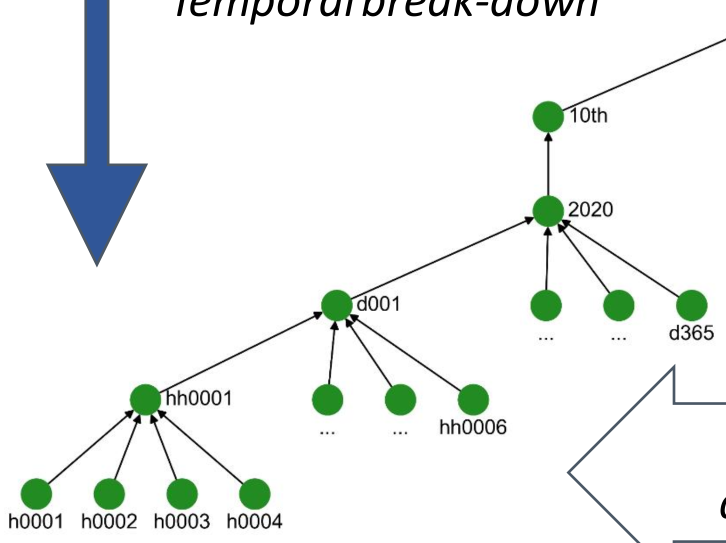
Approach 1 - Catching flexibility value by coupling of tools



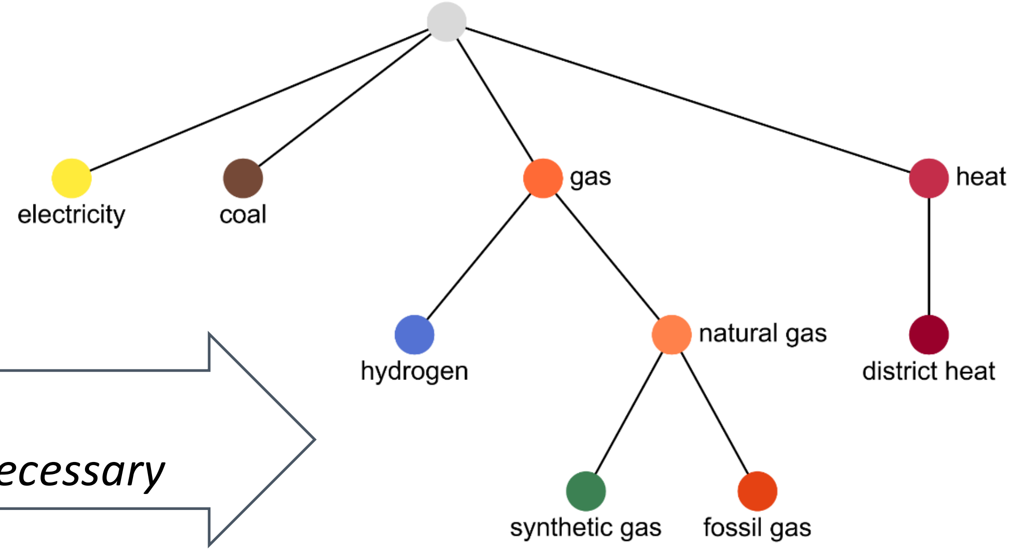
- Catching flexibility value in expansion planning has to accommodate:
  - Long-term investment path vision for CAPEX+OPEX cost-effectiveness
  - And hourly variability/uncertainty to ensure Security of Supply
- Inherently a **huge** problem
- The soft-linking architecture enables to benefit of the best of both worlds.

Approach 2 - Graph-based formulation for energy systems

Temporal break-down



Energy carrier break down

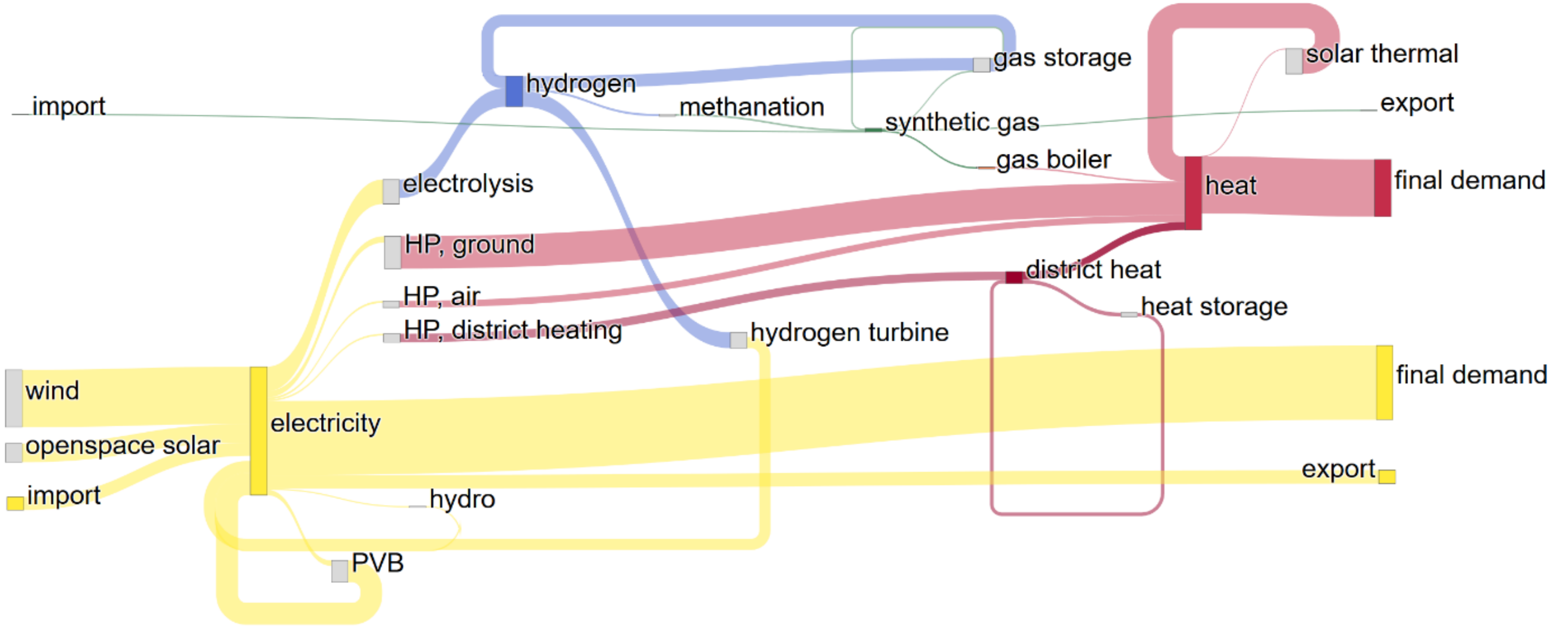


For each technology
depending on the level of detail necessary

- Temporal and spatial resolution of dispatch and expansion can be varied by energy carrier
- Temporal resolution of dispatch is an implicit assumption on a carrier's inherent flexibility

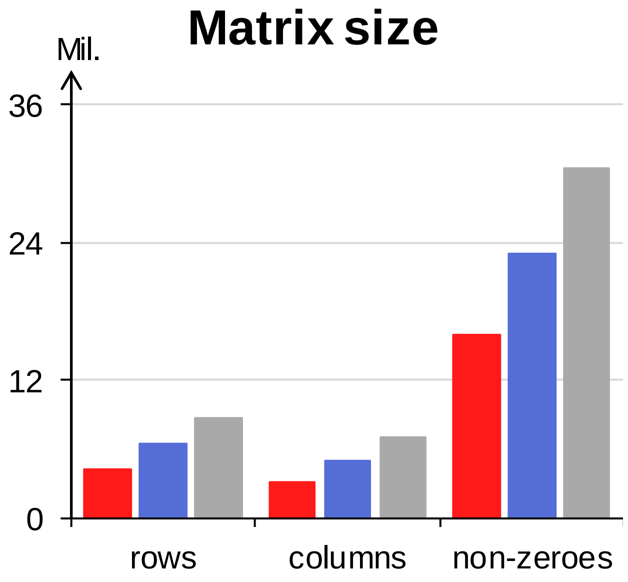
Approach 2 - Graph-based formulation for energy systems

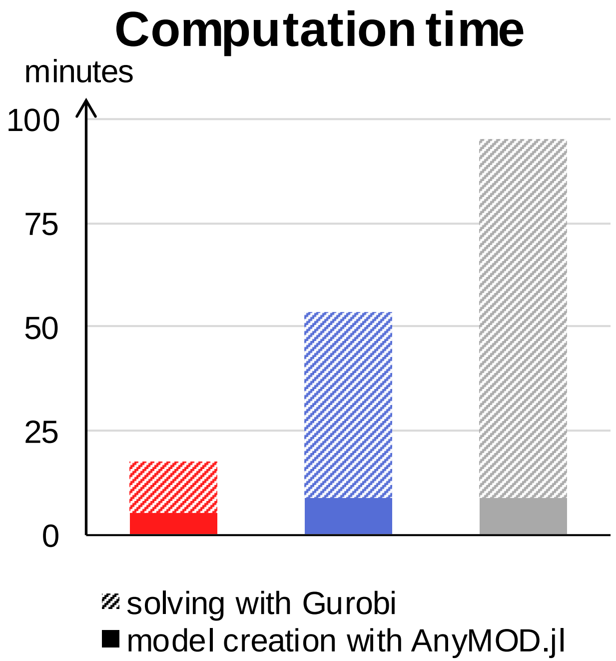
- Exemplary Sankey diagram resulting from AnyMOD.jl

