MINOA
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Solving European Electricity System Optimization problems using the latest Modelling and Optimisation methods advances

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The electricity system: context and challenges

The European Energy Transition

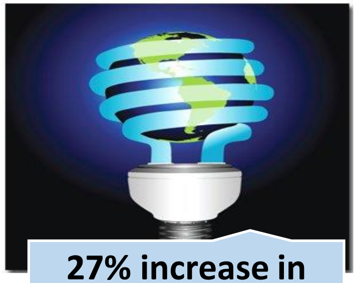
2050 EU’s carbon reduction targets ⇒ High share of Renewable Energy

Criteria for the European Energy System in 2050:

- ✓Sustainability
- ✓Security of supply
- ✓Competitiveness

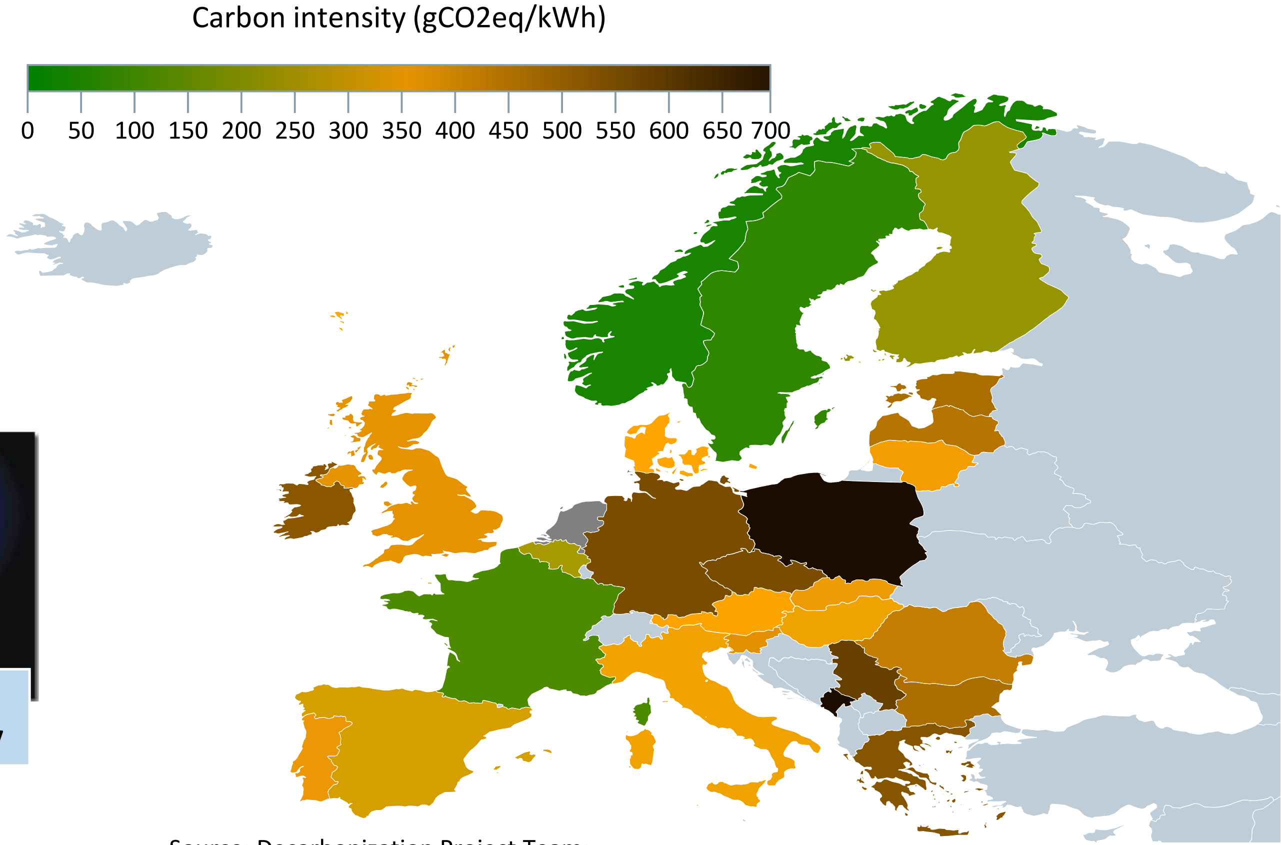
At least 27% RES-E

40% Reduction in GHG emission



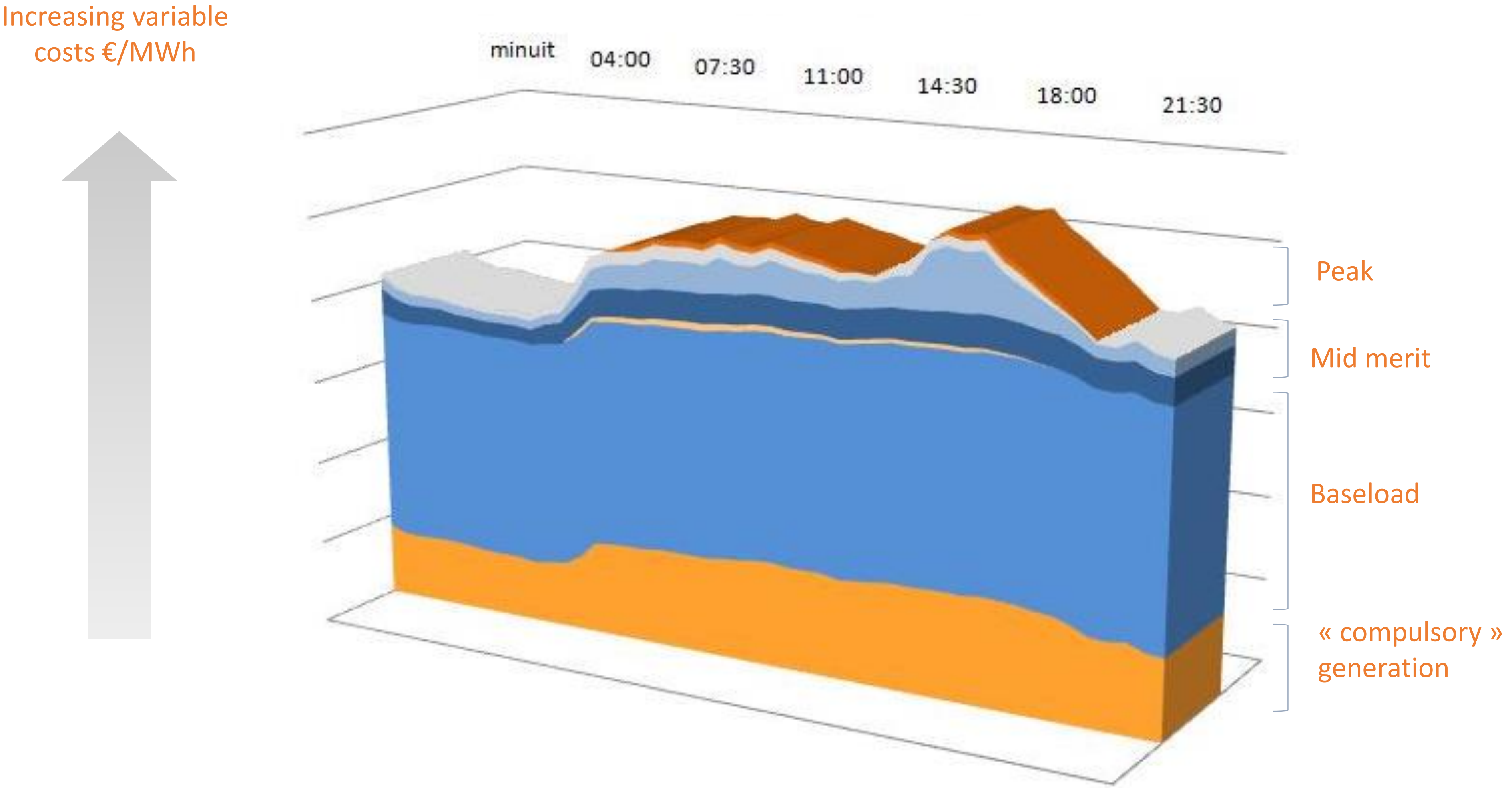
27% increase in energy efficiency

EDF

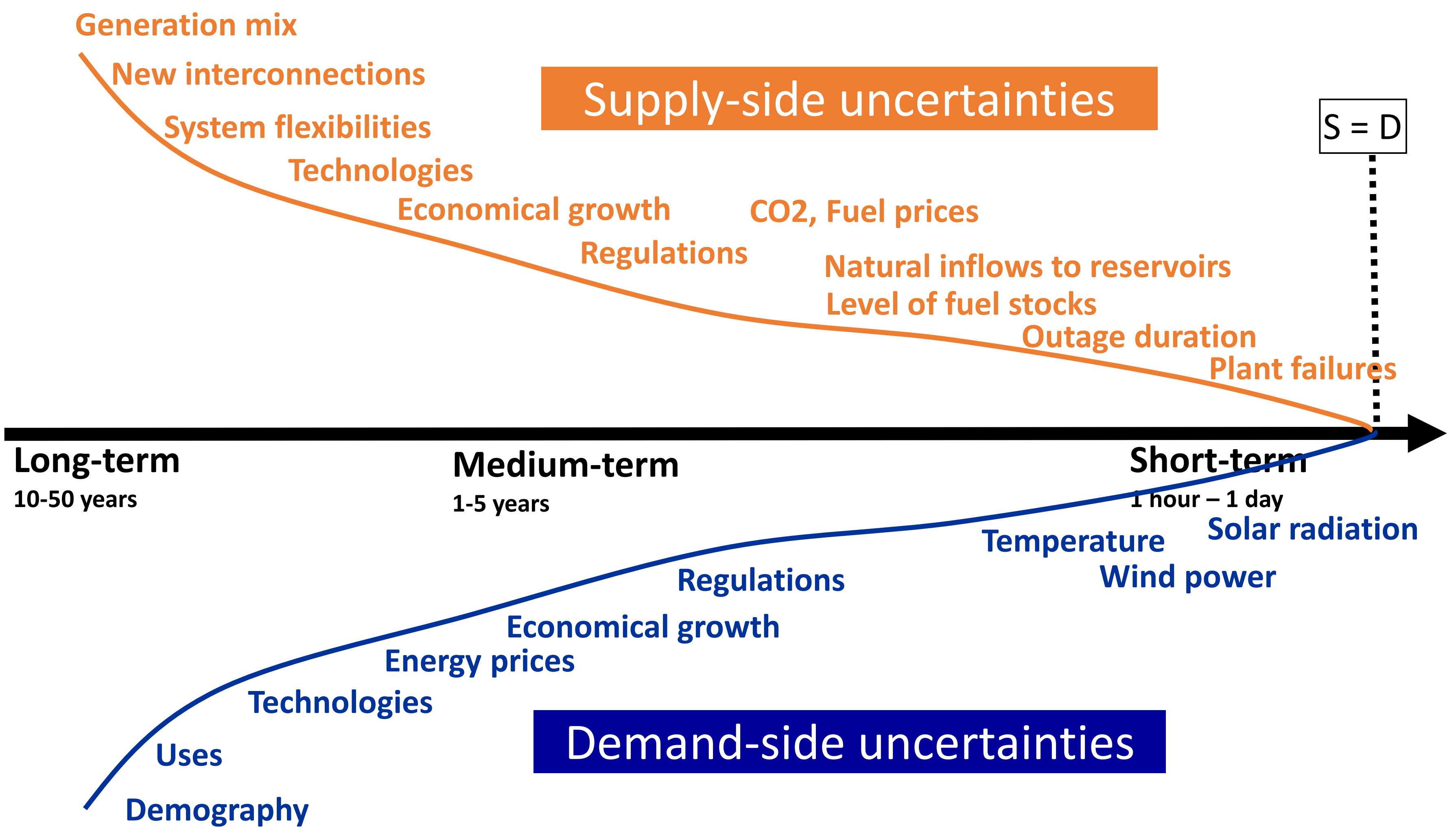


Source: Decarbonization Project Team; http://www.electricitymap.org/

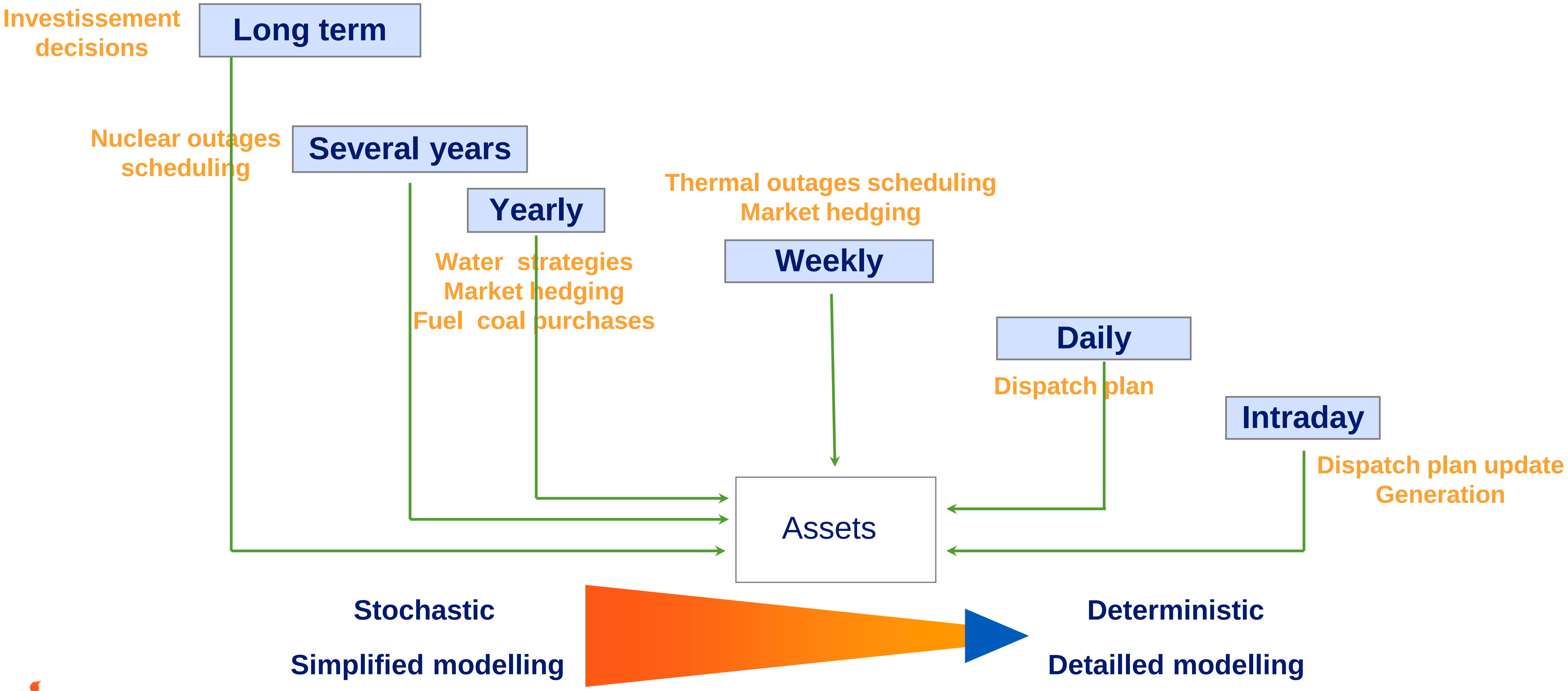
Scheduling of electricity: supply-demand balance



