EURO Practitioners’ Forum 4th Annual Conference

April 20, 2023

OR challenges related to the electricity system transition: a glance at some latest modelling and solving advances

EDF GROUP : KEY FIGURES

€85 billions revenue
167 000 Salariés

2nd in the world as Electricity Utility

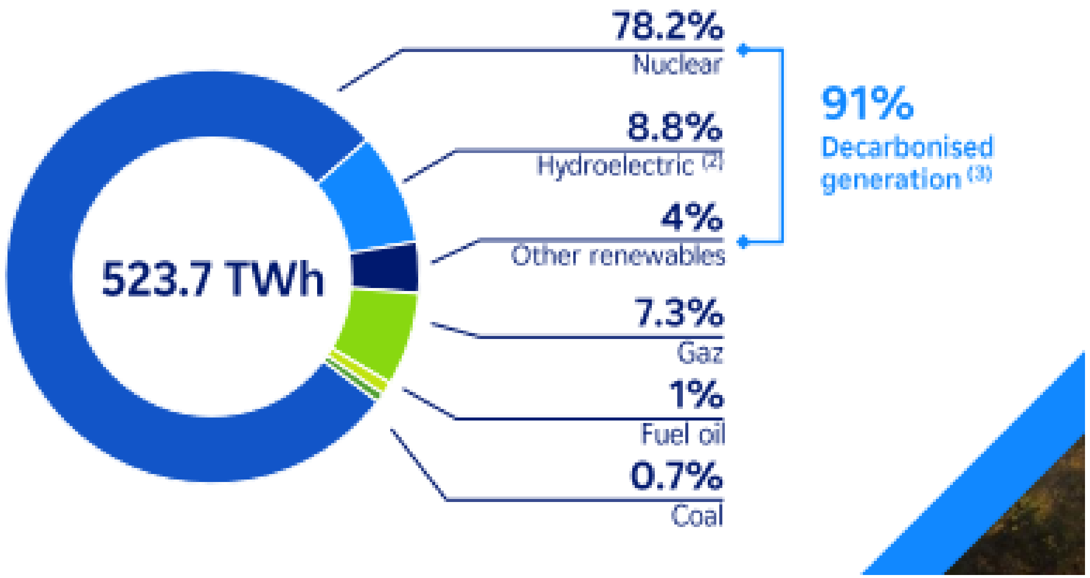
World leader in
CARBON FREE ELECTRICITY

1. N°1 **in the world for nuclear energy**
2. N°1 **in Europe for renewable energy**
3. N°3 in Europe **for energy** services

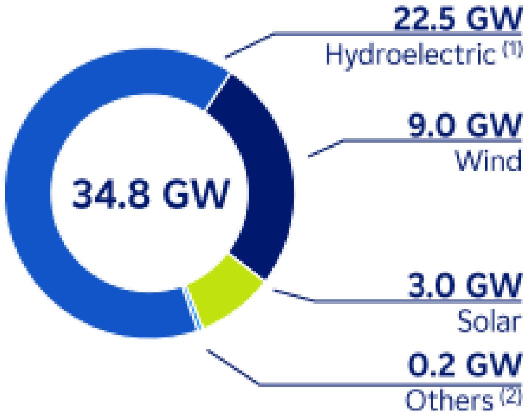
All EDF Activities related to ELECTRICITY

1. **Power generation**
2. **Power grid**
3. **Supply grid**
4. **Trading**
5. **Energy services**

Our generation mix by sector (in TWh, 2021) (1)



Our renewables generation mix by sector
(in GW net, at end of 2021)



« to build a net zero energy future with electricity and innovative solutions and services, to help save the planet and drive wellbeing and economic development. »

Electric mobility Plan

By 2023, achieve:

- 30% market share for the supply of electricity in France, the UK, Italy and Belgium
- 150,000 charging stations in Europe
- 10,000 smart charging stations

Electricity storage Plan

By 2035, develop:

- 10 GW of new storage capacity worldwide

By 2030:

- 1 million off-grid kits in portfolio

Solar Plan

By 2035, be:

- the leader in photovoltaic energy in France
- targeting a 30% market share

Excell Plan

For the nuclear sector:

- strive for excellence so it continues to play its full role in decarbonising energy

AIMS OF R&D

Improve EDF Group performance in all of its current ventures and enable its customers to benefit.

Prepare for the energy scenarios of the future by working on disruptive technologies.

Carry out **research for external commissioning bodies** within the framework of partnerships or orders.

R&D IN FIGURES

2,158 patents

11 pétaflops of computing capacity

20 joint **laboratoires**

EDF R&D SCIENTIFIC PLAN 2021-2024

1
2
3
4

FOCUS 1
DECARBONISING OUR CUSTOMERS' USES WITH ELECTRICITY

FOCUS 2
STRENGTHEN THE PERFORMANCE OF GENERATION ASSETS

FOCUS 3
INVENTING THE ENERGY SYSTEMS OF TOMORROW

FOCUS 4
ACCELERATE THE DIGITAL TRANSFORMATION

R&D OUR EXPERTISE

Consumer knowledge
Data Science
Economy
Electrotechnology
Telecommunications / Industrial data processing
Polymer / Corrosion chemistry
Energy efficiency
High-power electricity
Environment / Waste
Data processing - virtual reality / Augmented reality
Civil engineering
Scientific computing
Applied mathematics
IT / Telecom
Fluid mechanics
Mechanics
Mathematics / Physics / Computing
Neutronics technology
Cycle / Fuel physics
Intellectual property
Materials science metallurgy
Thermal-hydraulics and simulation

eDF

Content

1. The energy transition and the electricity system

2. Modelling the european electricity system

3. Case studiy: how residential flexibility can help the electricity system

1

The energy transition and the electricity system

The European Energy Transition

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

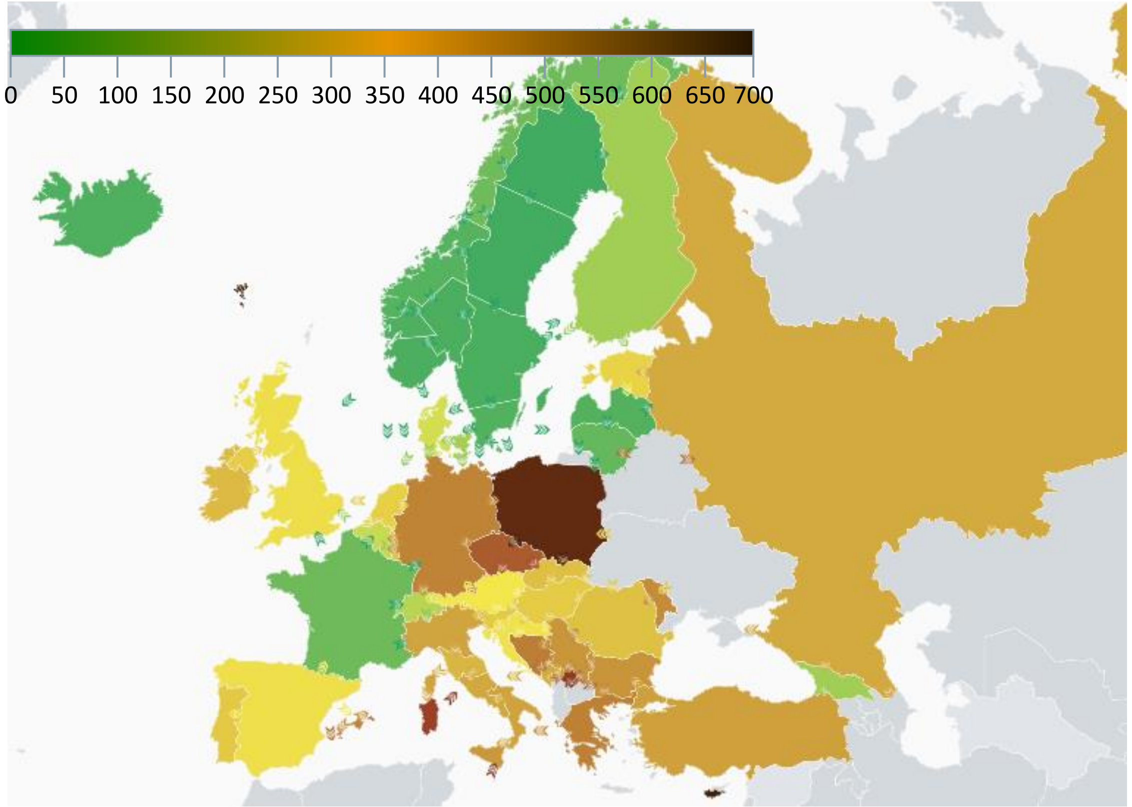
Criteria for the European Energy System in 2050:

- ✓Sustainability
- ✓Security of supply
- ✓Competitiveness

At least 40% RES-E in 2030

55% Reduction in GHG emission in 2030, 95% in 2050

Energy efficiency: 11.7% reduction in final energy consumption in 2030



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

EDF

Major changes of the European Energy transition

Objective: max +1.5 or 2 °C in 2050

⇒ Emissions in 2030 must be 1/3 of today's level

⇒ Phase out of fossil energies

⇒ ~1/2 residential and commercial Heating must convert to Heat Pumps in 2035

⇒ ~1/2 passenger transport must convert from traditionnal fuel

⇒ High energy efficiency measures are necessary to decrease the final energy consumption

⇒ **High increase of the electricity share**

Energy transition scenarios – the openEntrance project

open ENTRANCE

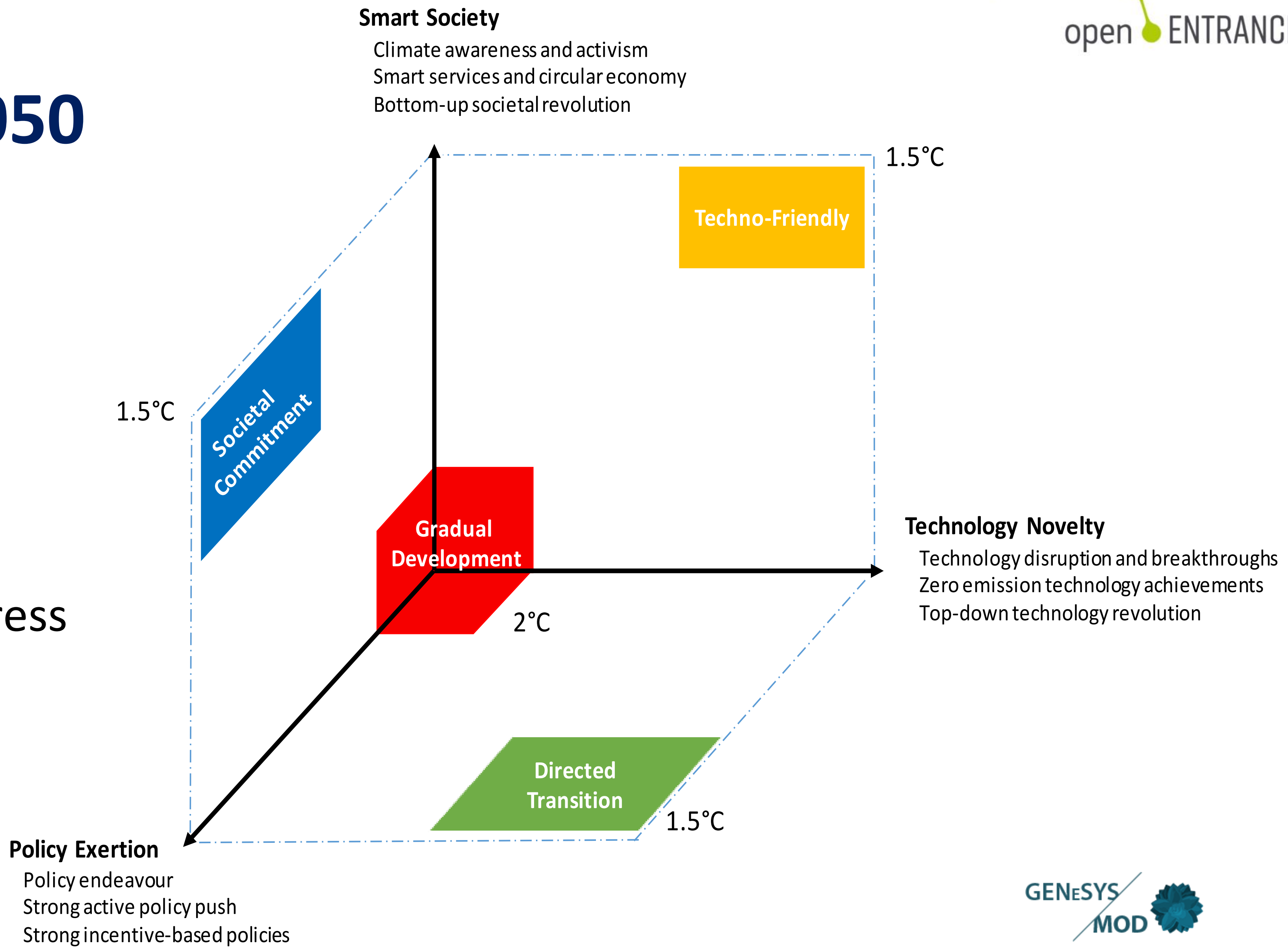
Aim: to develop, apply and disseminate an open, transparent and integrated modelling platform designed to assess low-carbon transition pathways in Europe