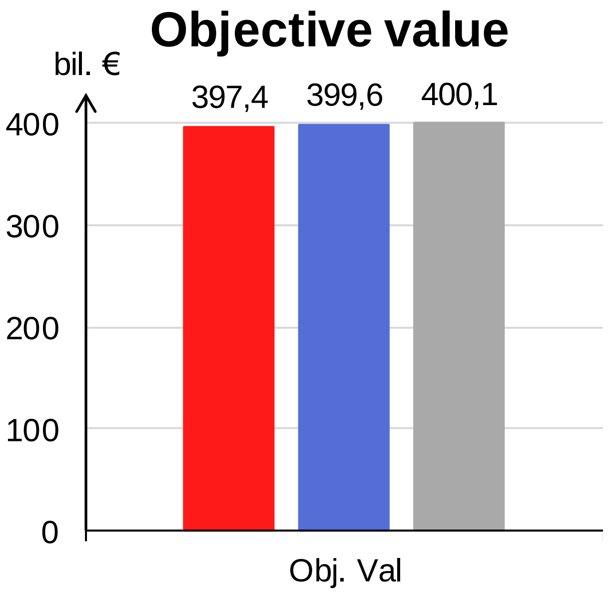


- Several analyses using the framework are already available.

Impact of resolution on graph-based formulation performance







only power hourly only power and heat hourly all hourly

- Selective variation of temporal resolution greatly reduces computational complexity while preserving the optimality of the energy mix
- Reductions of the objective can be interpreted as the value of system inherent flexibility

OSMOSE

Open-source modeling tool for graph-based formulation

build passing | codecov 91% | chat on gitter | License MIT

AnyMOD.jl

Documentation

- STABLE — last thoroughly tested and fully documented version
- DEV — *in-development version of the tool*

- Complexity of graph-based formulation hinders its application
- Development of an open modeling framework to make the graph-based formulation accessible

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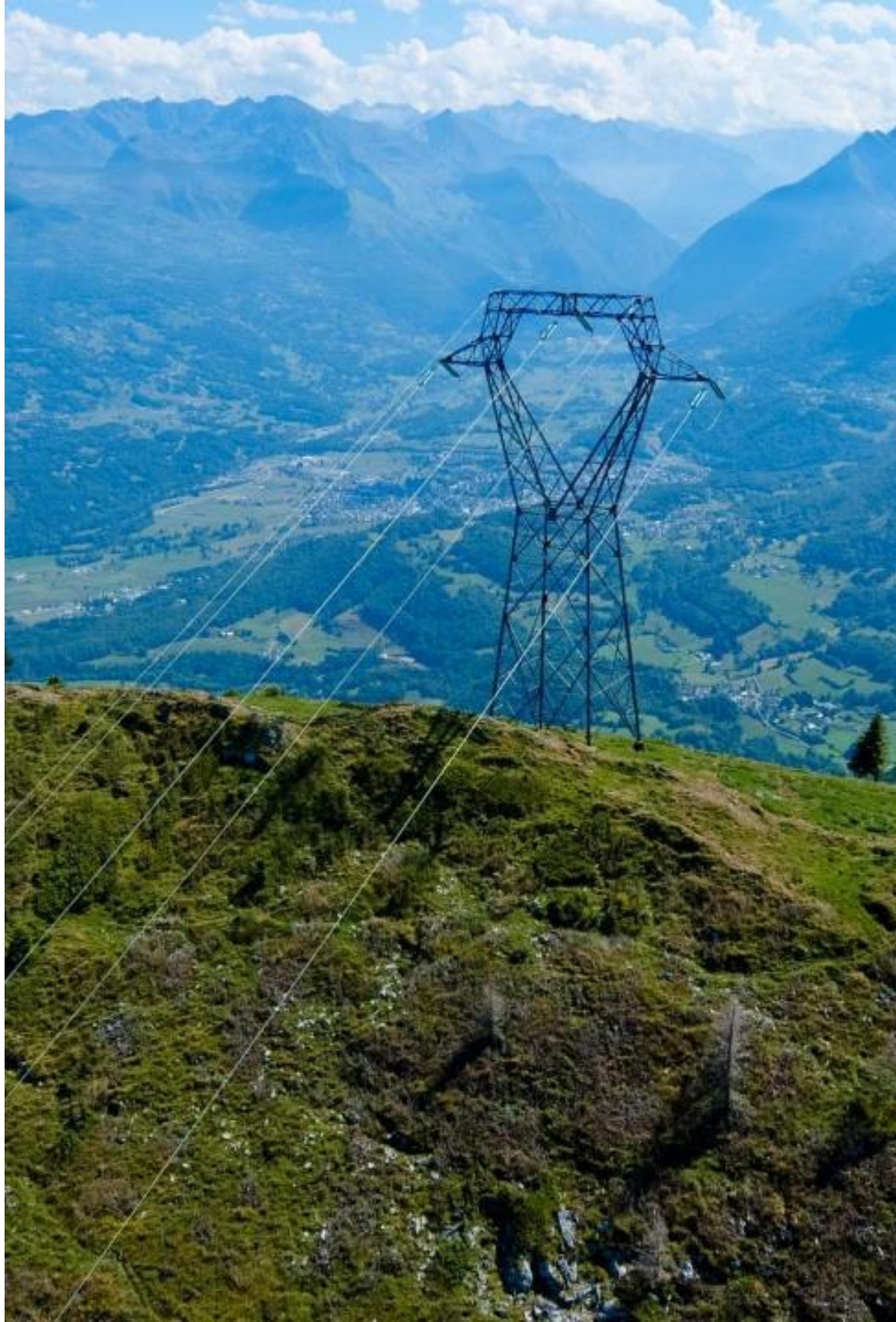
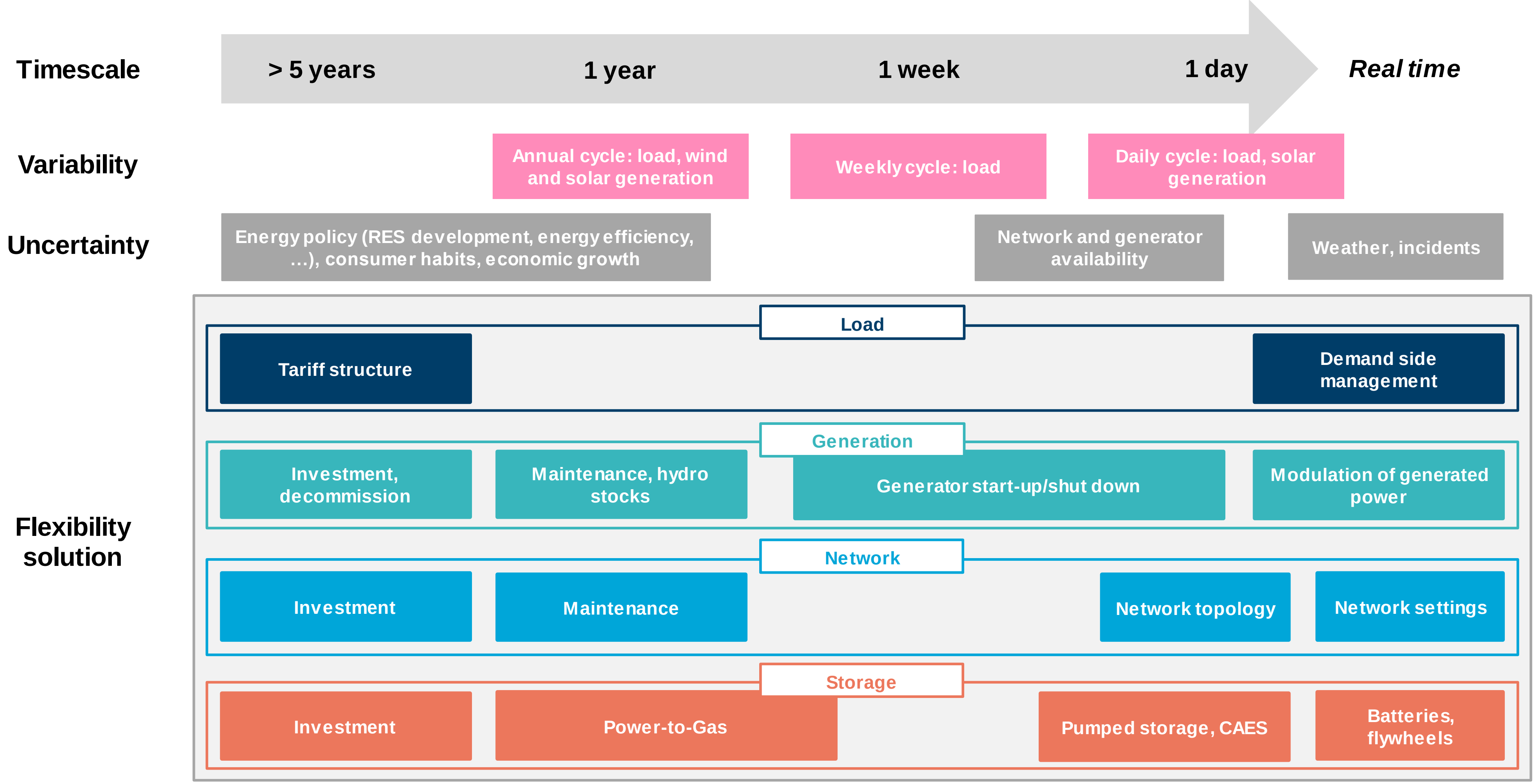
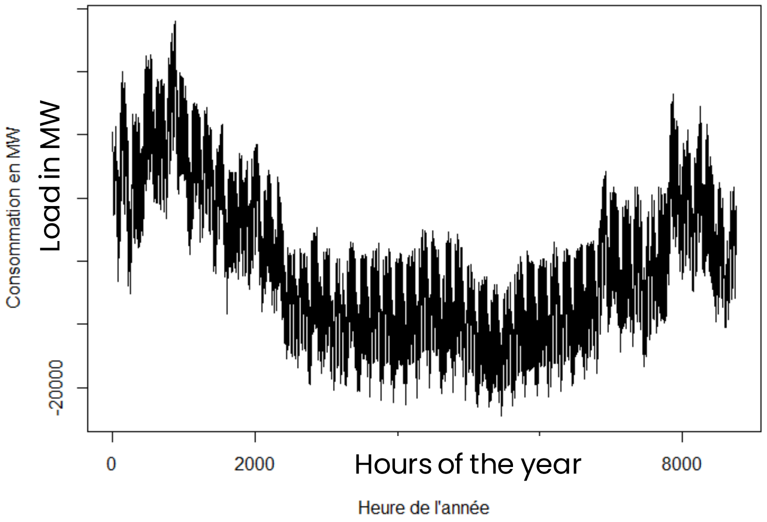
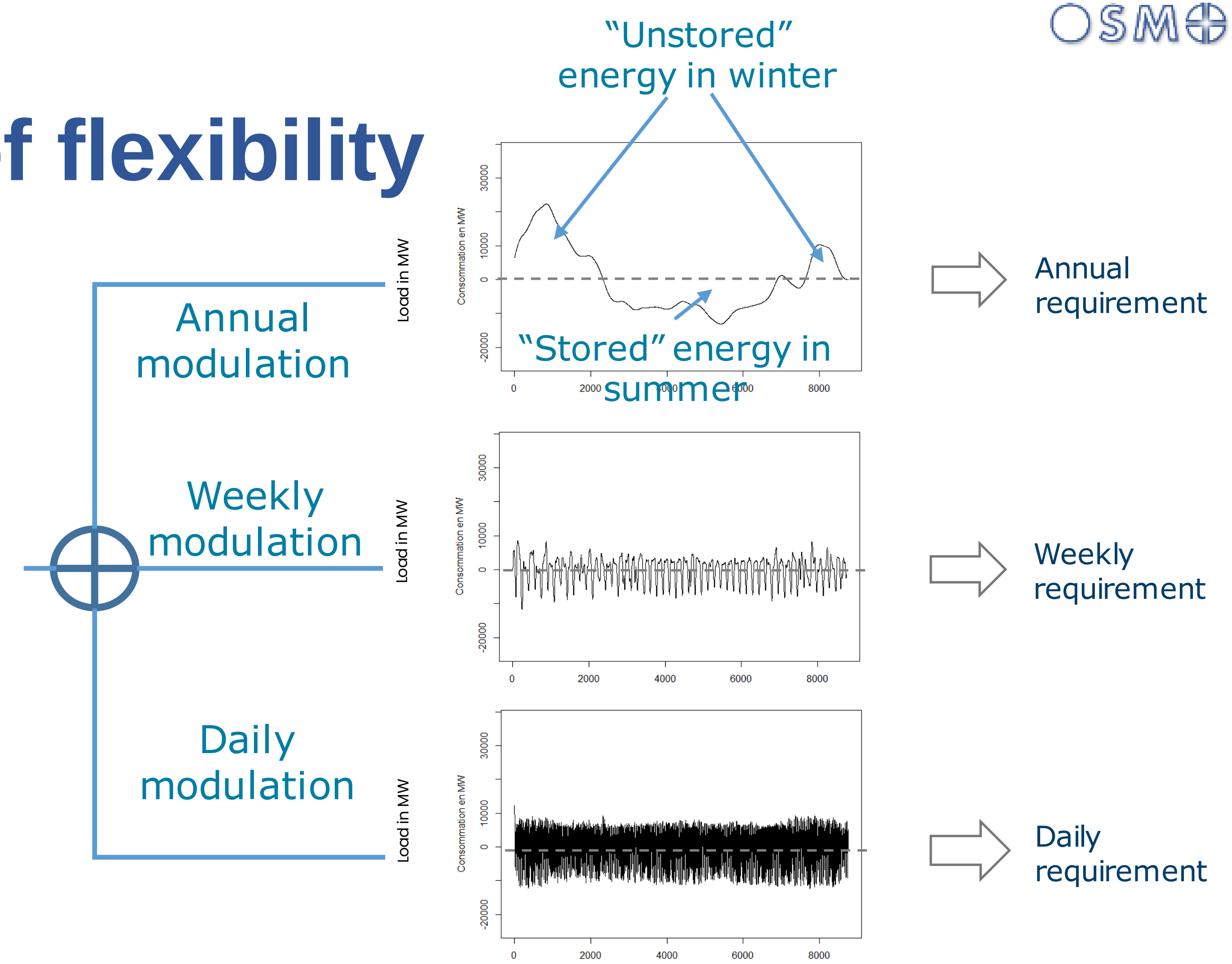