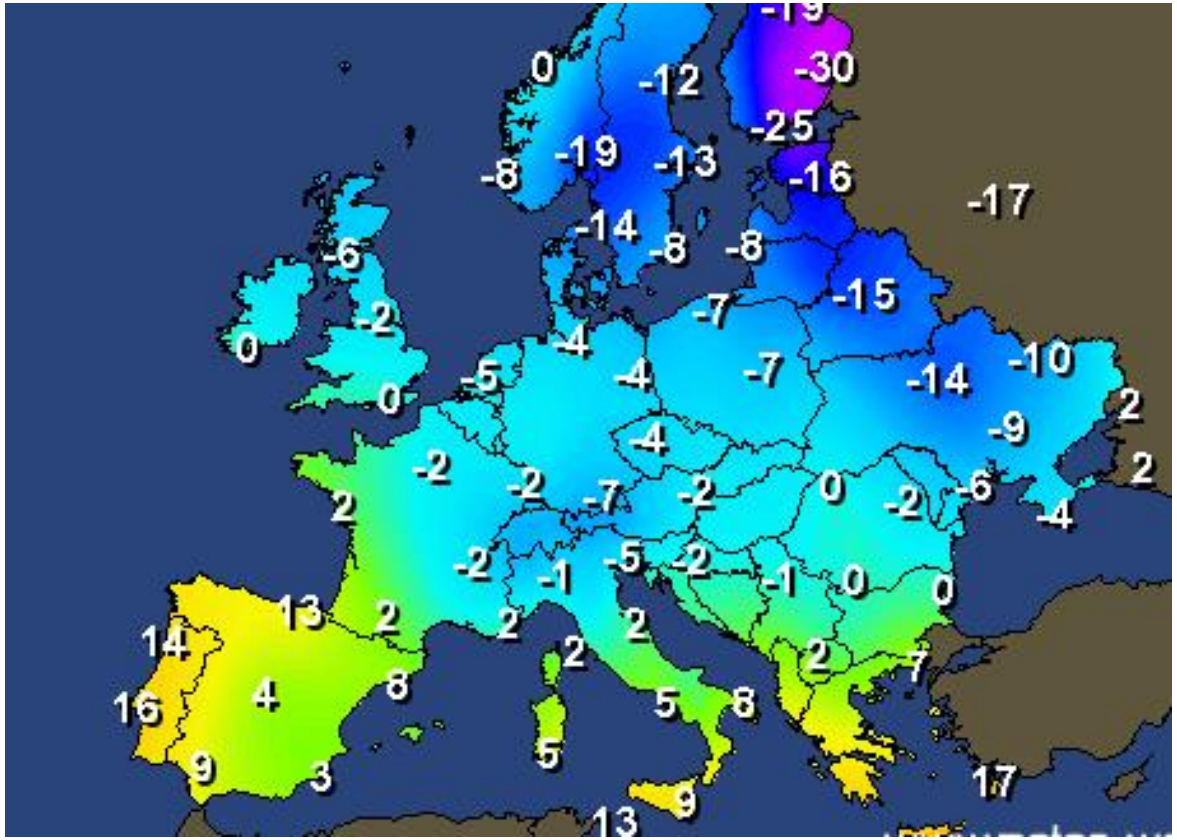
From long to very short term



The management process



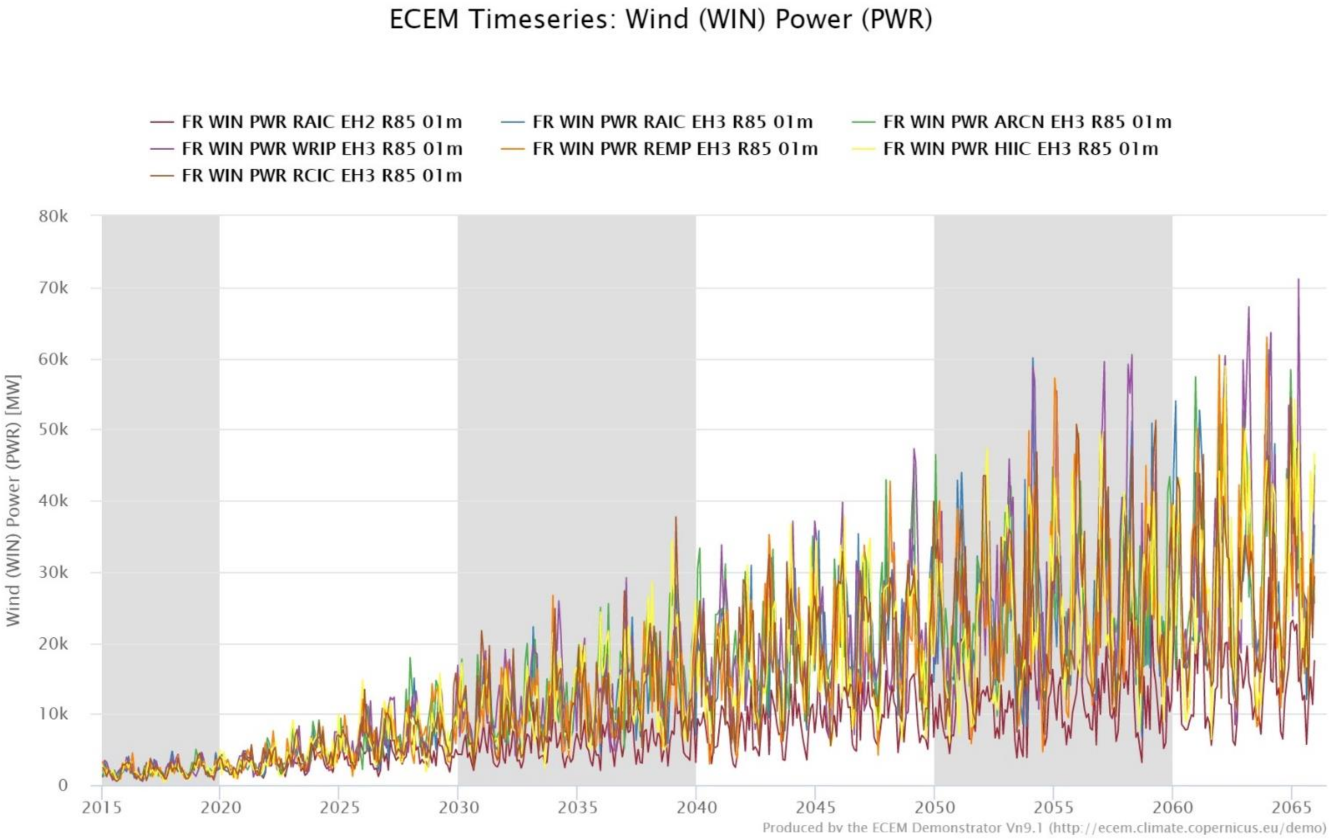
A highly interconnected system



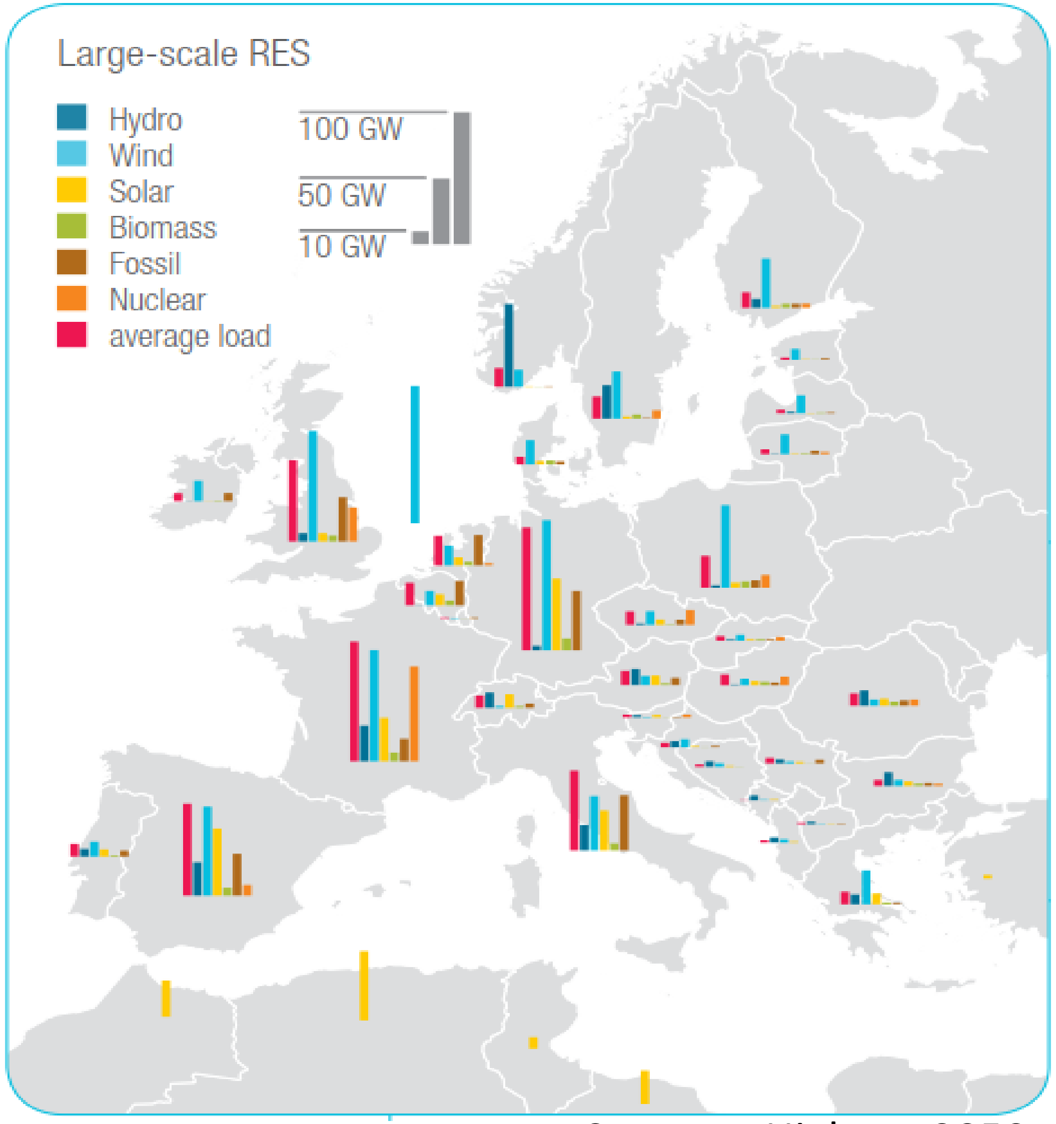
Significant and increasing interconnections