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 835896

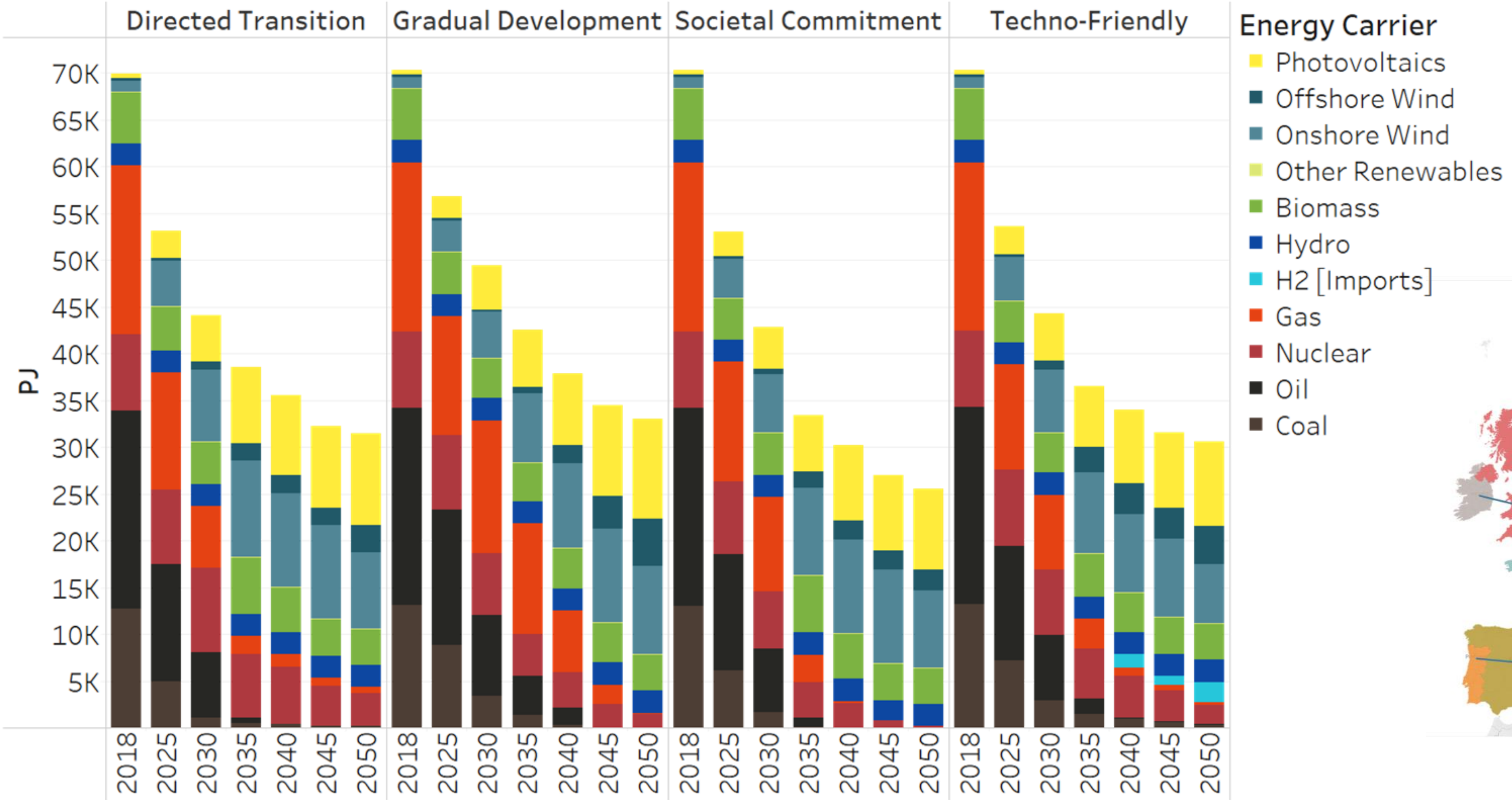
Energy transition scenarios

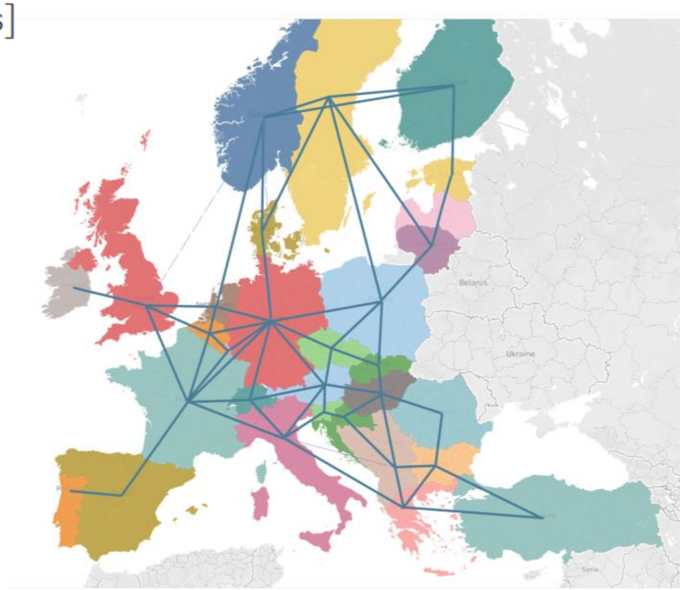
4 scenarios 2018-2050

- Directed Transition
  - Strong policy push
- Societal Commitment
  - Willingness of society
- Techno-Friendly
  - High technological progress
- Gradual Development
  - Little of everything