Power system's ability to cope with variations



Multi-scale nature of flexibility





The multi-scale nature of flexibility is not accurately captured by Capacity Expansion Tools.

How can we address this limitation based on existing operational frameworks/tools?

Sector coupling a key for flexibility needs and provision

In energy mixes with a very high share of VRES, sector coupling must be accounted for

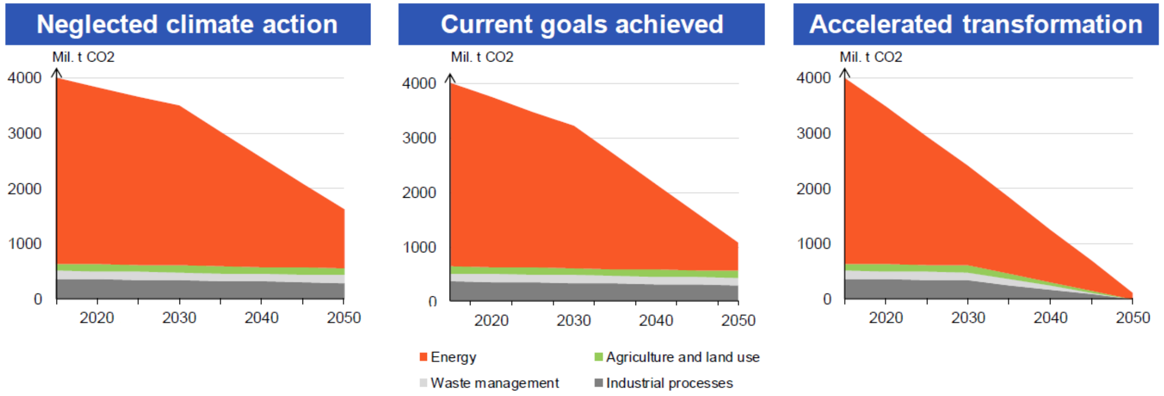
- Devices coupling carriers (e.g. electrolysers or fuel cells) modify the load curve,
- While they can also provide flexibility by modulating their power consumption

The merit order of decarbonisation solutions heavily depends on the list of considered options

- this list is the combined result of technological maturity trajectories ,
- … and political decisions!

In OSMOSE, a limited number of options has been considered

- RES, gas units, nuclear, electric vehicles, heat pump, electrolysers, fuel cells and batteries