Demands and RES generations (partially) correlated at European level

With and increasing level of uncertainties



Source: C3S Energy/ECEM demonstrator



Source: eHighway2050

An increased Need for flexibility

Uncertainties + Security of supply

Need for More flexibility

Need for Integrated simulation models:

- Detailed (as much as possible) representation of all flexible assets and network
- Including uncertainties

Detailed Modelling of complex and big size problems

Need for enhanced solving methods

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Modelling and solving

The plan4res project

plan4res: Synergistic approach of Multi-Energy Models for a European Optimal Energy System Management Tool

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773897

The plan4res project

<u>Implement models and tools</u> that provide

an integrated energy system representation able to optimize and simulate expansion and operation with a high share of Renewable Energy

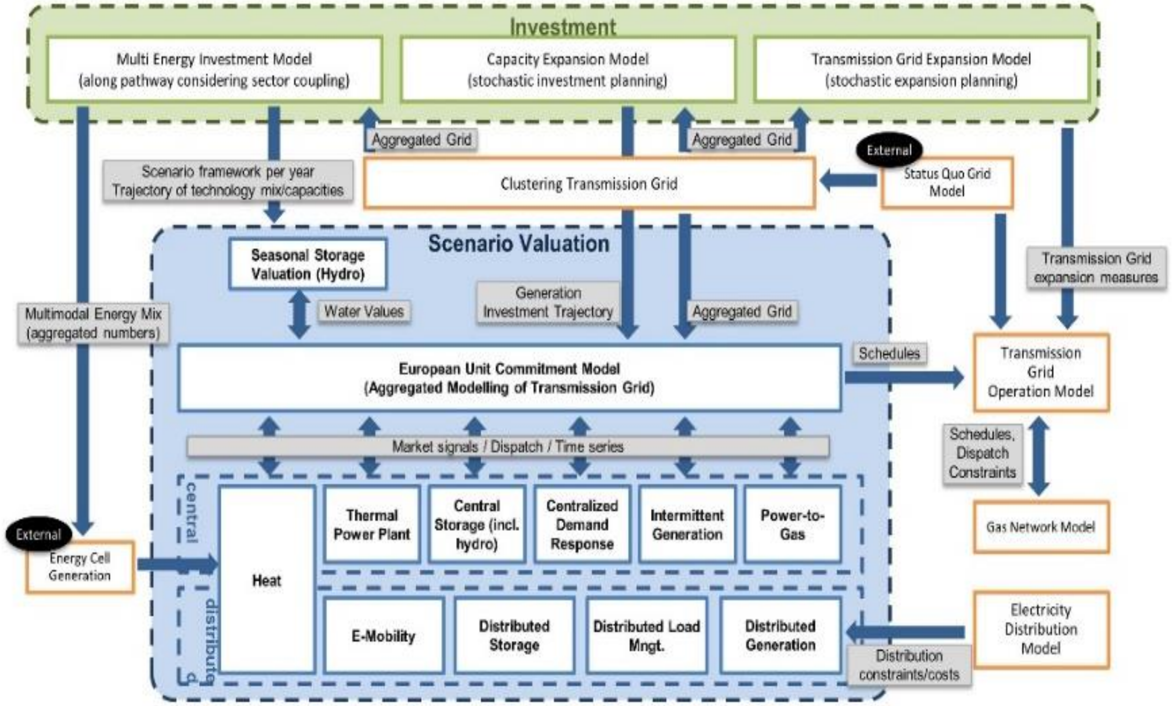
For contributing to European targets for reduction of emissions while maintaining high quality of supply at lowest cost

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773897

Integrated modelling of the electricity system

An end-to-end planning and operation tool, composed of a set of optimization models based on an integrated modelling of the pan-European Energy System

- **Investment layer**: Determine investment decisions
- **Scenario valuation**: Evalute investment decisions/operational planning
- **Analysis/additional tools**: Impact of scenario on electricity & gas grid



Capacity Expansion

Design the optimal generation, transmission and distribution mix for a given long-term horizon (eg. 2050)

$$\min_{\kappa} \left\{ C^{inv}(\kappa) + \max_{\eta \epsilon \Upsilon} C^{op}(\kappa, \eta) \right\}$$

$\boldsymbol{\kappa}$: Investment decisions (generation assets, transmission)
$\boldsymbol{\Upsilon}$: Set of uncertainty scenarios
$\boldsymbol{C^{inv}}$: Costs induced by installing capacitiy κ
$\boldsymbol{C^{op}}$: Expected operational costs with given capacity κ

Seasonal Storage Valuation

Compute strategies for managing seasonal storage on a mid-term horizon (eg 1 year)

$$C^{op}(\kappa) = \min_{x \epsilon \mathcal{M}} \mathbb{E}\left[\sum_{s \epsilon S} C_s(x_s)\right]$$

$\boldsymbol{C^{op}(\kappa)}$: Operational costs depending on investment decisions κ

$\boldsymbol{C_s}$: Operational costs on sub-period s

$\boldsymbol{\mathcal{M}}$: Feasible set associated with operation decisions

$\boldsymbol{S}$: Set of sub-periods (e.g. weeks)

$\boldsymbol{x}$: Operation decisions on sub-period s

$\boldsymbol{\kappa}$: Investment decisions taken by capacity expansion model

Unit Commitment

Compute dispatch for all assets on a short-term horizon (eg. 1 week)

$$\min \sum_i C_i^{op}(p_{:,i}, p_{:,i}^{pr}, p_{:,i}^{sc}, p_{:,i}^{he}) + \alpha(v^{hy})$$

$\boldsymbol{C_i^{op}}$: Operational costs of unit i subject to it‘s operational variables

$\boldsymbol{p_{t,i}, p_{t,i}^{pr}, p_{t,i}^{sc}, p_{t,i}^{he}}$: Provision of power, primary/secondary reserve, heat by unit i in timestep t and dynamic constraints

$\boldsymbol{\alpha}$: Approximation of the value of seasonal storages

$\boldsymbol{v^{hy}}$: Storage level

Submodels

❑ Power plants

- Operational decision of power plants based on their specific fuel costs
- Technical constraints (ramping, min up-/downtimes,...)