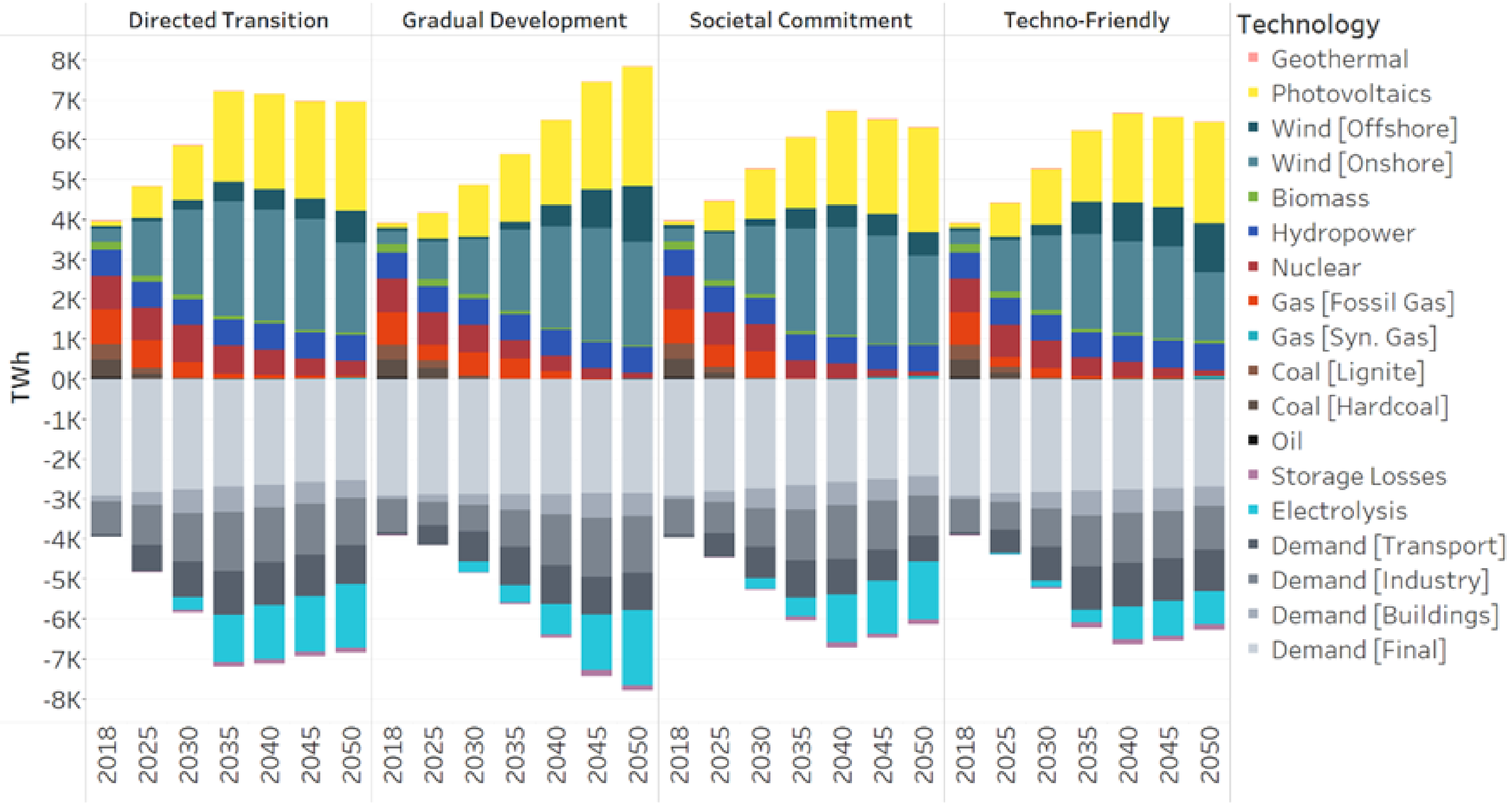


Energy transition scenarios – Primary Energy

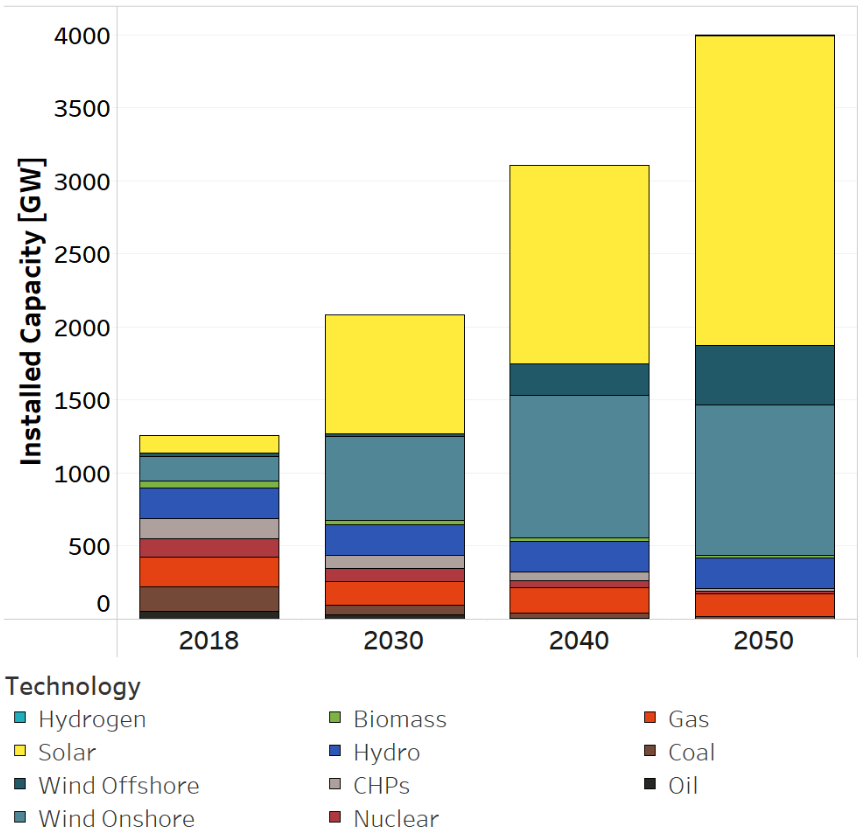


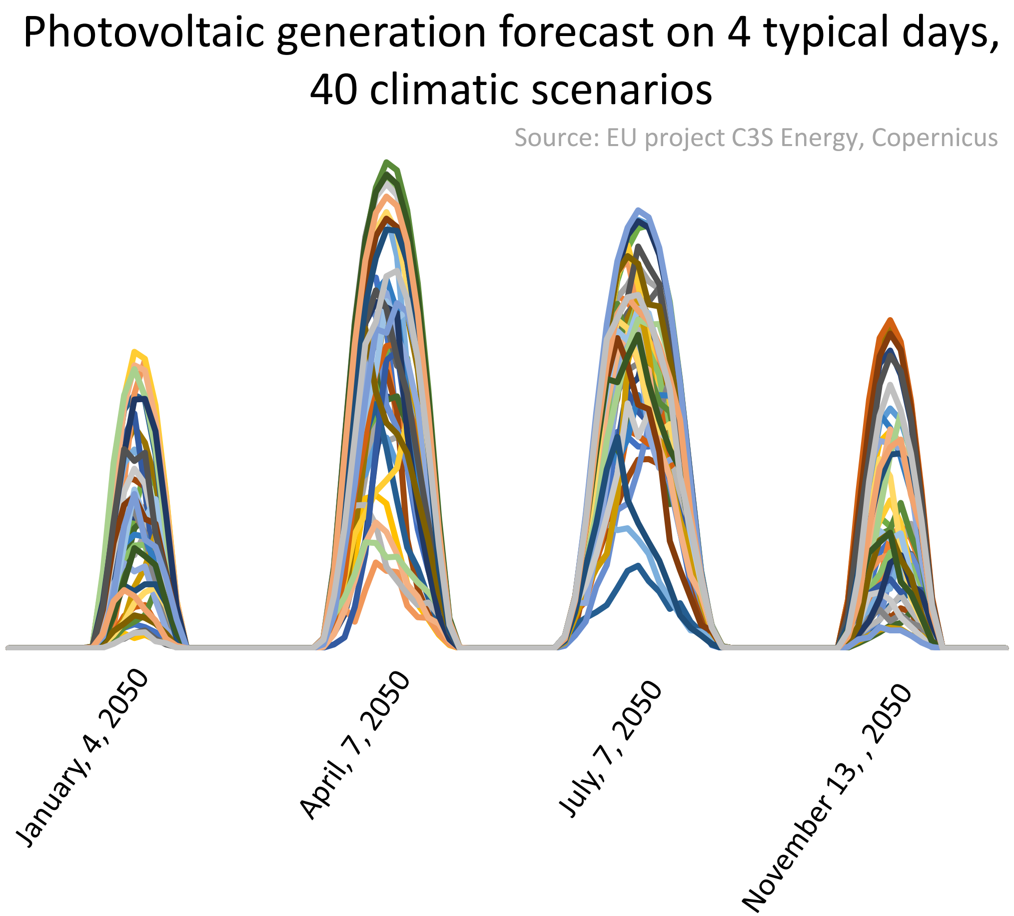


Energy transition scenarios – Electricity



The future power system will require more flexibility....





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

↓

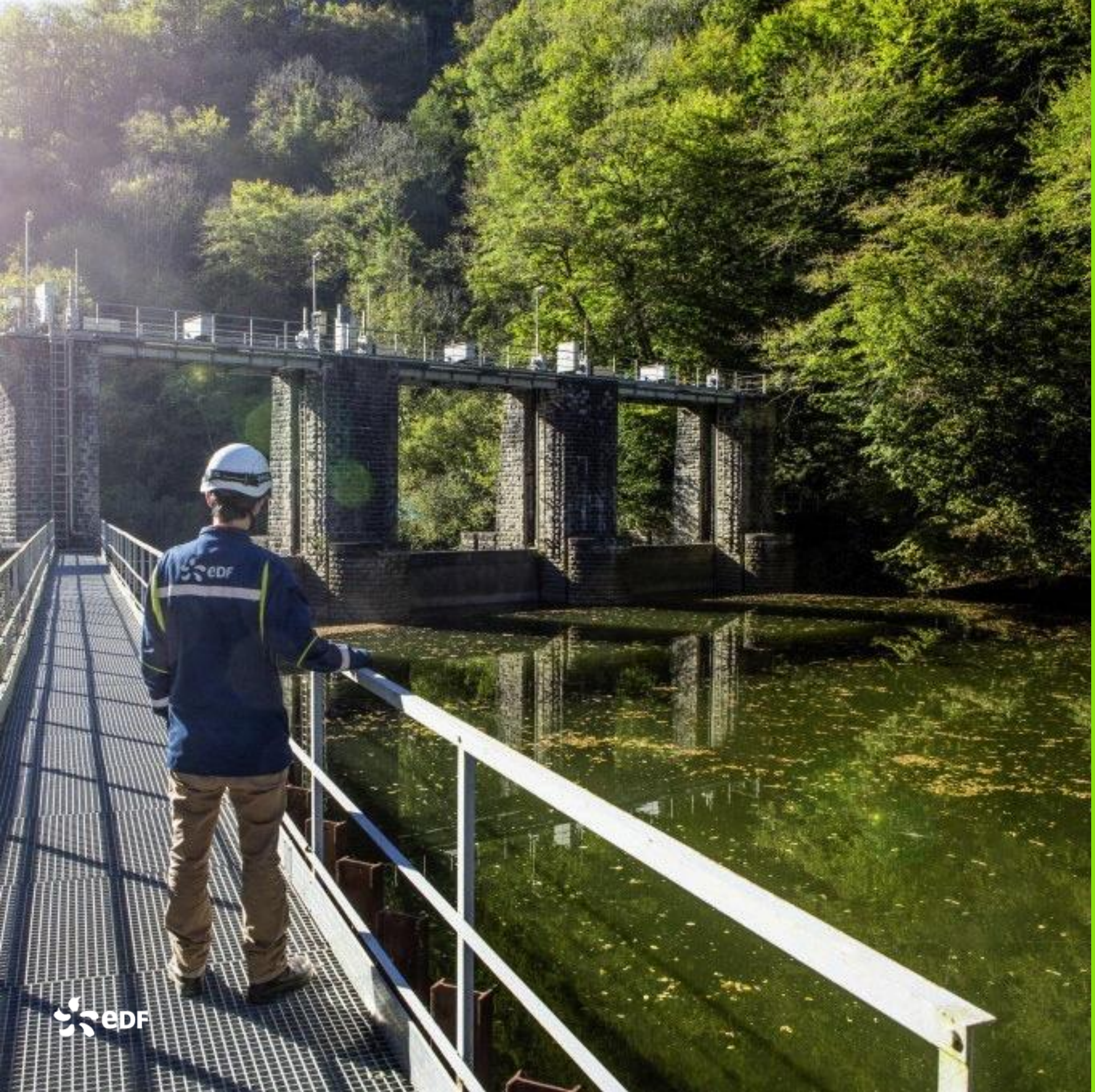
Detailed Modelling of complex and big size problems

←

Need for enhanced solving methods

2

Modelling the european electricity system



The plan4res modelling suite

The plan4res project

Hewlett Packard Enterprise · EDF · Università di Pisa · RWTH Aachen University · Siemens · UNIMORE Università degli Studi di Modena e Reggio Emilia · ZIB · Imperial College London

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

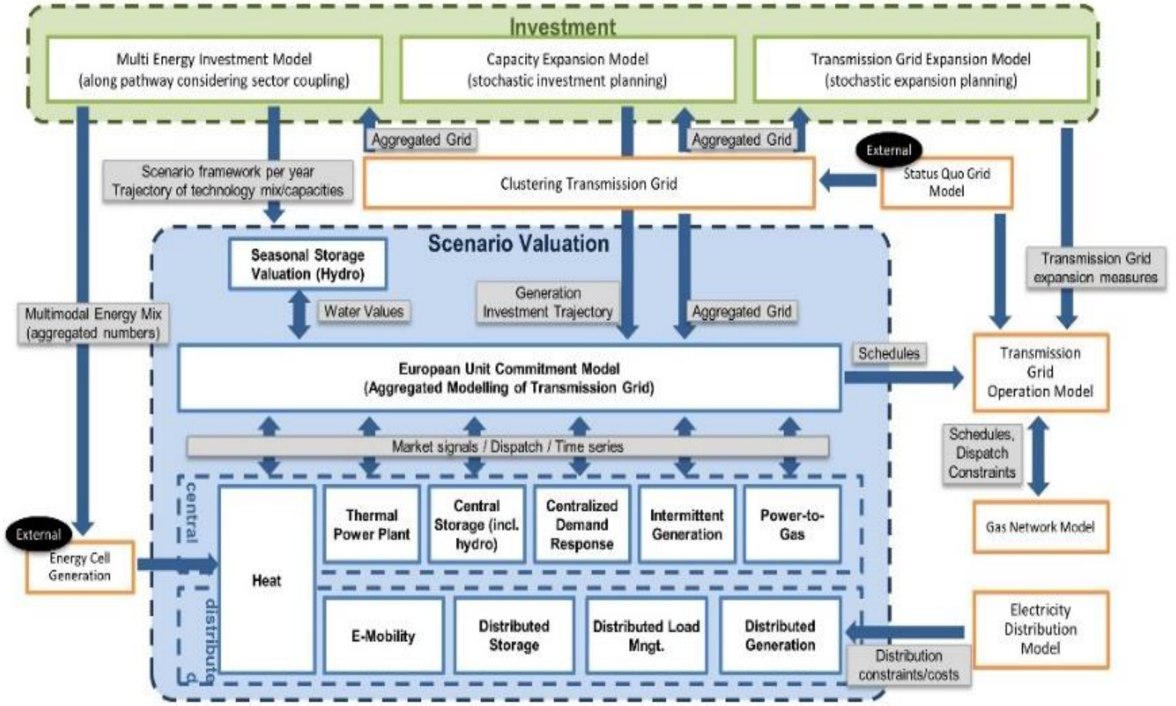
For contributing to European targets for reduction of emissions while maintaining high quality of supply at lowest cost