- 35 % CO2 in 2030
- 70 % CO2 in 2050

- 40 % CO2 in 2030
- 80 % CO2 in 2050

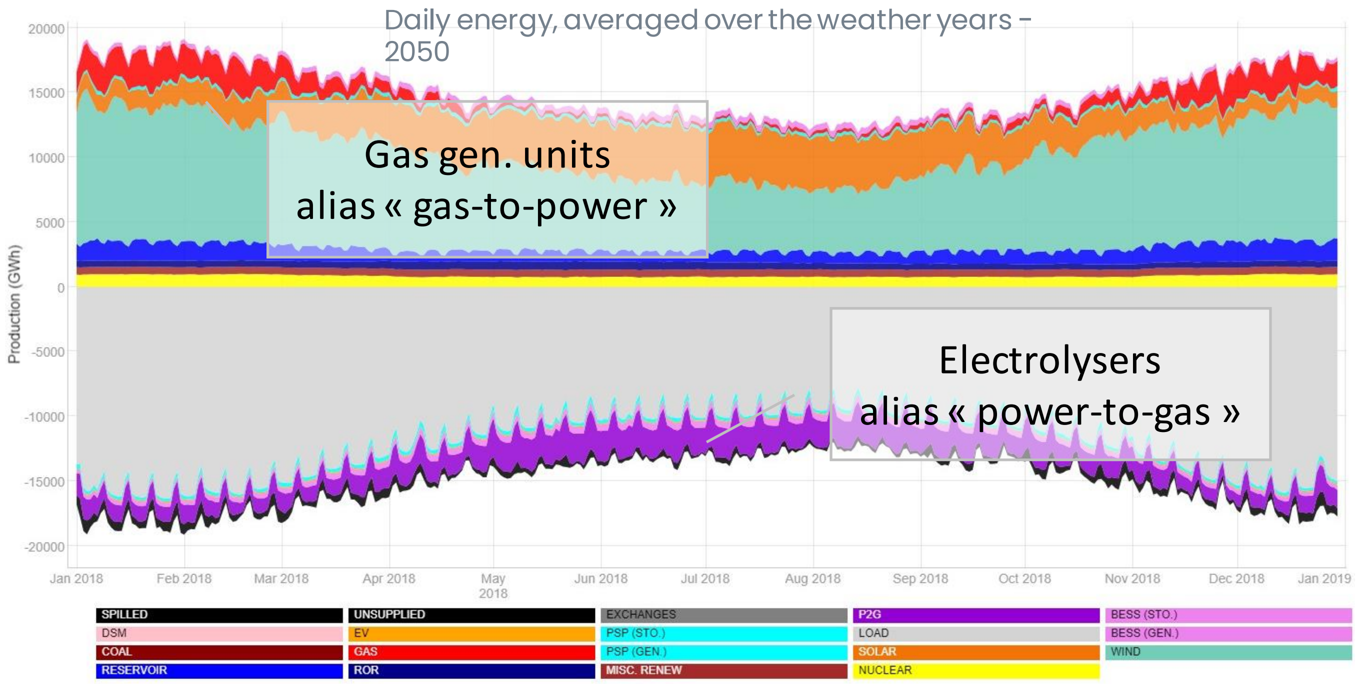
- 55 % CO2 in 2030
- 98 % CO2 in 2050

In OSMOSE scenarios for 2050, power-to-gas stands out

- In 2050, power-to-gas is a key long-term flexibility provider in mixes with very high VRES share

Generation storage out and imports

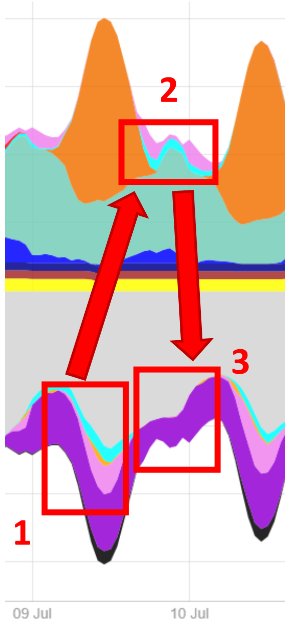
Demand storage in and exports



- Power-to-gas and VRES investment co-optimisation enables to drastically reduce European CO_2 emissions by enabling gas units to switch to "100% green gas"
- With high penetration of Power-to-gas, price is mostly set by demand (rather than generation)

Collaboration among flexibility sources is essential

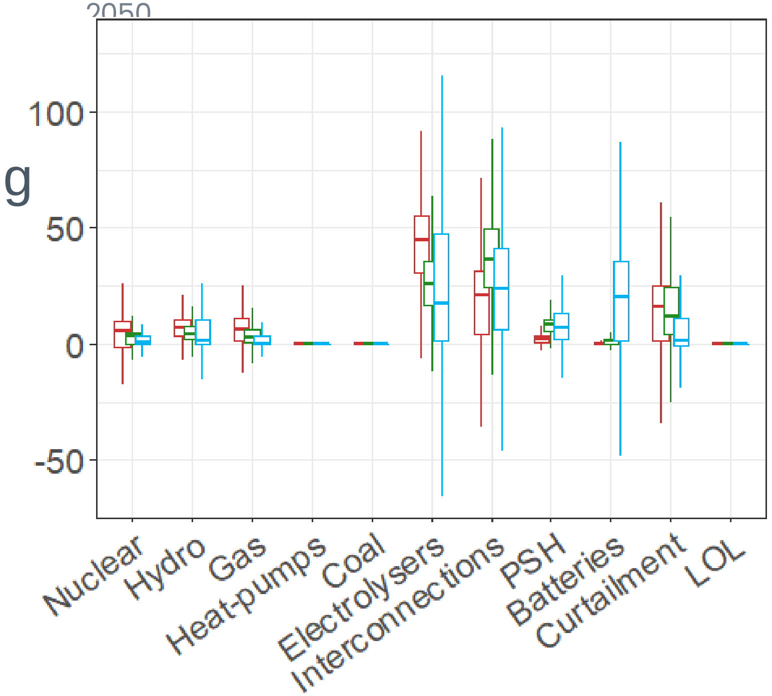
Collaboration btw. batteries and PtG



A holistic vision of flexibility is needed:

- Short-term flex. (e.g. batteries) help optimise long term flex. (e.g. PtG)
  - Electrolysers may run outside sunny (or windy) hours
- Interconnections and internal power grid play a major role in leveraging flex. solutions,
  - Even with "no limit" for gas storage and grid!

Flexibility provision for FRANCE (FSCD indicator) - 2050

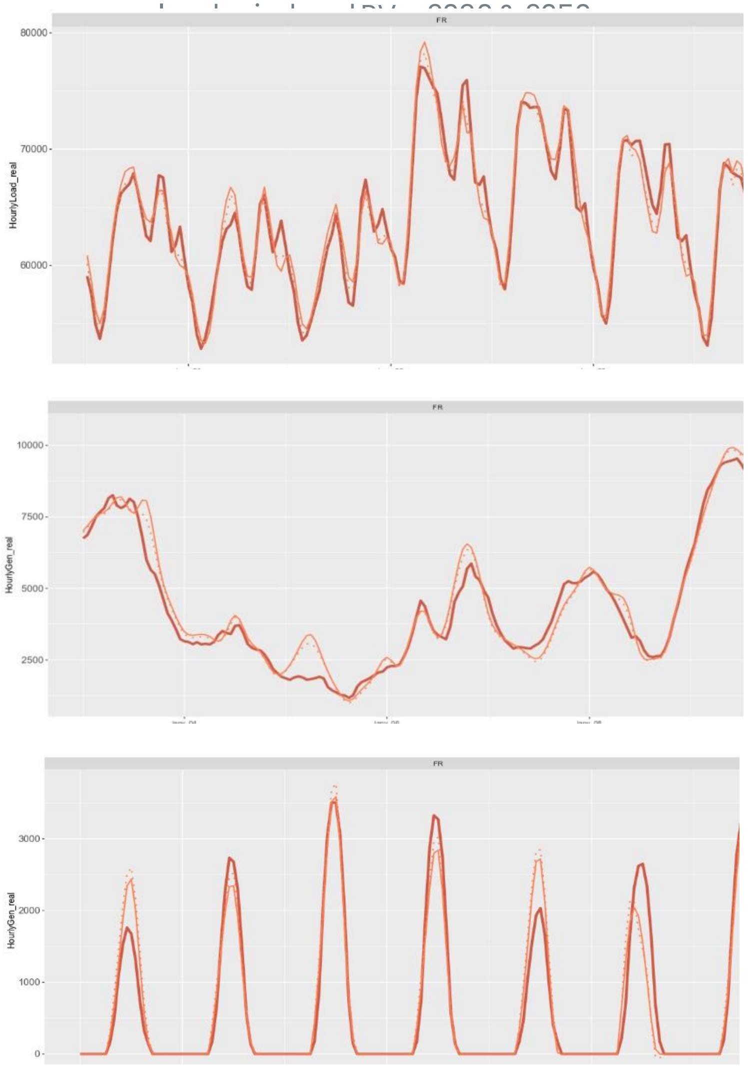


Flexibility providers collaboration and access to interconnections and grid must be fostered through appropriate market design

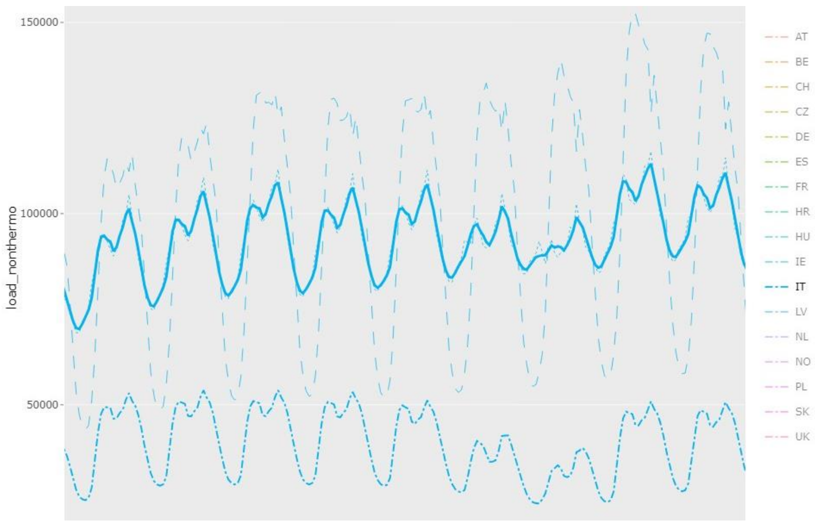
WP1 dataset available for transparency and reuse

- Data collection and model development represented more than 90% of the work and is a common barrier.
- The full dataset developed to reflect correlations is based on open data (Copernicus, Plan4RES, PECD, JRC…) and in turn made publicly available