❑ Storages

- Hydro storages including complex cascaded systems
- Battery storages

❑ Intermittent generation

- Generation of wind, solar, run of river based on meteorological profiles

❑ E-mobility

- Storage capability of electric vehicles (vehicle-to-grid, power-to-vehicle)
- Limitation of storage availability by driving profiles

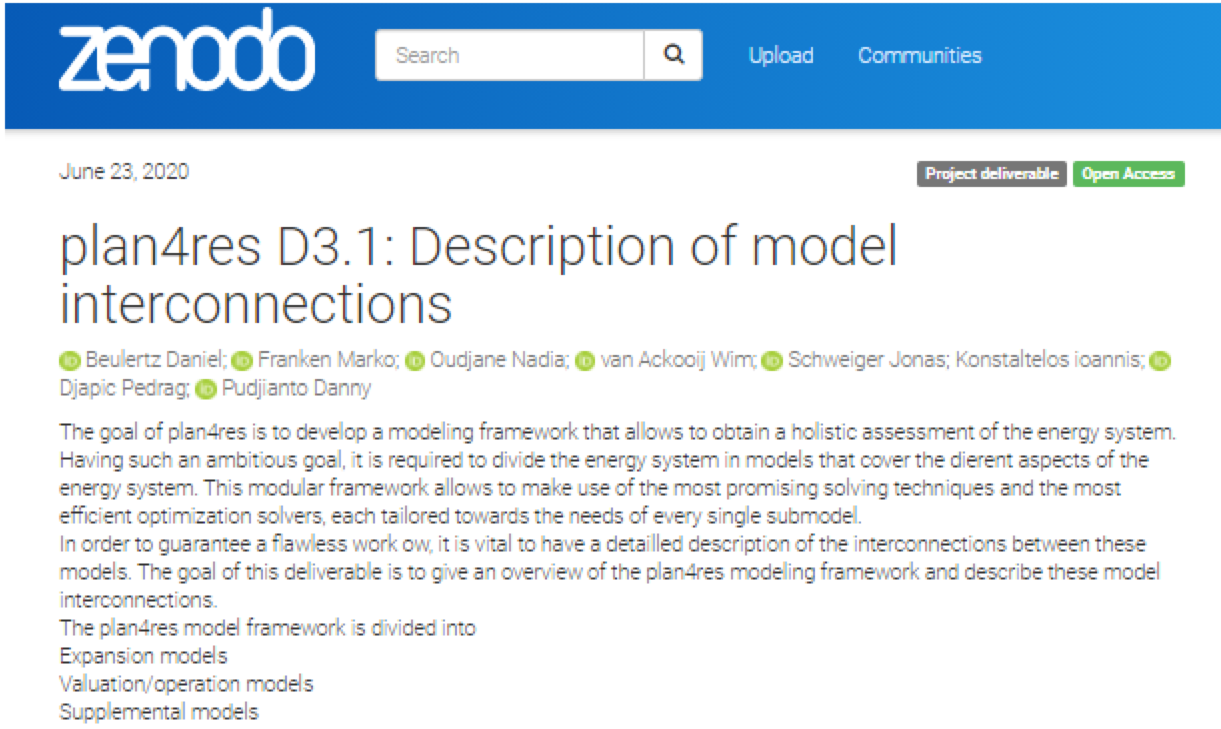
❑ Load management

- Load shifting of a given energy consumption during a sub-period
- Load curtailment based on a given potential (e.g. during one year)

Detailed modelling

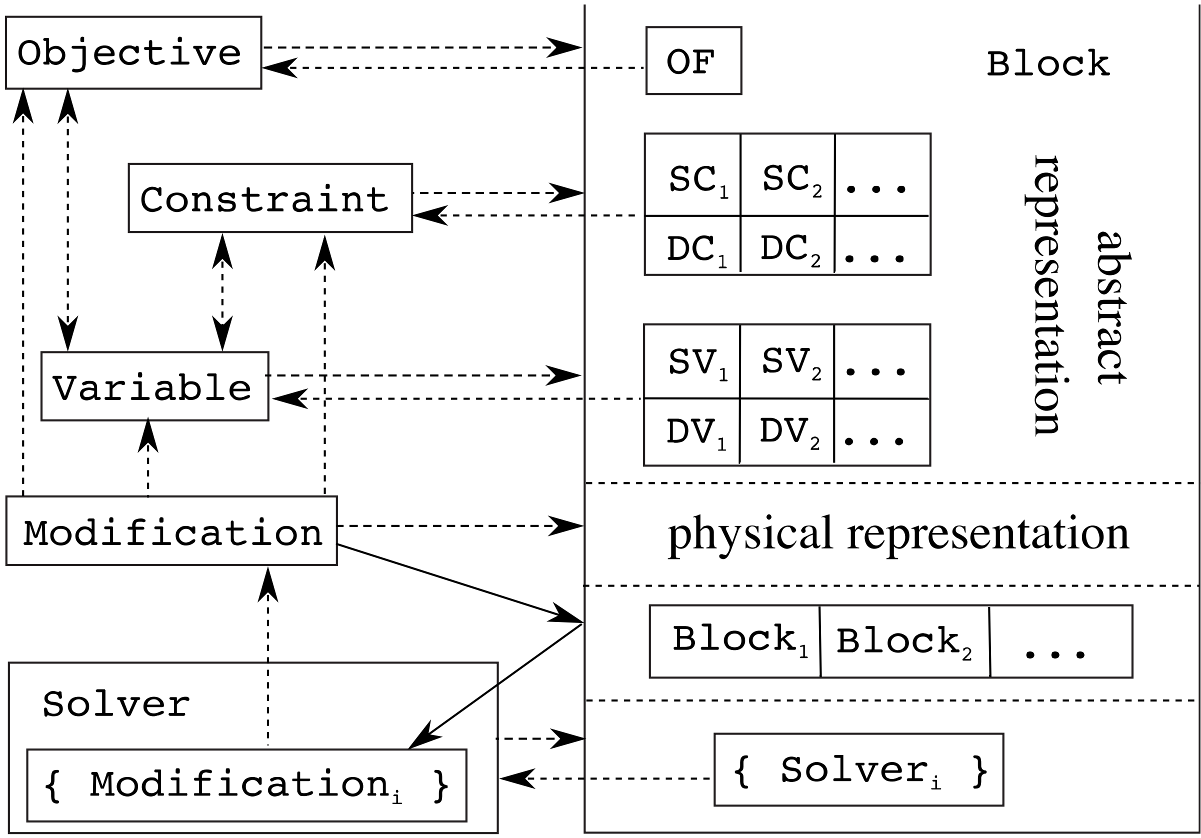
Detailed equations are available on:

https://zenodo.org/record/3904272#.YD3yFmhKjIU



Modelling with SMS++

- **SMS++ is a set of C++ classes implementing a modelling system that:**
- allows exploiting specialised solvers
- manages all types of dynamic changes in the model
- Explicitely handles reformulation/restriction/relaxation
- does parallel from the start
- should be able to deal with almost anything (bilevel, PDE,..)
- ***Includes specialized blocks for energy system modelling***