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



The plan4res electricity system modelling suite

a Stochastic Power System model composed of 3 embedded layers:

- ❑ ***The Capacity expansion model computes the optimal mix on a given year***
  - ✓ electric generation plants,
  - ✓ Short term storages (batteries….),
  - ✓ interconnection capacities
- ❑ ***The seasonal storage valuation model computes the optimal strategy for seasonal storages***
  - ✓ For Hydro reservoirs
  - ✓ And also all other 'seasonal' flexibilities such as Seasonal Demand response
- ❑ ***The European unit commitment (EUC) model computes the optimal dispatch:***
  - ✓ Supply power demand and ancillary services
  - ✓ Minimal inertia in the system
  - ✓ Maximum transmission and distribution capacities between clusters
  - ✓ Technical (including dynamic) constraints of all assets

Main characteristics

❑ Adaptable Geography perimeter

- Europe or lower perimeter
- Subcountry representation is possible

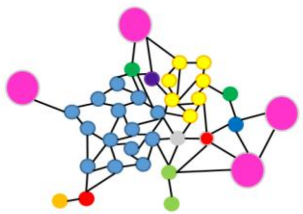
❑ Uncertainties:

- Electricity demand
- RES profiles (PV, Wind, RoR…)
- Inflows
- Failures

❑ Modular Time horizon and granularity

- Typically 1 yr. with hourly granularity

❑ Modular Grid



❑ 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

❑ Demand Response

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

Thermal power plants

- Constraints
  - Minimum and maximum power
  - Ramping rate limits
  - Minimum up and down times
  - Simple constraints between active power and reserves
- Cost functions
  - Convex quadratic or piecewise linear (cutting plane model)
  - Start up costs

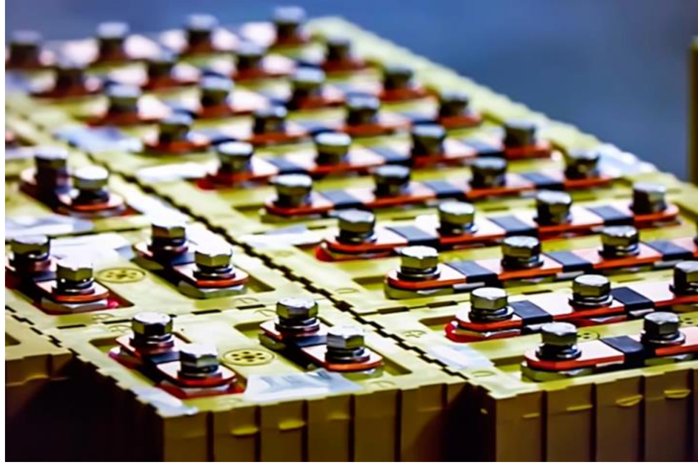
Intermittent Generation

- Constraints
  - Maximum power depending on uncertainty scenarios
  - Ramping rate limits
  - Simple constraints between active power and reserves
- Cost functions
  - linear

Seasonal storage

- Constraints
  - Minimum and maximum volume of the reservoir
  - Minimum and maximum power injections
  - For each turbine, minimum and maximum ow rate of water
  - Power is given as a function of ow rate by a concave cutting plane model
  - Ramping rate limits on ow rates
  - Simple constraints between active power and reserves
- Valleys can be modeled
  - Valley are modeled as a graph with arcs connecting the reservoirs
  - For each arc, uphill and downhill ow delays
- Cost functions are provided by the Seasonal Storage Valuation (SSV) as a Cutting plan model

Short term storage



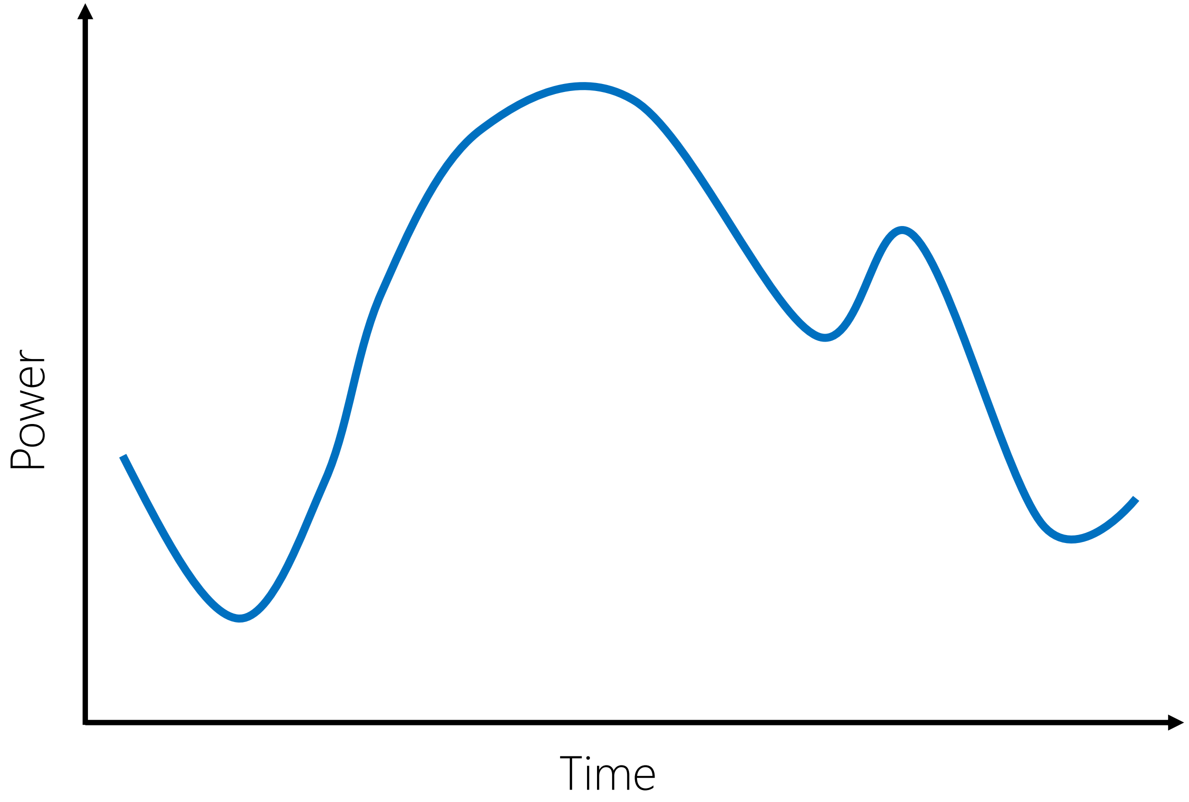
- Constraints
  - Minimum and maximum volume of the storage
  - Minimum and maximum injected power into the grid
  - Ramping rate limits
  - Potentially different injection and withdrawing efficiency ratio
  - Simple constraints between active power and reserves
- Cost functions
  - Linear costs

Demand response

- Load shifting (Ex: Appliances with fixed energy needs on a given period allowing some flexibility on the load prole e.g. EV battery)
  - Data: a reference consumption signal with a given energy consumption on a given period
  - The flexible prole (to be optimally chosen) should
    - in terms of energy: consume the same energy as the reference prole on the given period
    - in terms power: not deviate to much from the reference prole
- Load curtailment Ex: Mid-term contracts (for instance annual contracts) between utilities and consumers, where each consumer agrees to reduce his consumption when this is required by the utility
  - Energy storage that can be optimized over the whole mid-term horizon as a seasonal storage

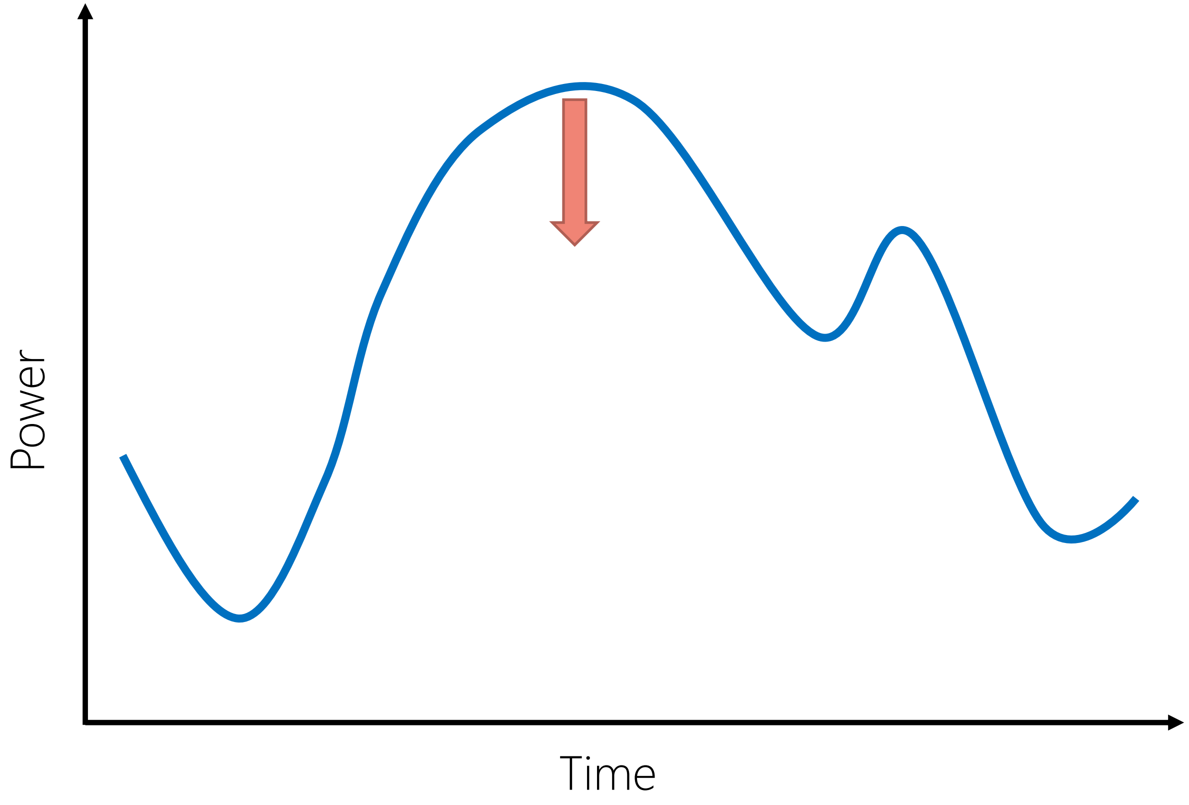
Demand Response : load shifting vs load curtailment