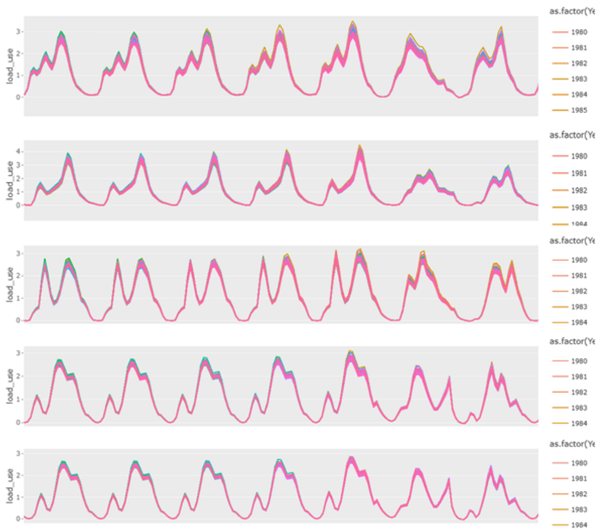
Pseudo-forecast vs pseudo-realized TS for 33 countries



Upd. thermosensitive load TS for 33 countres
2030 & 2050



Electric vehicles thermosensitive TS for 33 countries
2050



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Integration of Innovative Flexibility Options in the context of Planning, Operation and Stability

Sizing and Siting of Flexibility Options

Planning – based on the OSMOSE scenarios for 2030 and 2050, a tool for Dispersed Energy Storage Planning (DESPlan) was applied to the Portuguese power system to find the **optimal sizing and siting of flexibility options**.

Cross-Border Reserve Exchange

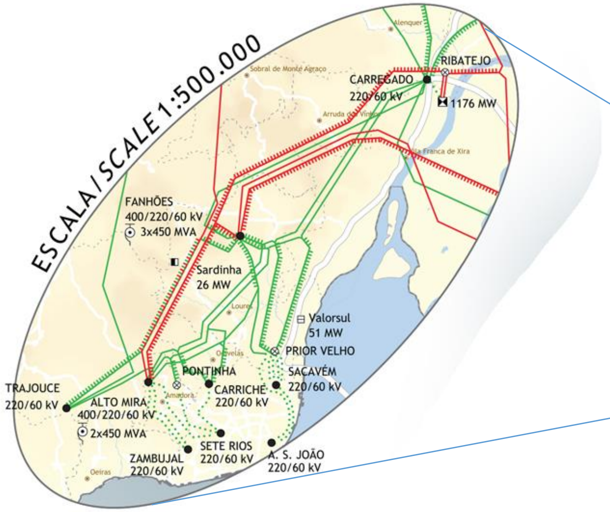
Operation – starting from the OSMOSE scenarios for 2030 and 2050, the **available flexibility options** for each cluster are studied using PS-MORA for the CSW region, which includes Portugal, Spain and France.

Stability Aspects

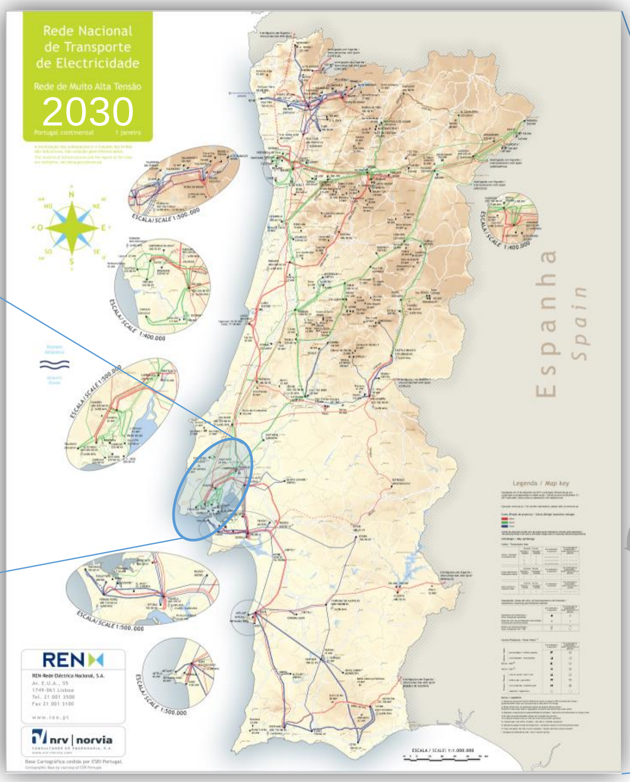
Stability – a **dynamic study** was performed to a portion of the Italian power system, updated according to the capacities considered in the OSMOSE scenarios for the two time horizons, 2030 and 2050.

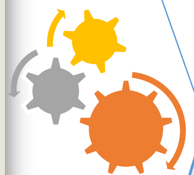
Sizing and Siting of Flexibility Options

Detailed up-to the distribution interface (60kV)

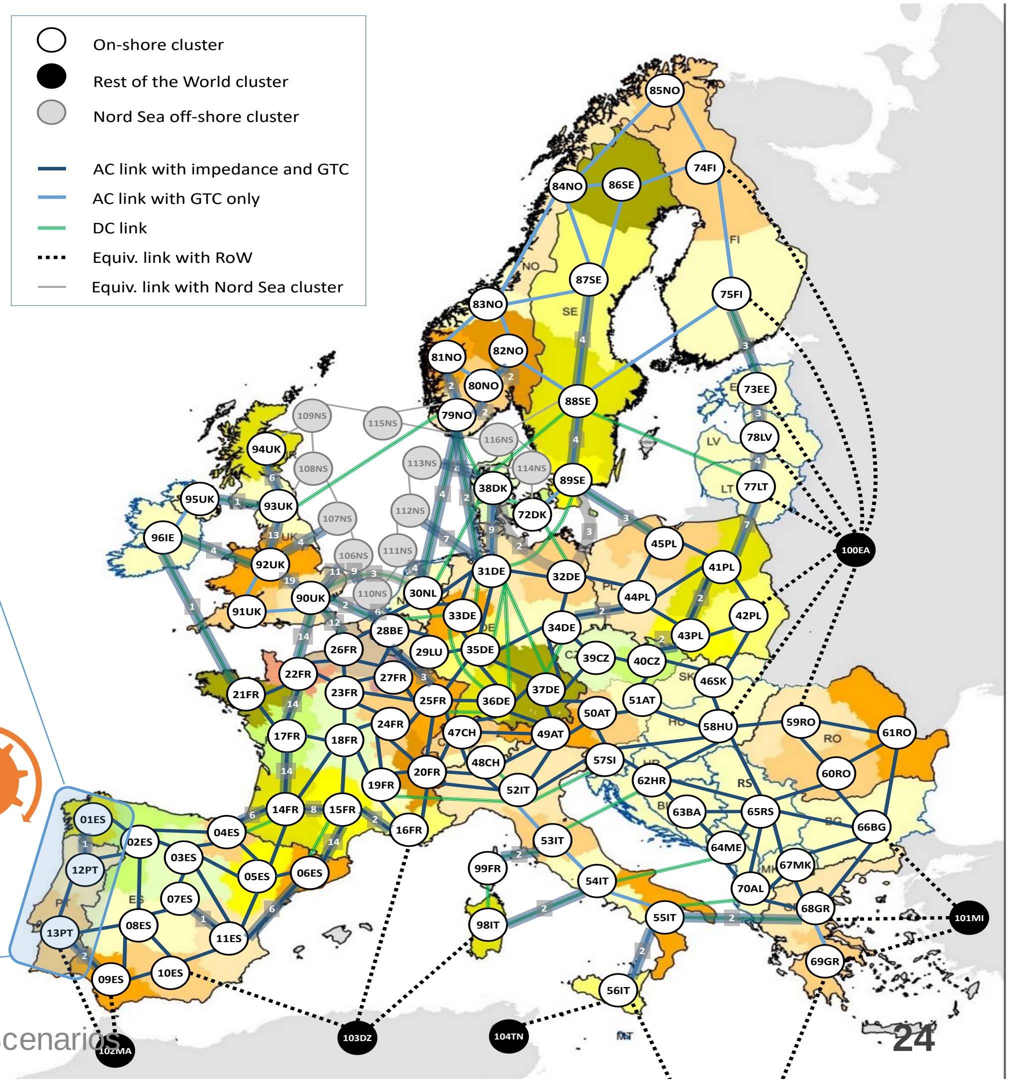


Portuguese Transmission Network





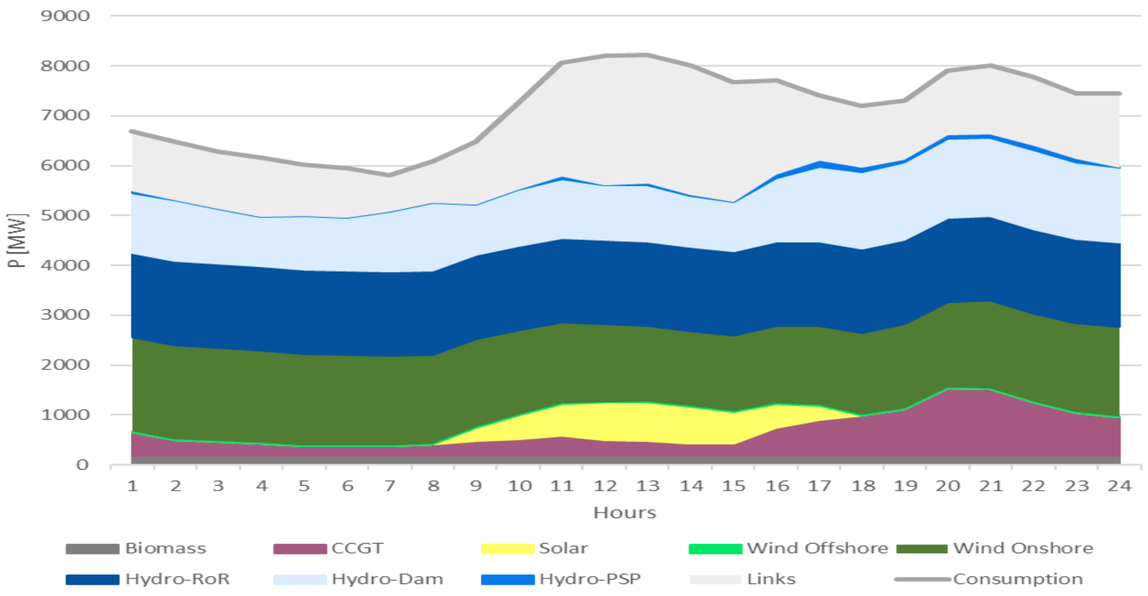
OSMOSE datasets (2030, 2050)