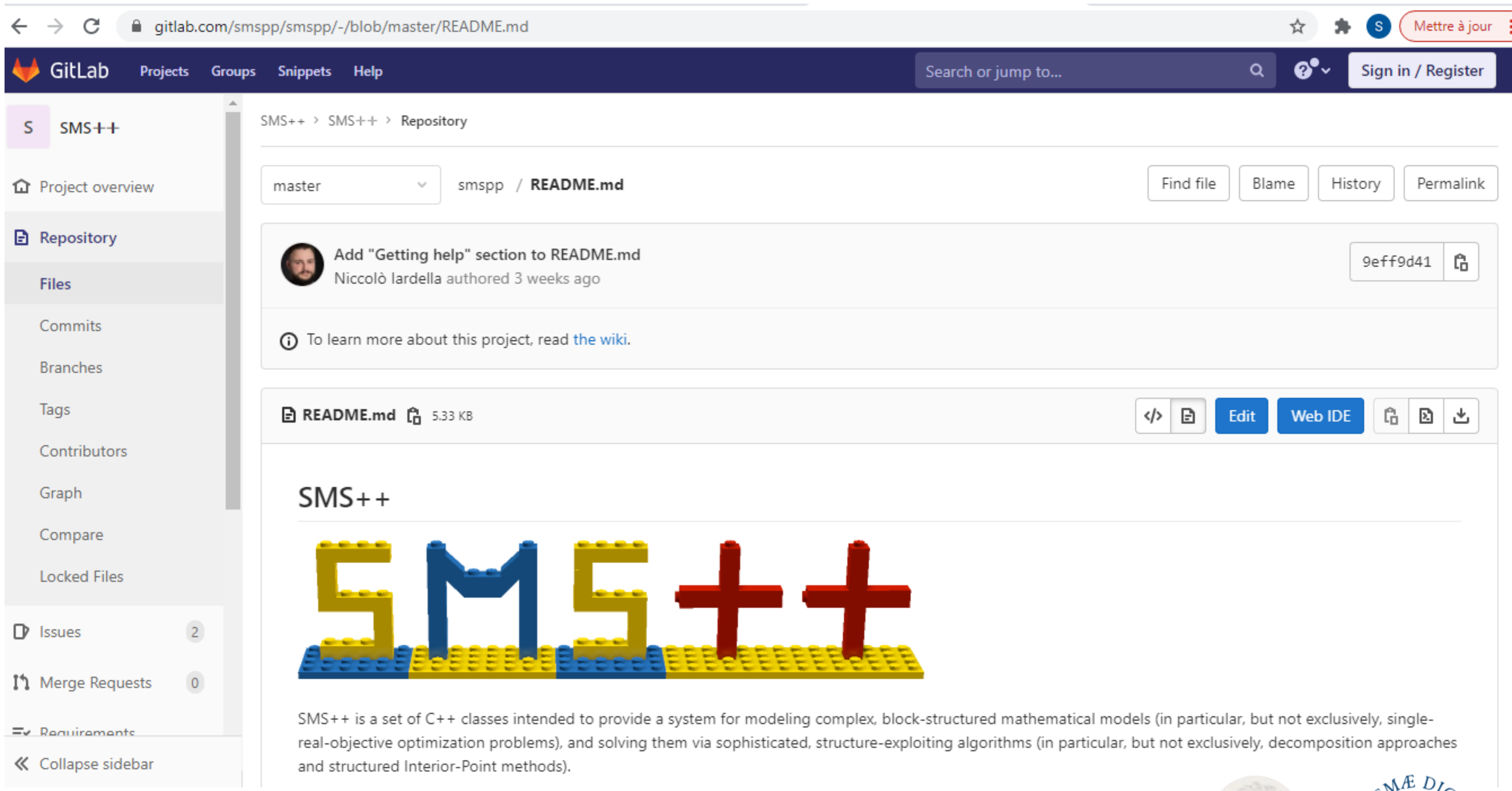


Modelling with SMS++

SMS++ is available on

https://gitlab.com/smspp

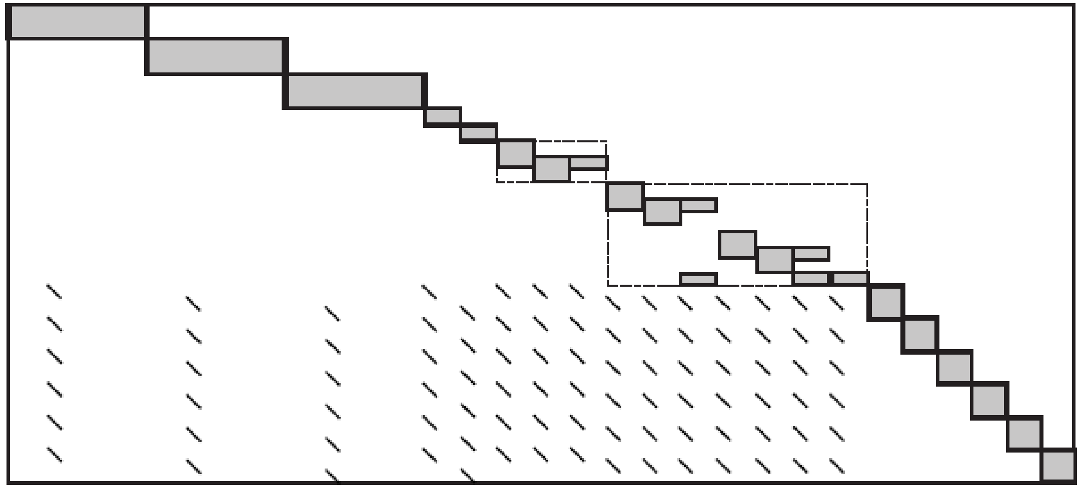
Listen for a full SMS++ presentation at 'ESR Days', Thursday 11'30, by Antonio Frangioni



Modelling with SMS++

Nested decompositions at different time horizons

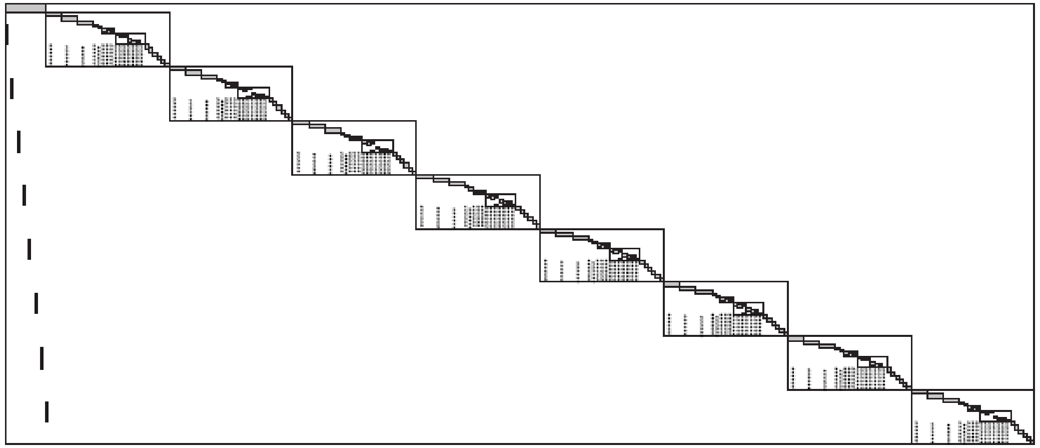
- Schedule a set of generating units to satisfy the demand at each node of the transmission network at each time instant of the horizon (24h)



- Several types of almost independent blocks + linking constraints
- Perfect structure for Lagrangian relaxation[1,2]

[1] Borghetti, F., Lacalandra, Nucci "Lagrangian Heuristics Based on Disaggregated Bundle Methods [...]", *IEEE TPWRS*, 2003
[2] Scuzziato, Finardi, F. "Comparing Spatial and Scenario Decomposition for Stochastic [...]" *IEEE Trans. Sust. En.*, 2018

- Manage water levels in reservoirs considering uncertainties (inflows, temperatures, demands, ...) to minimize costs over the time horizon

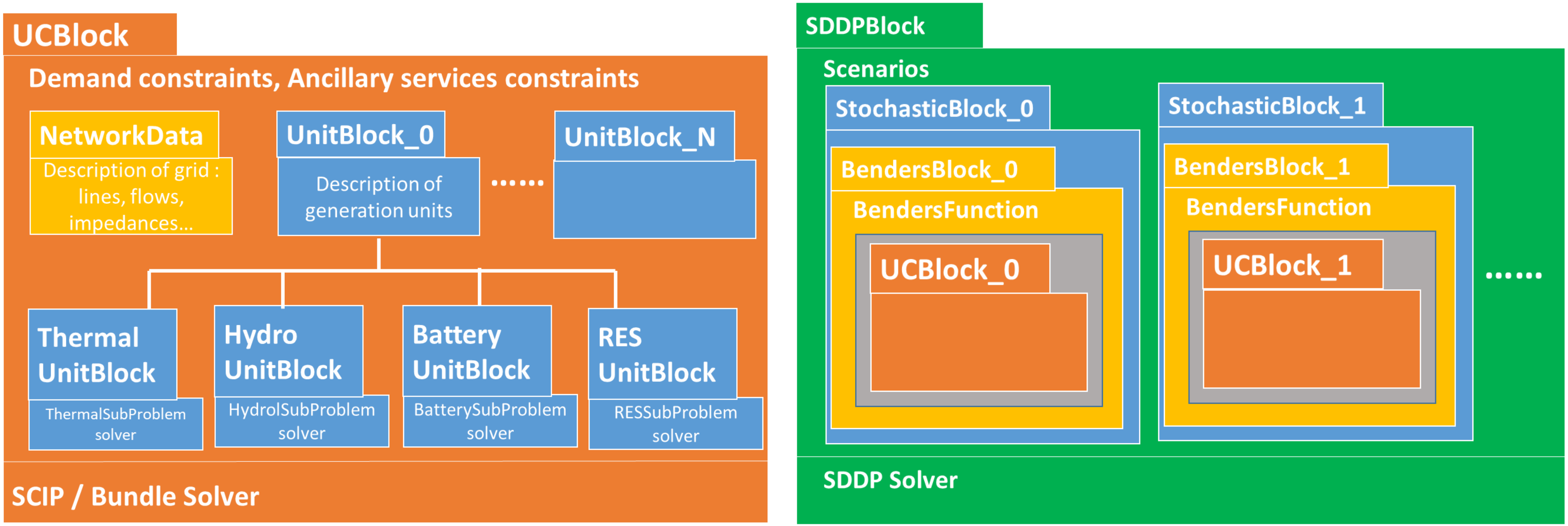


- Very large size, nested structure
- Perfect structure for Stochastic Dual Dynamic Programming[3,4] with multiple EUC inside