Curtailment



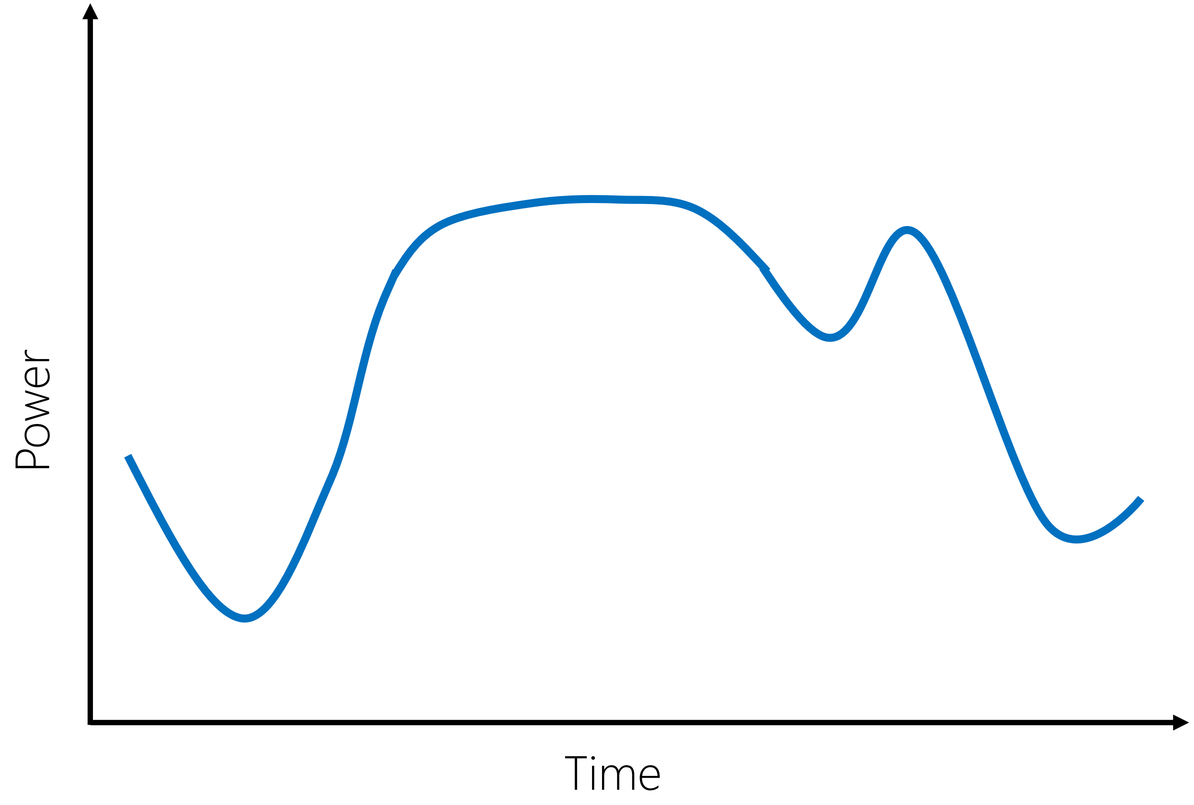
Demand Response : load shifting vs load curtailment

Curtailment

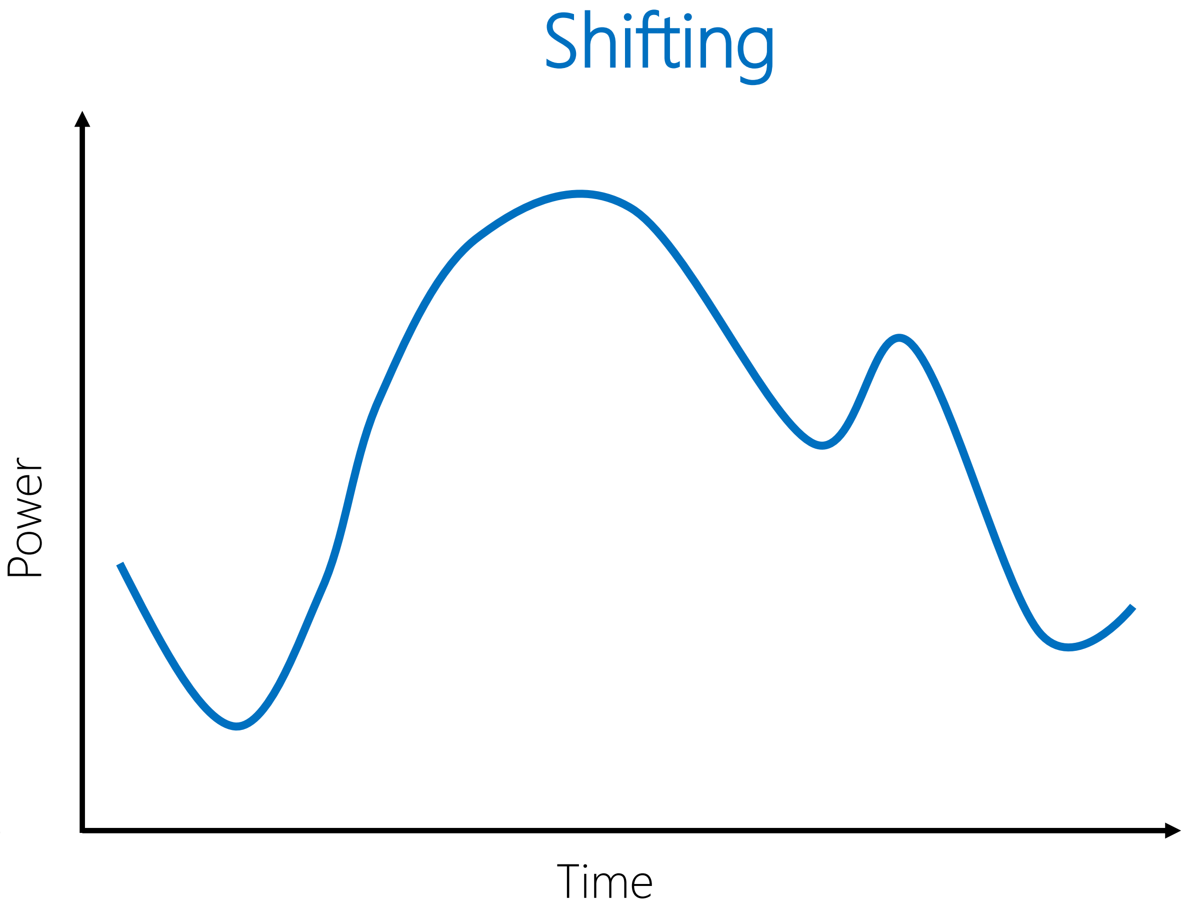


Demand Response : load shifting vs load curtailment

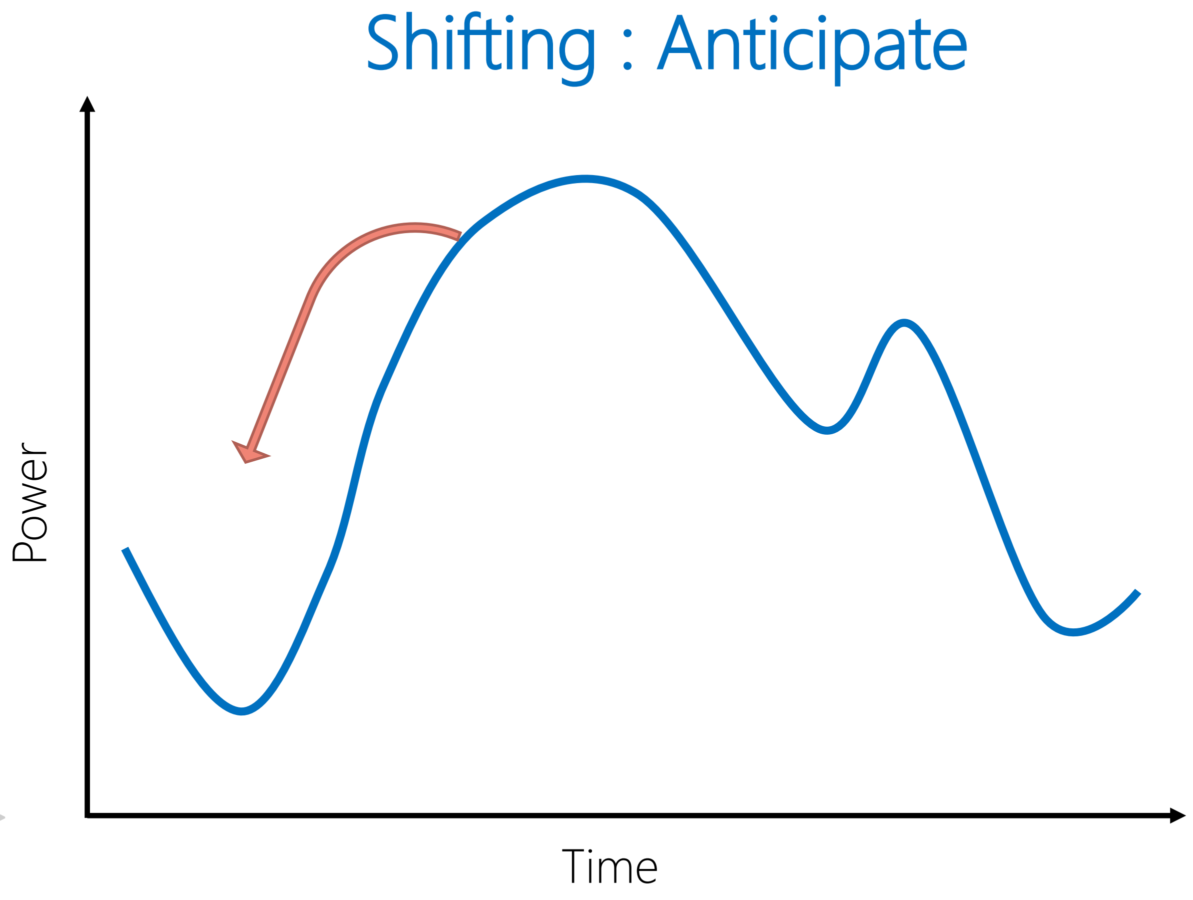
Curtailment



Demand Response : load shifting vs load curtailment



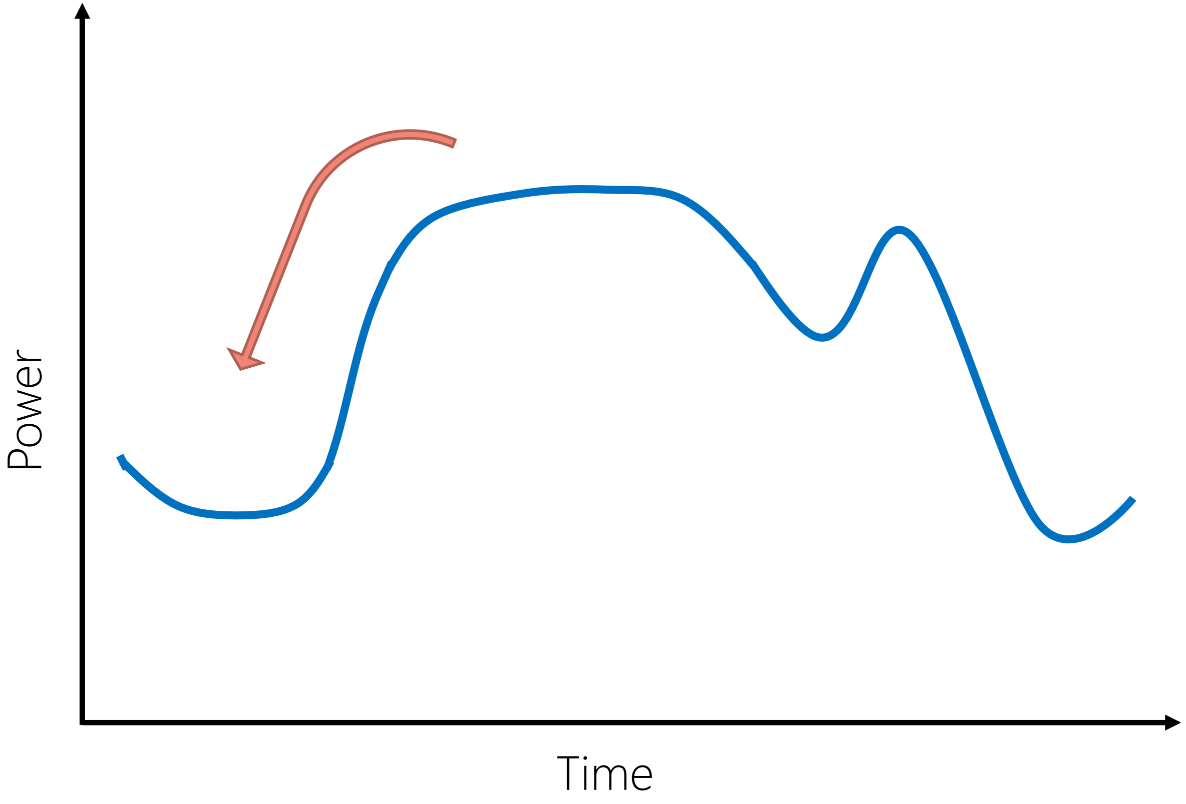
Demand Response : load shifting vs load curtailment