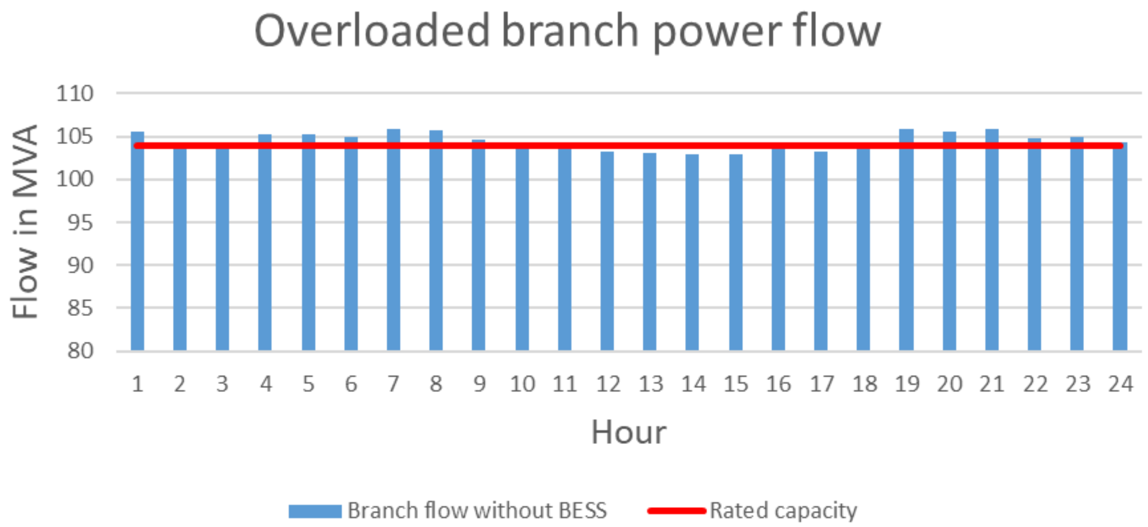


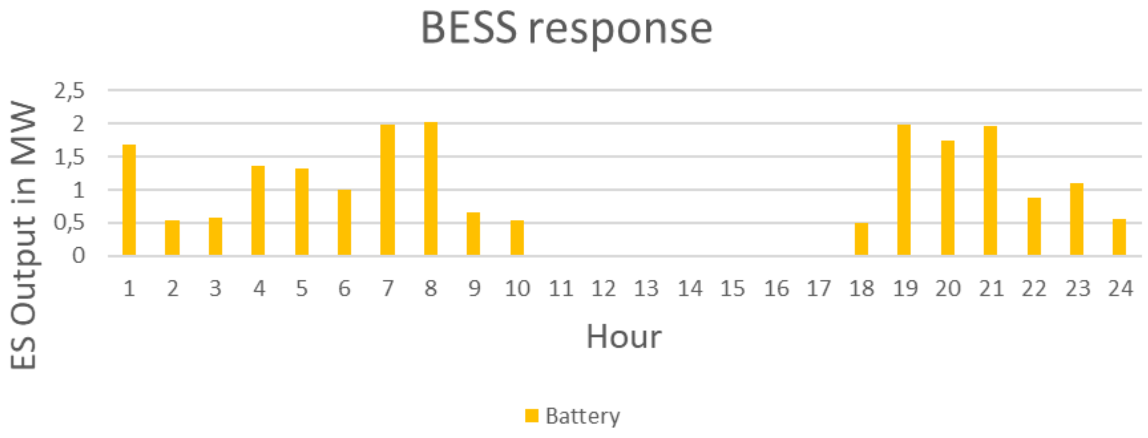
Sizing and Siting of Flexibility Options

✓ **SCG_2030**

- Congestions detected in **32%** of the period of analysis
- Congestions up to **8% above limits**
- ESS solutions between **2MW/20MWh** and **28MW/28MWh**