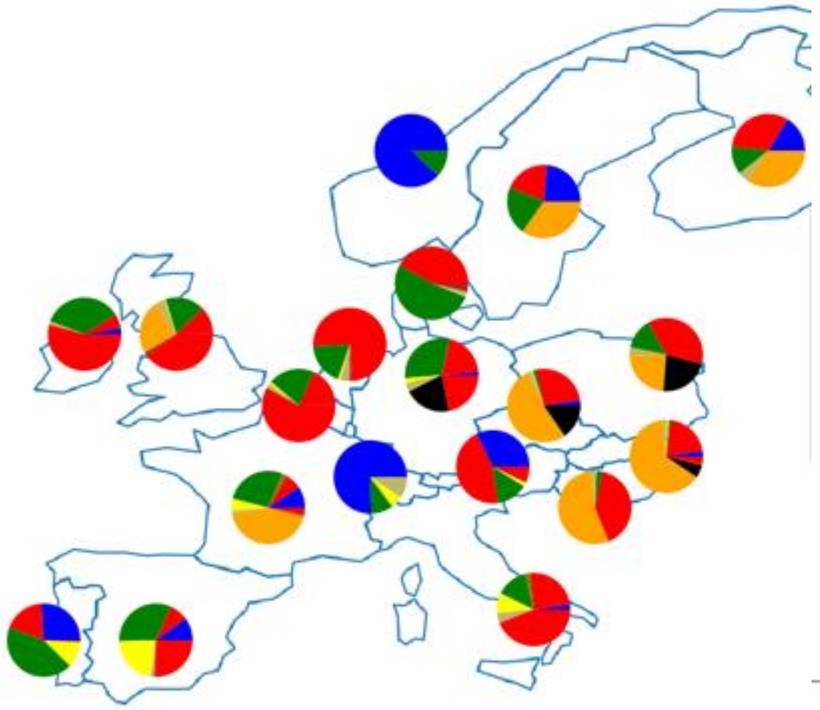
[3] Pereira, Pinto "Multi-stage stochastic optimization applied to energy planning" *Math. Prog.*, 1991
[4] van-Ackooij, Warin "On conditional cuts for Stochastic Dual Dynamic Programming" arXiv:1704.06205, 2017

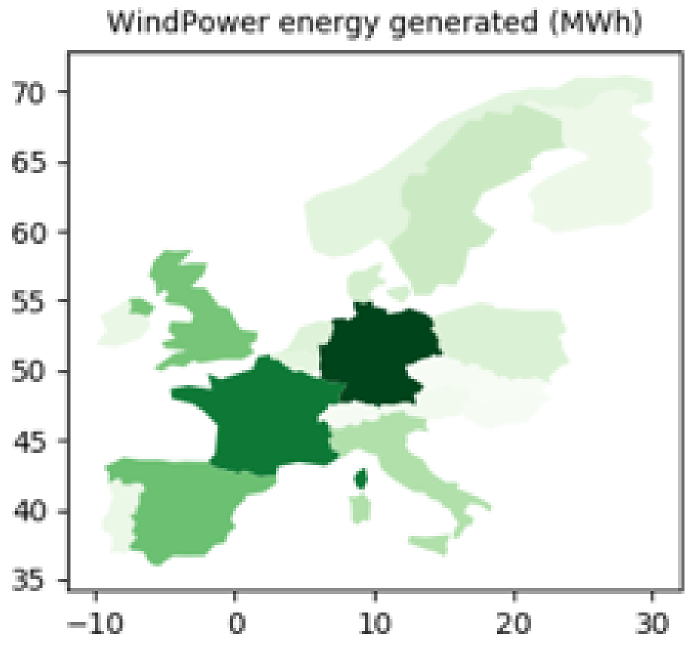
Source: A. Frangioni, Uni Pisa

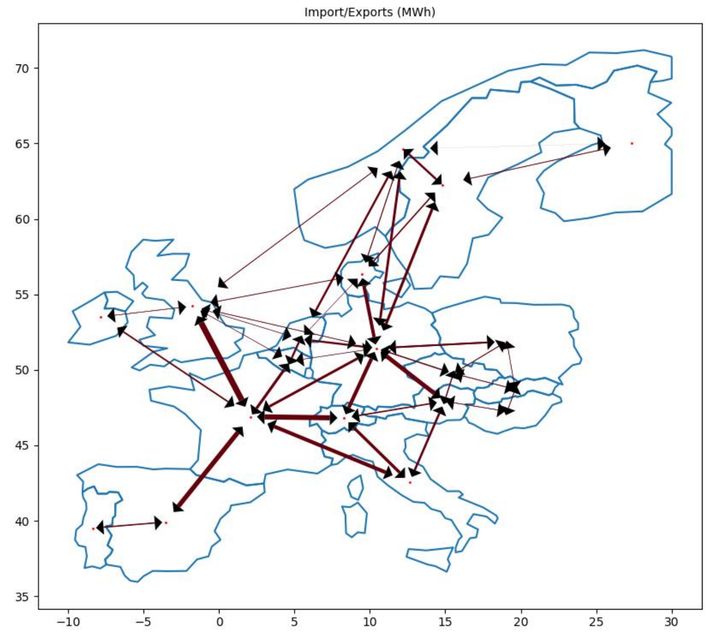
The Seasonal Storage Valuation and Unit Commitment in SMS++