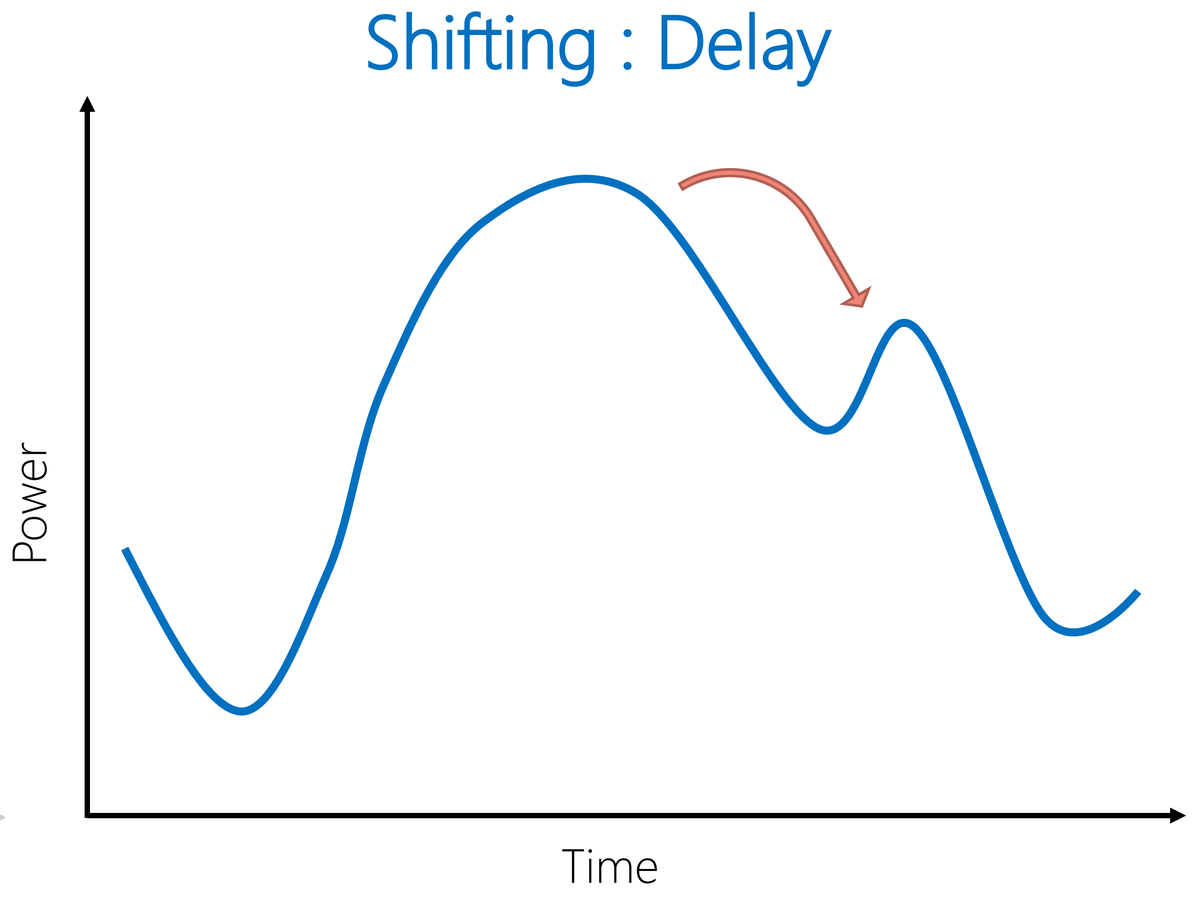
Demand Response : load shifting vs load curtailment

Curtailment

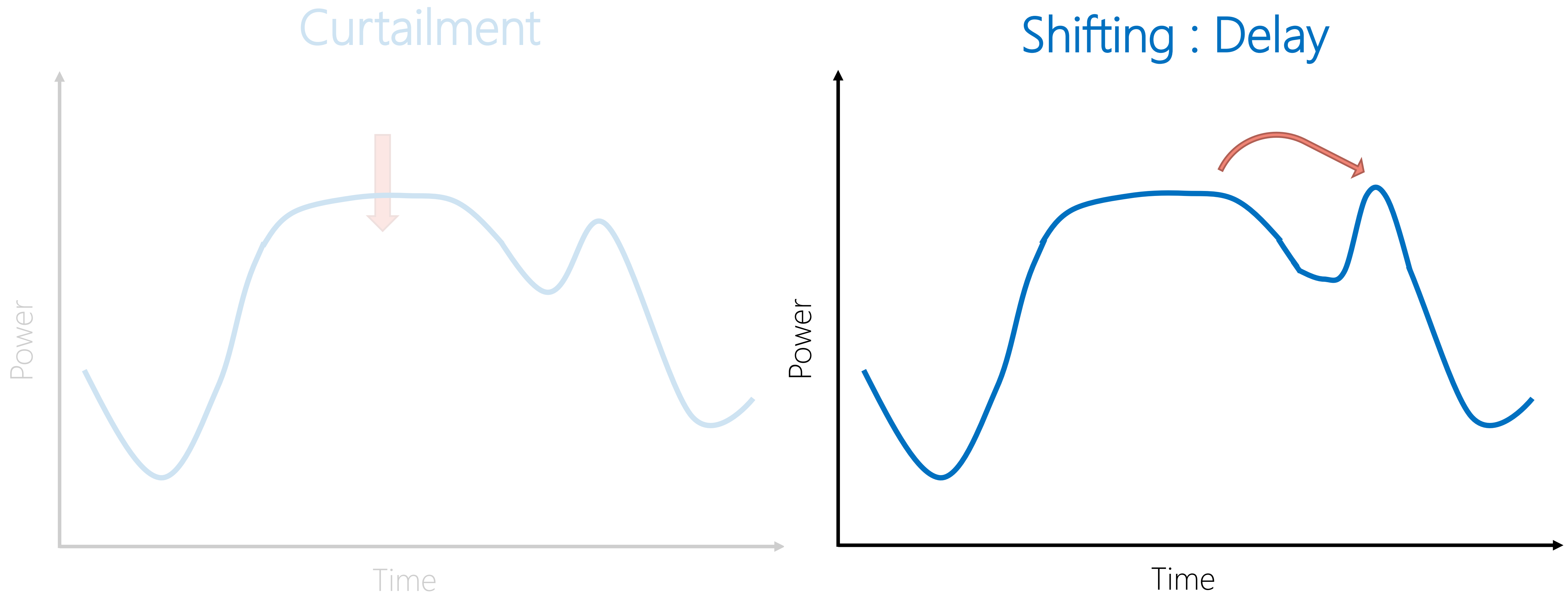
Shifting : Anticipate



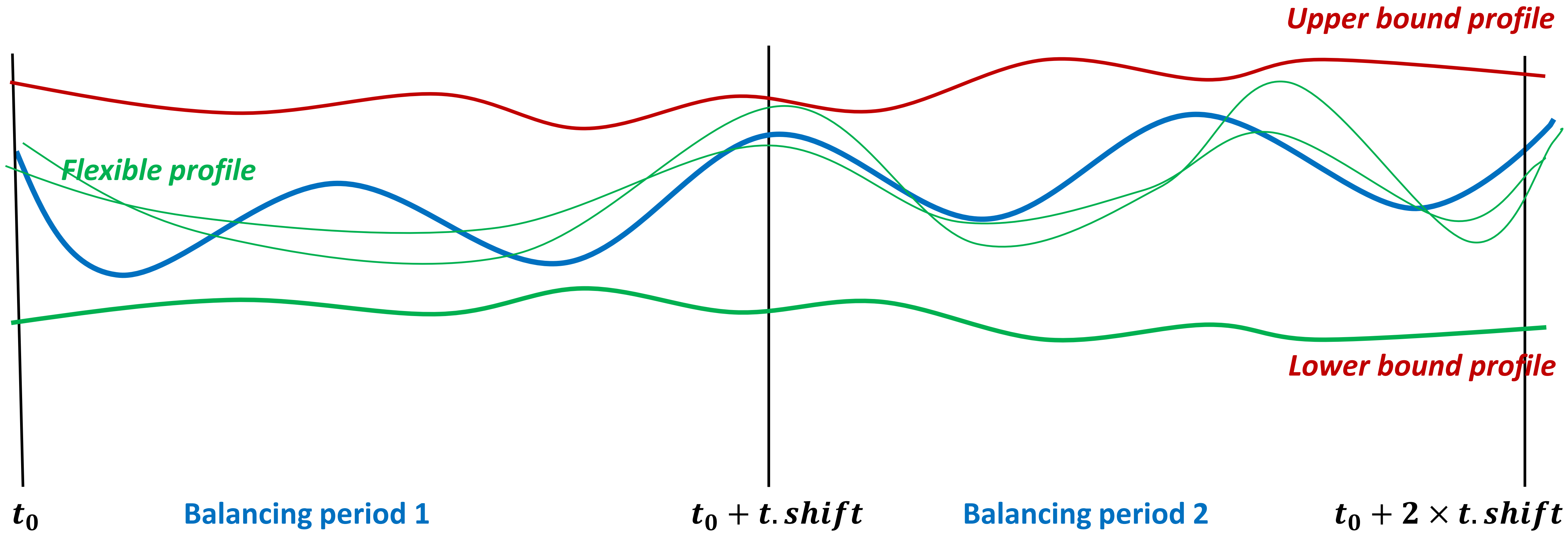
Demand Response : load shifting vs load curtailment