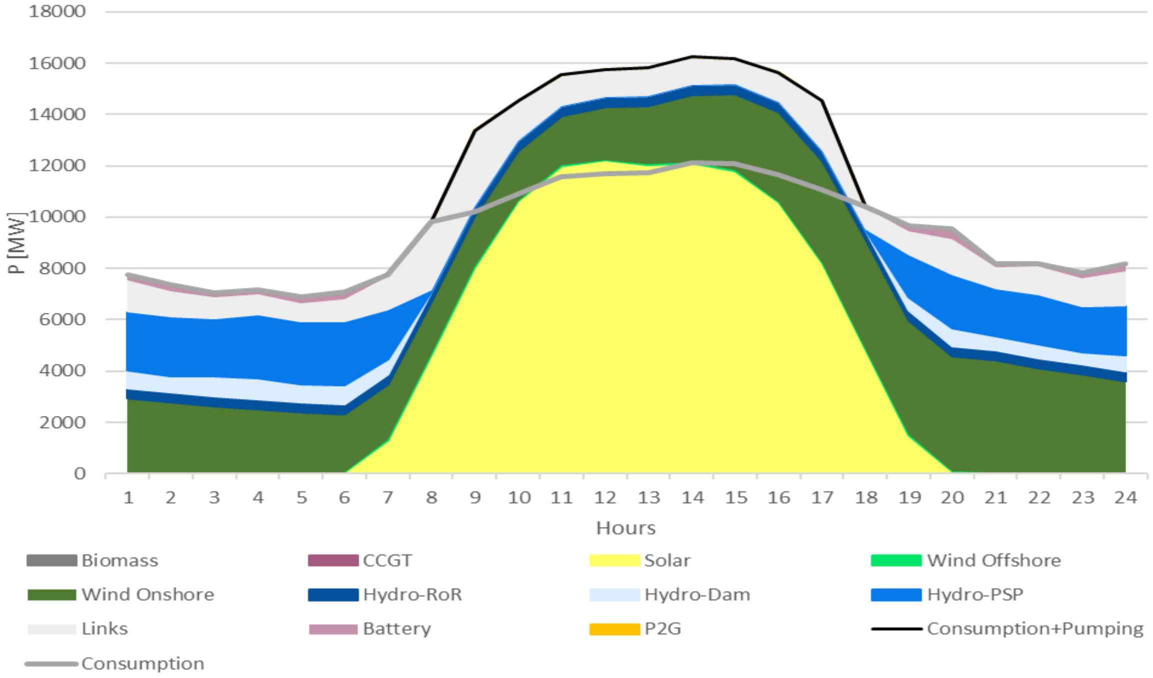


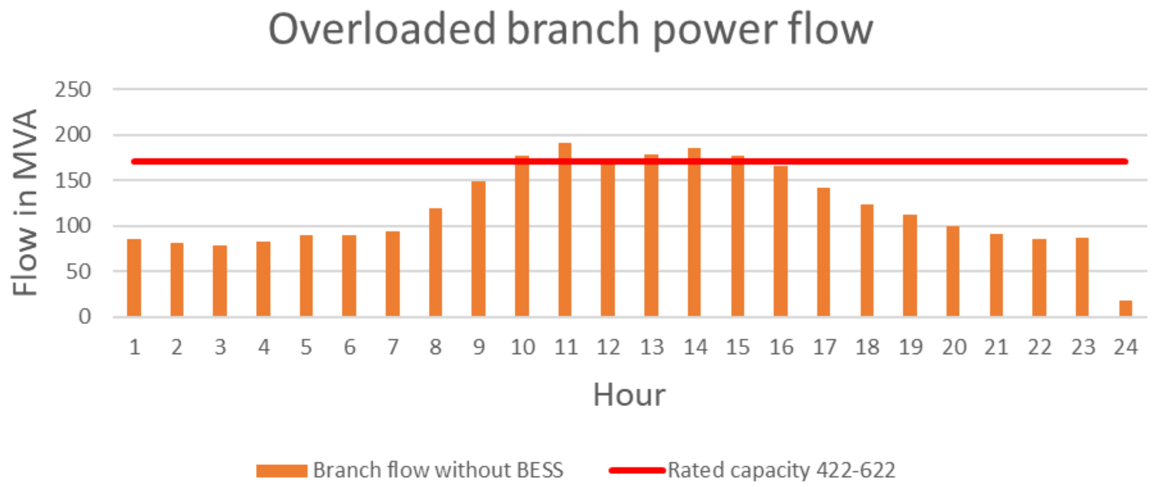


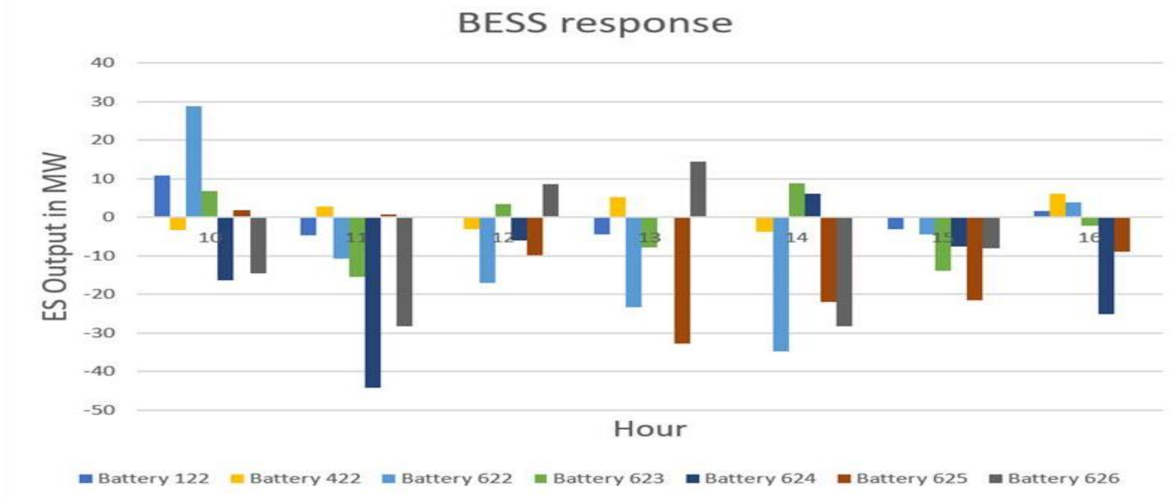
Sizing and Siting of Flexibility Options

✓ **SCG_2050**

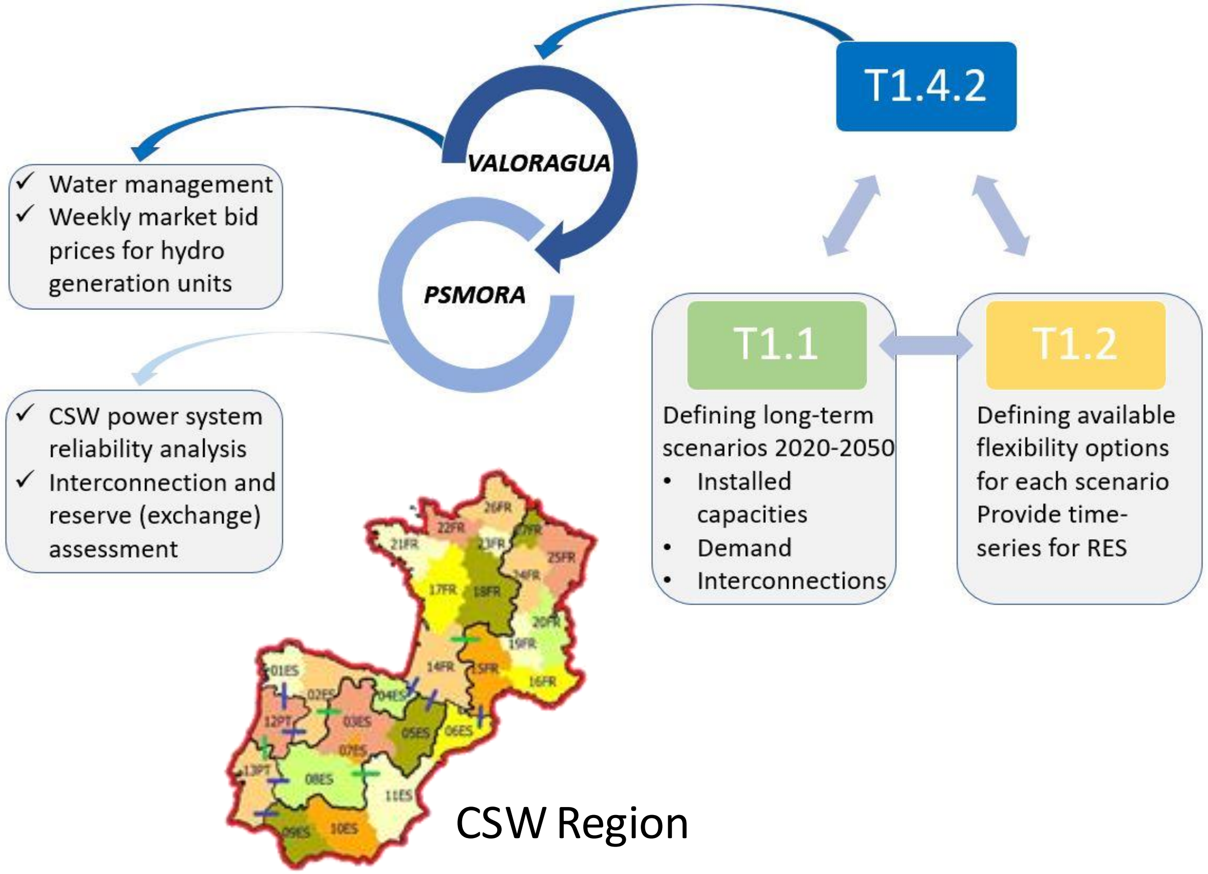
- Congestions detected in **49%** of the period of analysis
- Congestions up to **55% above limits**
- Solutions between **15.6MW/15.2MWh** and **172.2MW/383.9MWh**







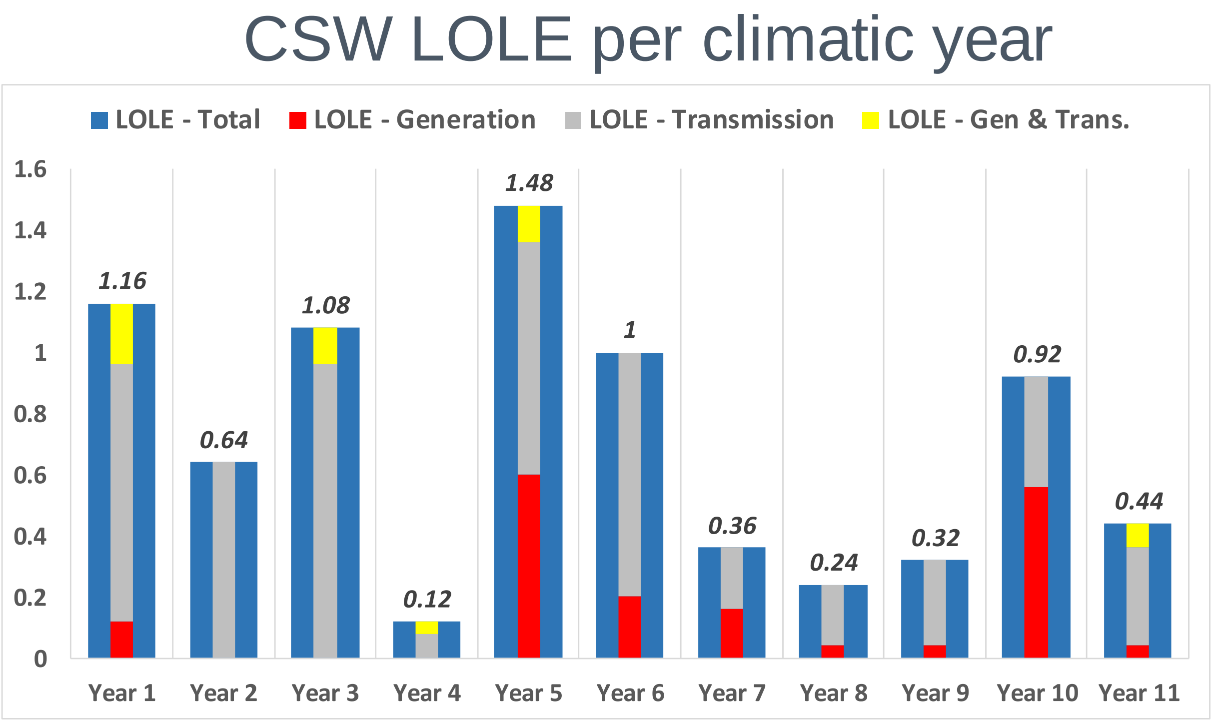
Cross-border reserve exchange



- OSMOSE defines operating conditions for PS-MORA simulations
- ANTARES results provide: reserve requirements, hydro and P2G energy availability per week, demand and RES profiles, …
- Energy flow between FR and rest of EU imposed as fixed demand for FR

Cross-border reserve exchange

Results – SCG_2050



- Impact of different operating condition becomes clear
- Substantial share of LOLE explained by *congested interconnections*; and, in some climatic years, lack of generation capacity
- Further analysis shows that LOLE is mostly "located" in FR