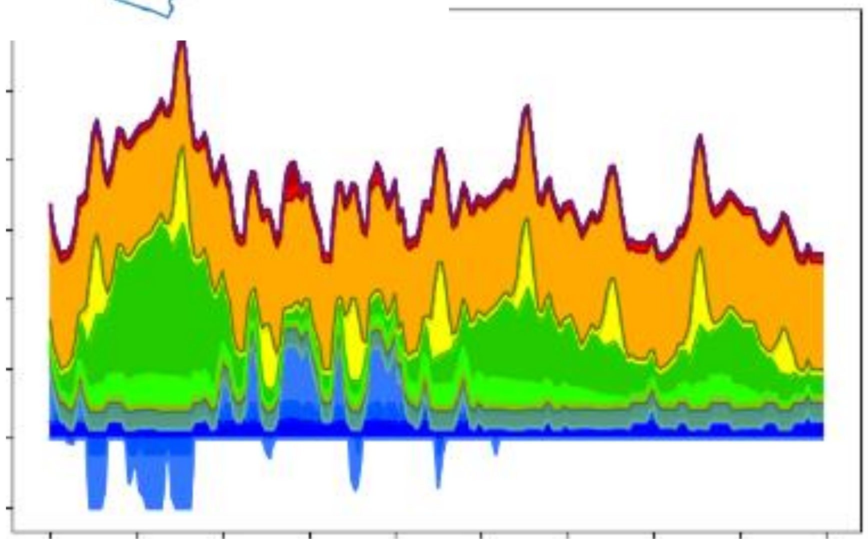


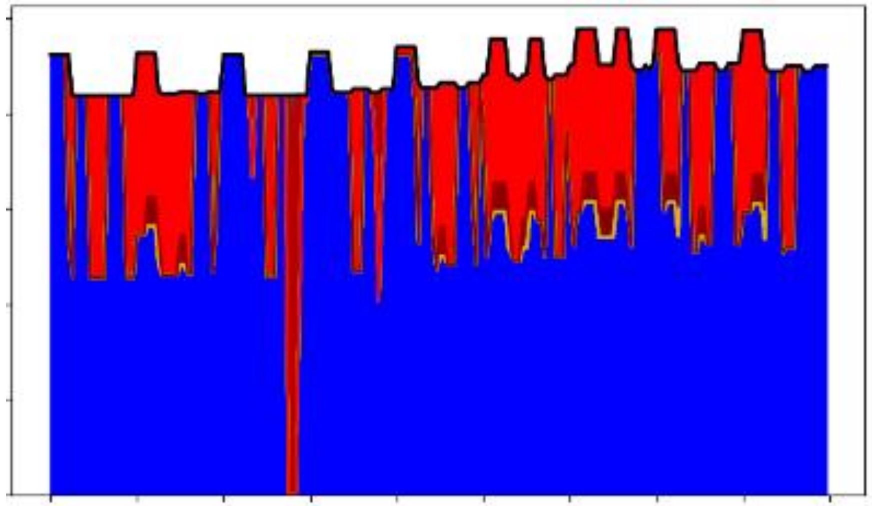
Examples of Results







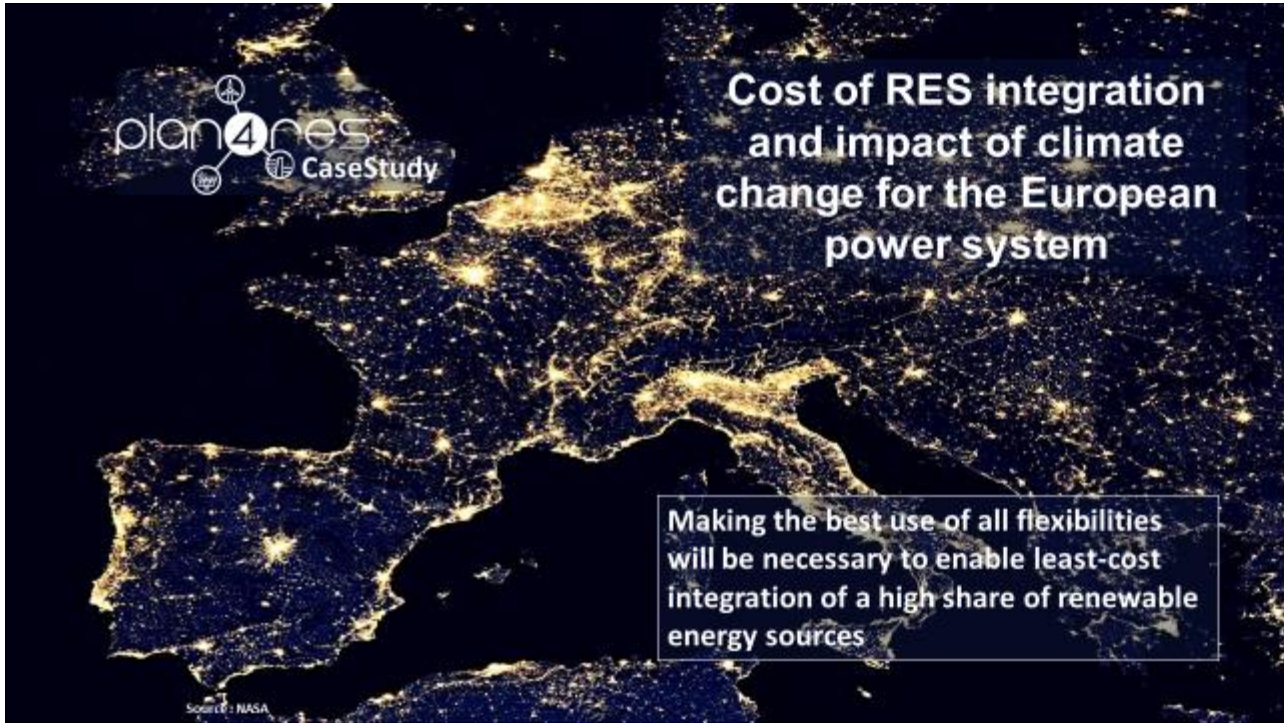




3 Perspectives

Use Cases

- What Impact do different levels of RES integration have on system costs?
  - Electricity generation cost
  - Cost to ensure the dynamic robustness of the system (Reserves, Inertia)
- What is the value of flexibility? (system cost reduction coming from using flexibility potentials of different system assets)
  - RES can be represented as non-flexible, i.e. all generation is 'fatal' or we can account for their ability to be curtailed or can contribute to ancillary services
  - Flexibilities from storages and additional storages can be represented
  - Different demand response flexibilities can be modelled

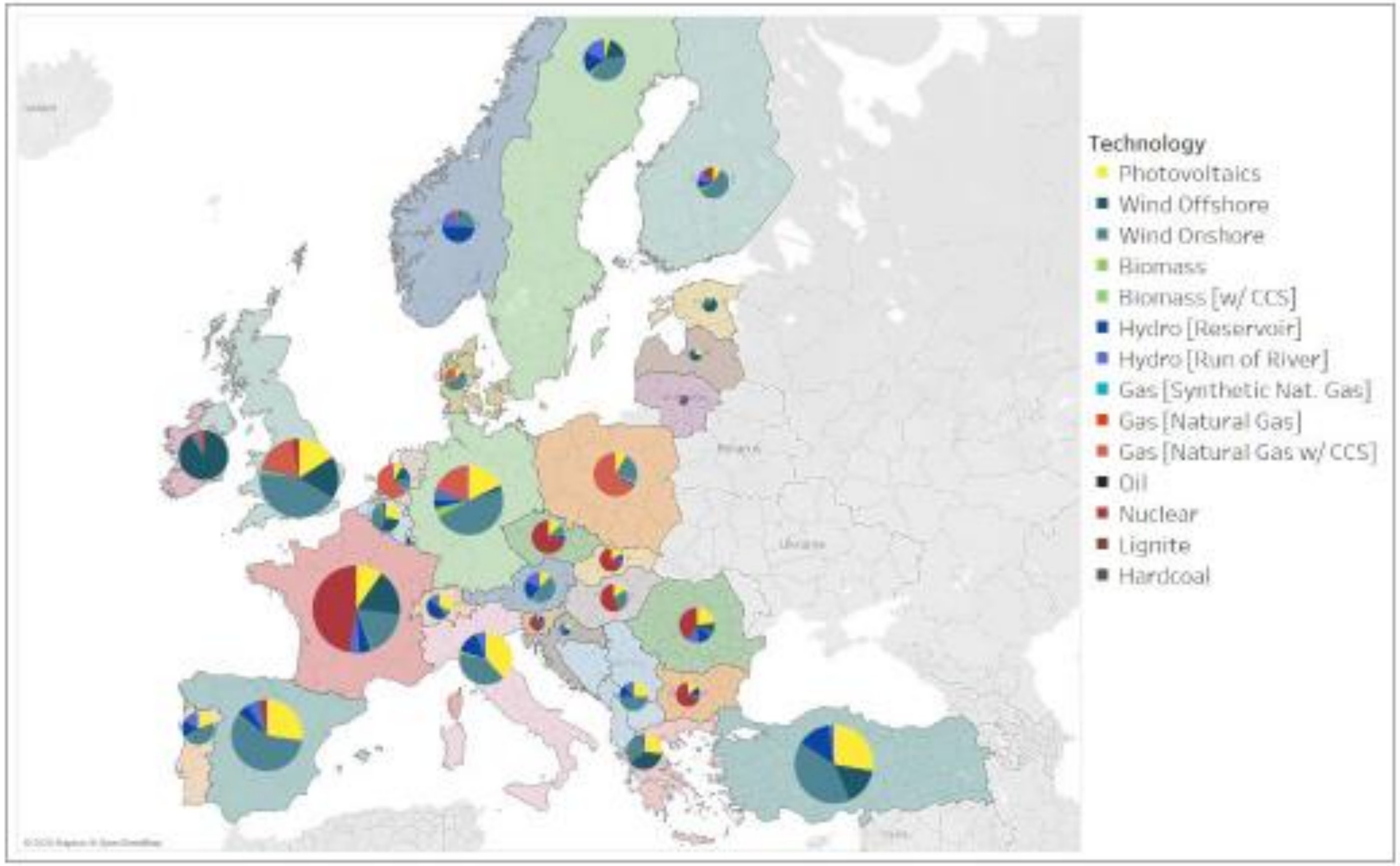


Use Cases

❑ Assesment of the feasibility and cost of a long-term scenario

openENTRANCE scenarios 2025-2050

file:///C:/Users/F04340/Downloads/openENTRANCE-D3.13.pdf



Use Cases

❑ Case Studies in openENTRANCE

Demand response – behaviour of individuals

Exploits recent real-life data on households' demand-response capabilities from field-tests across the EU to assess accurate response potentials and their impacts on the European power system.

Need of flexibility – sector coupling

Focus on transport sector coupling technologies such as electric vehicles and electric overhead-line trucks. It aims to assess how associated flexibility potentials can be tapped when local information and regional (distribution) network constraints are included in the analysis.

Decentralisation

Comparison of different levels of European/national coordination aimed at facilitating the integration of local/regional decentralisation.

❑ See more : www.openentrance.eu

Further potential uses

- Short-term generation management (including detailed hydro)
- Other energy related problems

Thanks

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www.plan4res.eu