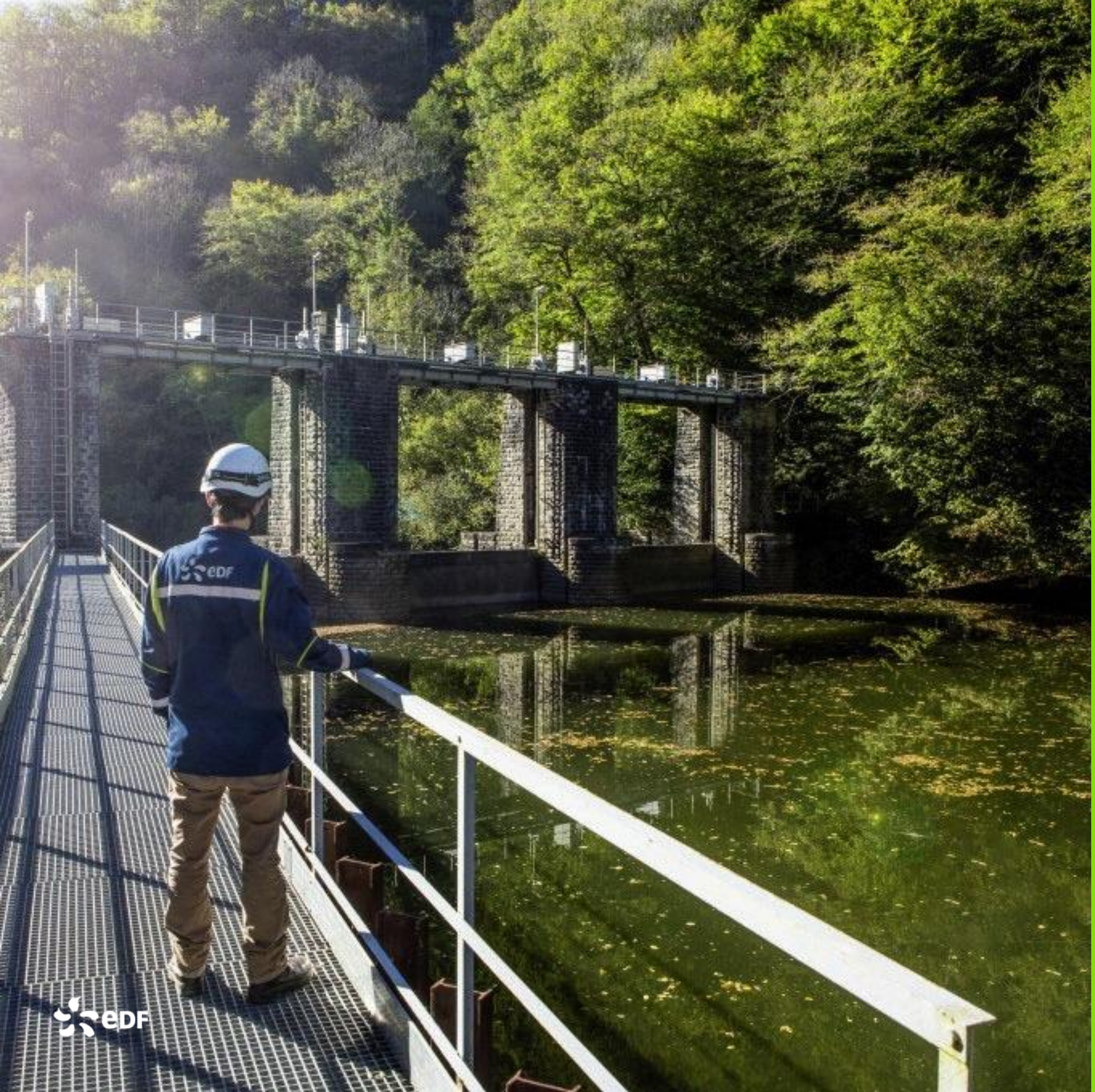


Demand Response : load shifting vs load curtailment



Modelling load shifting





Optimisation problems

- **The Capacity expansion model** computes the optimal mix:
  - ✓ *electric generation plants,*
  - ✓ *storages,*
  - ✓ *interconnection capacities between clusters*
  - ✓ *distribution grid capacities,*
- **The seasonal storage valuation model** computes the operation strategies for seasonal storages:
  - ✓ *For Hydro reservoirs*
  - ✓ *And also all other 'seasonal' flexibilities such as Demand response*
- **The European unit commitment model** computes the optimal operation schedule for all the assets dealing with constraints:
  - ✓ *Supply power demand and ancillary services*
  - ✓ *Minimal inertia in the system*
  - ✓ *Maximum transmission and distribution capacities between clusters*
  - ✓ *Technical constraints of all assets*

Capacity Expansion

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

→ Generation Mix

→ Interconnexion Capacities

Seasonal Storage Valuation

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

→ Water Values

→ Strategies

Unit Commitment

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

→ Optimal Schedules

→ Marginal Costs

Unit Commitment

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

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

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

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

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

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

- **The Capacity expansion model** computes the optimal mix:
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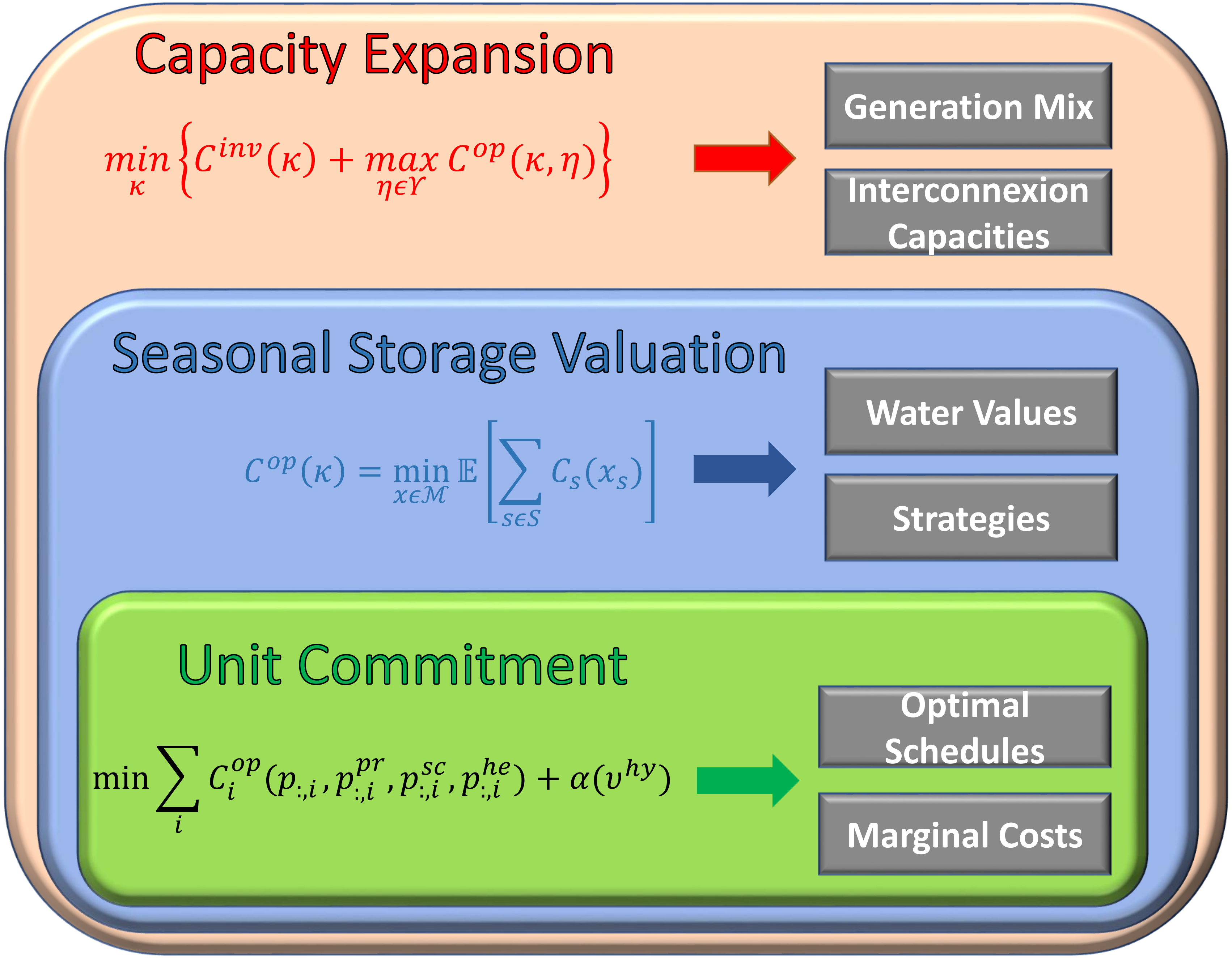

Seasonal Storage Valuation

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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