Cross-border reserve exchange

Results – SCG_2050

Sensitivity analysis on increasing flexibility in FR

	SCG_2050	Run 1	Run 2	Run 3	Run 4
NTC % available for flexibility	5%	7.5%	10%	20%	30%
MW available cluster 6 + cluster 7	2405	3607.5	4810	9620	14430
LOLE (h/year)	***0.74***	***0.62***	***0.50***	***0.30***	***0.14***
EENS (MWh/year)	***1902.83***	***1514.57***	***1293.37***	***690.52***	***371.7***

- Base case for SCG_2050 assumes 5% interconnection FR-EU as flexible
- Increasing % leads to alleviated reliability indexes
- Increasing 12GW of flexibility reduced **LOLE from 0.74 to 0.14 h/year** and **EENS from 1900 to 370 MWh/year**

Cross-border reserve exchange

Results – SCG_2050

Sensitivity analysis on interconnection reinforcement

	SCG_2050	Run 1	Run 2	Run 3	Run 4
C3 – C6	3800	4000	4400	4800	5500
C4 – C6	1900	2100	2300	2800	3000
C5 – C7	3600	3600	3800	4600	5000
C1 – C3	2210	2210	2210	2600	3000
C2 – C4	1900	1900	1900	2100	2300
C2 – C5	1596	1596	1596	1900	2200
LOLE (h/year)	***0.74***	***0.64***	***0.46***	***0.34***	***0.26***
EENS (MWh/year)	***1902.83***	***1679.99***	***1295.03***	***857.35***	***720.56***

- Increasing interconnection capacity within CSW region (focus on ES-FR) reduces LOLE and EENS
- A 7GW interconnection reinforcement in CSW reduced **LOLE from 0.74 to 0.26 h/year** and **EENS from 1902 to 720 MWh/year**

Stability Aspects

Focusing on the Sicilian HV network (400, 230 kV and partially 132 kV and 150 kV):

- *More than 600 busbars, 441 lines and 516 substations*
- *30 large (>10 MW) static generators representing wind and solar plants*
- *379 loads, representing Primary Substations (including equivalent dynamic models of DG, batteries) and HV loads*
- *72 synchronous machines, representing thermal and hydro plants with their associated controllers (AVR, GOV and PSS)*

Flexibility options modelled and implemented:
- **Inertial response and fast frequency response of wind plants and storage systems**
- **Demand Side Response**
- **Voltage regulation provided by RES**

Stability aspects considered for selected operating conditions:
- **Frequency stability**
- **Large perturbations angle stability**
- **Small perturbations angle stability**
- **Voltage stability**

Stability Aspects 2030

Type of stability	Is the grid stability guaranteed without flexibility options?	Problems identified	Solution / Notes	Does the flexibility solve the problem?
High Export				
Large perturbation angle stability	Yes	None	SI helps to reduce frequency deviations	-
Small perturbation angle stability	No	The interarea mode is not properly damped (ζ <5%)	SI and PSS tuning	Yes
Voltage stability	Yes	None	-	-
High Import				
Large perturbation angle stability	Yes	Stressful events (3 cables trip) may not be handled without flexibilities	DSR FCR are required	Yes
Small perturbation angle stability	Yes	Two modes are not properly damped (ζ <10%)	SI and PSS tuning	Yes
Voltage stability	No	Low loadability margin (<40%)	Reactive contribution from RES plants	Yes
High Load / Low Gas				
Large perturbation angle stability	Yes	None	SI helps to reduce frequency deviations	-
Small perturbation angle stability	Yes	None	-	-
Voltage stability	Yes	None	-	-
Island				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR FCR is required	Yes
Small perturbation angle stability	Yes	None	-	
Voltage stability	Yes	Loadability margin is close to 40 %	Reactive contribution from RES plants	Yes
Low Load / Low Gas				
Large perturbation angle stability	Yes	None	SI helps to reduce frequency deviations	-
Small perturbation angle stability	Yes	One mode is not properly damped (ζ <10%)	SI and PSS tuning	Yes
Voltage stability	Yes	None	-	-
Lines out of service				
Large perturbation angle stability	Yes	None	SI helps to reduce frequency deviations	-
Small perturbation angle stability	Yes	None	-	-
Voltage stability	Yes	None	-	-

Stability Aspects 2050

Type of stability	Is the grid stability guaranteed without flexibility options?	Problems identified	Solution / Notes	Does the flexibility solve the problem?
High Export				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR and BESS FCR are required	Yes
Small perturbation angle stability	Yes	None	-	-
Voltage stability	Yes	None	-	-
High Import				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR and BESS FCR are required	Yes
Small perturbation angle stability	Yes	Some modes are not properly damped (ζ <10%)	SI, BESS, and PSS tuning	Yes
Voltage stability	No	Low loadability margin (<40%)	Reactive contribution from RES plants + Local compensation in Priolo substation	Yes
High Load				
Large perturbation angle stability	Yes	None	SI helps to reduce frequency deviations	-
Small perturbation angle stability	Yes	None	-	-
Voltage stability	No	Low loadability margin (<40%)	Reactive contribution from RES plants	Yes
Islanding				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR and BESS FCR are required	Yes
Small perturbation angle stability	Yes	None	-	
Voltage stability	No	Low loadability margin (<40%)	Reactive contribution from RES plants + Local compensation in Priolo substation	Yes
Low Load				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR and BESS FCR are required	Yes
Small perturbation angle stability	No	The interarea mode is not properly damped (ζ <5%)	SI, BESS, and PSS tuning	Yes
Voltage stability	Yes	None	-	-
Lines out of service				
Large perturbation angle stability	No	Normal operating conditions are not guaranteed without load shedding	DSR and BESS FCR are required	Yes
Small perturbation angle stability	No	The interarea mode is not properly damped (ζ <5%)	SI, BESS, and PSS tuning	Yes
Voltage stability	Yes	None	-	-

Key takeaways

Capacity Expansion Models should be improved to better account for flexibility in future energy investment plans like with

- Coupling existing planning tools with dispatch models
- Integrated investment and dispatch models with graph-based approach

The flexibility needs and sources will evolve significantly between now and 2050 on all time scales

- WP1 developed contrasted scenarios to question flexibility needs and sources from 2030 to 2050 in Europe, the full scenario data set having being publicly available
- Electrolysers, if they become common in the future power system, could be a complete game changer for flexibility provision
- Flexible electrification can efficiently provide a major share of system flexibility if incentivized by regulation. Especially electricity demand for the production of hydrogen is flexible, if hydrogen pipelines and storage are deployed to match production with final consumption.
- Need for holistic view /improve coordination by market design

Key takeaways

Flexibility will be key for a successful energy transition in Europe

- DESPlan simulations for the Portuguese power system showed that for 2030 and 2050 OSMOSE scenarios grid congestions may occur as result of higher levels of RES penetration which calls for a smart use of flexibility options. Energy storage can provide a valuable technical alternative for flexibility provision and network reinforcement.

- PS-MORA simulations for the interconnected Continental South-West (CSW) region considering short-term RES generation uncertainty helped validating the flexibility options proposed by the OSMOSE scenarios for 2030 and 2050. The role of fast response and flexible units, such as hydro power plants, proved to be key while dealing with RES forecast deviations.

- Simulations of the power system of Sicily in 2030 and 2050 show that dynamic system security can be ensured and enhanced thanks to the flexibility provided by RES (synthetic inertia for instance), energy storage controls (Frequency control) and demand (DSR).

Next steps and proposed future work for research

Next steps and Proposed future work for research

- Improve the soft-linking feed-back-loop
  - How to efficiently signal under- and over-investment to the Capacity Expansion Model?
- Enrich the sector-coupling modelling in the optimization step (Capacity Expansion Model)
  - More investment candidates (gas grid, CCS, …)
- Enrich the sector-coupling modelling in the simulation step (Production Cost Model)
  - Other energy carriers (methane, gas grid, heat, …)
- Add feed-back on environmental impact beyond CO_2 emissions
  - Use parameterized models for system-wide LCA (resource depletion, human health,
  - Account for environmental impacts as constraints/penalizations
- AnyMOD.jl: Methodological advancements to further increase spatio-temporal detail and not be limited to a single year of hourly time-series, but account for different climatic years during the planning process.

Further Reading

Deliverables

- D1.1 European Long-Term Scenarios Description
- D1.2 Flexibility cost and operational data outlook (D1.2 Related data set)
- T1.4.1 Optimal sizing and siting of storage facilities
- T1.4.2 Cross border reserve exchange for improved flexibility and efficiency
- T1.4.3 Stability aspects
- D1.3 Optimal mix of flexibility (D1.3 Related data set)
- T1.5 Synergies between flexibility services

Publications

- Multi-temporal assessment of power system flexibility requirement, Applied Energy, March 2019
- Quantifying power system flexibility provision, Applied Energy, December 2020
- AnyMOD.jl, Julia framework for energy system models with a focus on multi-period capacity expansion, GitHub
- A graph-based formulation for modeling macro-energy systems, Applied Energy, November 2021
- AnyMOD.jl: A Julia package for creating energy system models, SoftwareX, December 2021
- Fictional expectations in energy scenarios and implications for bottom-up planning models, arXiv, December 2021
- How flexible electrification can integrate fluctuating renewables, submitted for publication, May 2022
- Stability analysis of the OSMOSE scenarios: main findings, problems, and solutions adopted, AEIT Conference, 4-8 Oct. 2021

THANK YOU

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And now
Q&A!

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