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- **The Capacity expansion model** computes the optimal mix:
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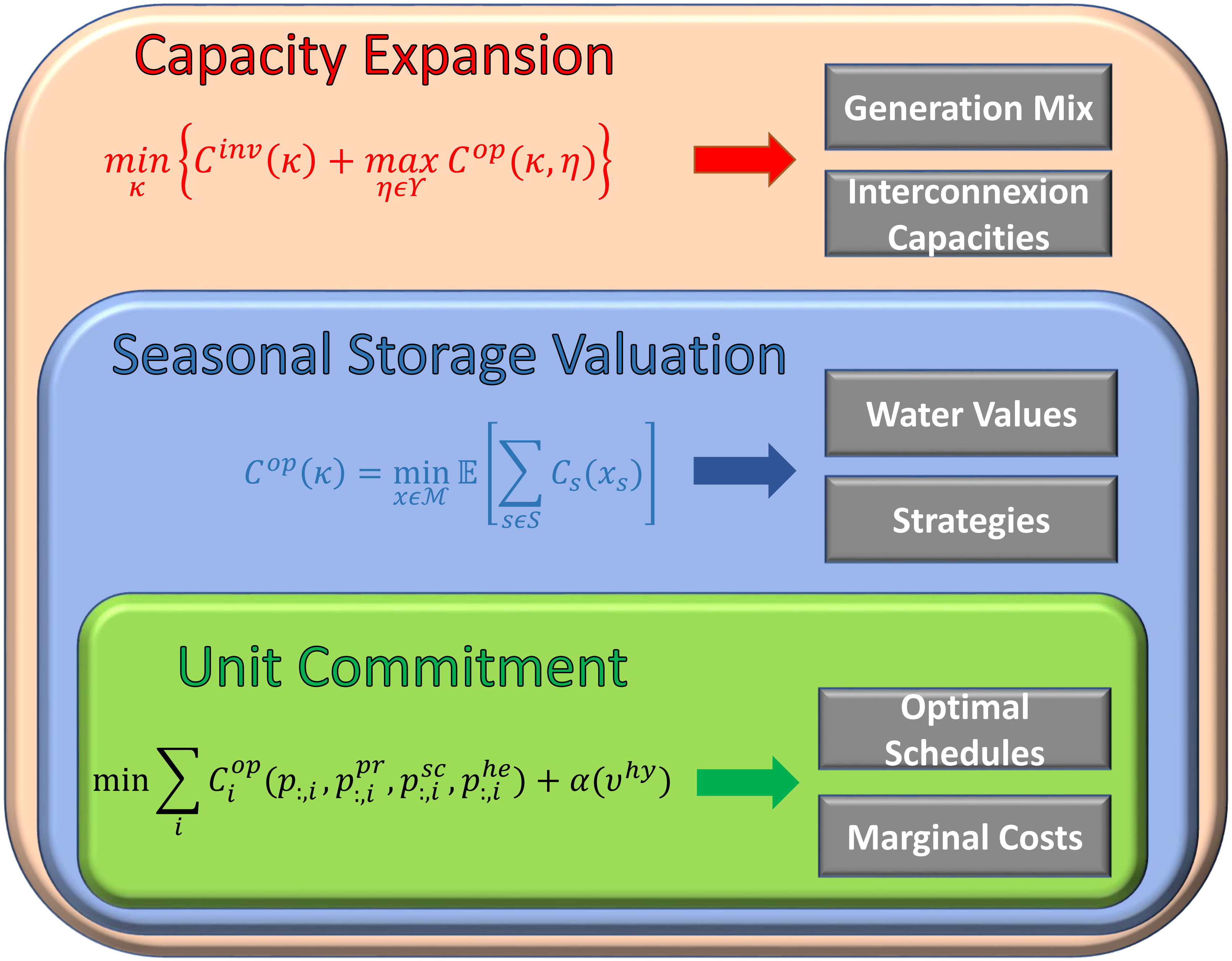
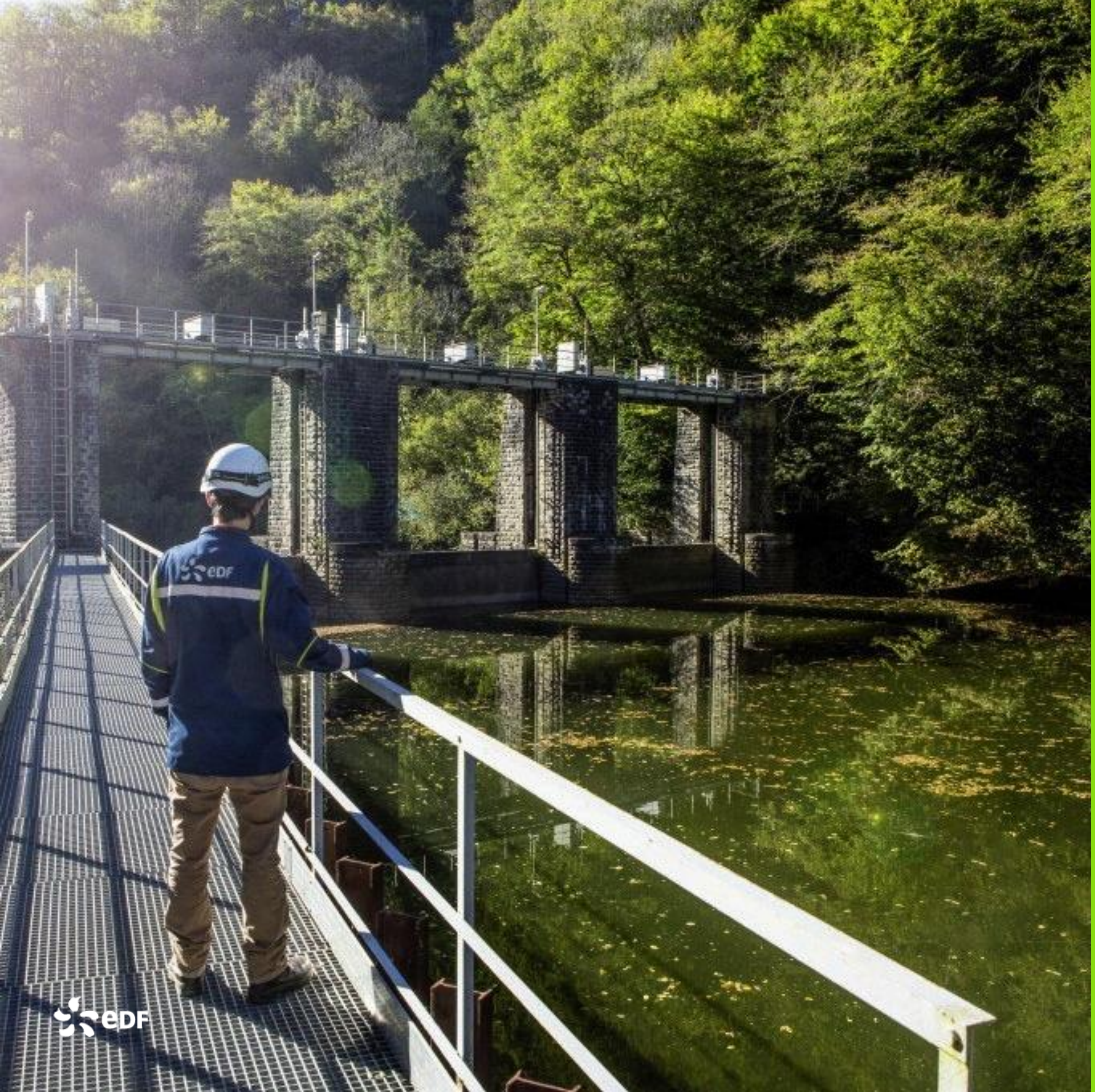


Capacity Expansion

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

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

$\boldsymbol{\kappa}$: 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

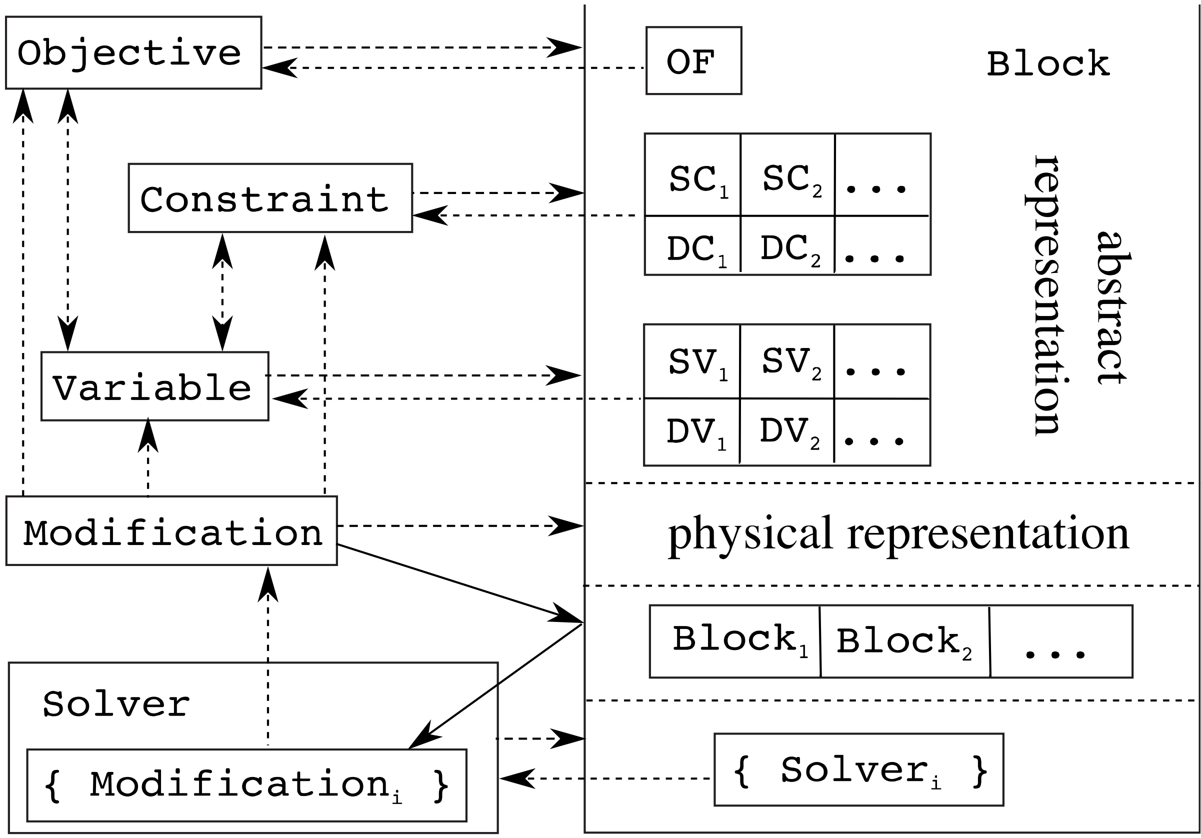


Modelling with

SMS++

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***



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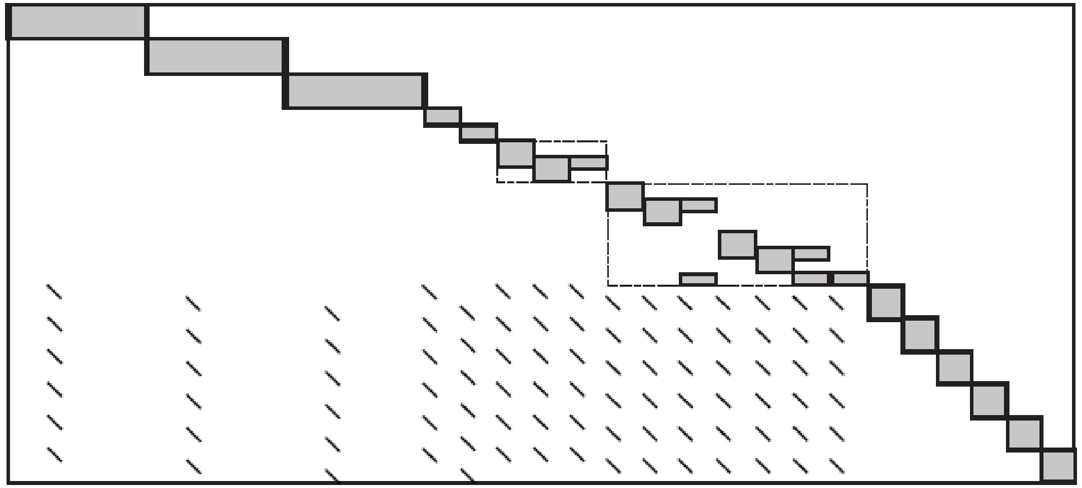
Modelling with SMS++

Nested decompositions at different time horizons

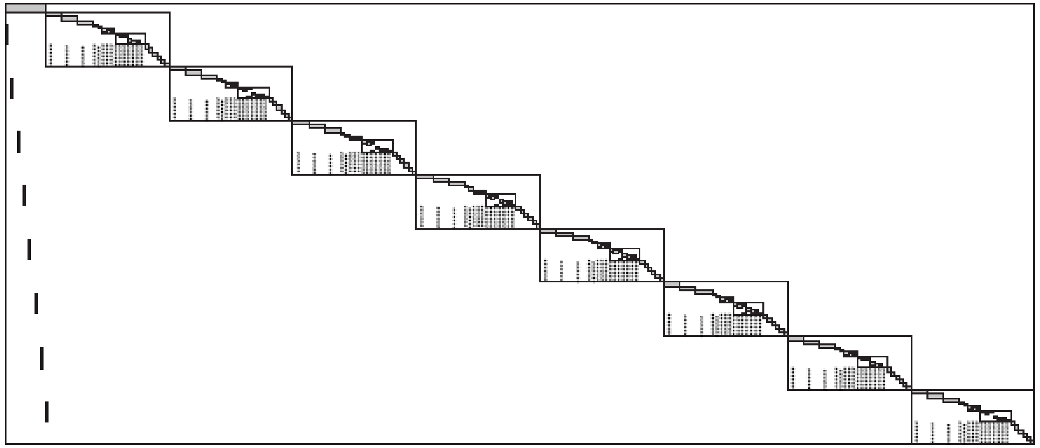
- Schedule a set of generating units to satisfy the demand at each node of the transmission network at each time instant of the horizon (24h)



- 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

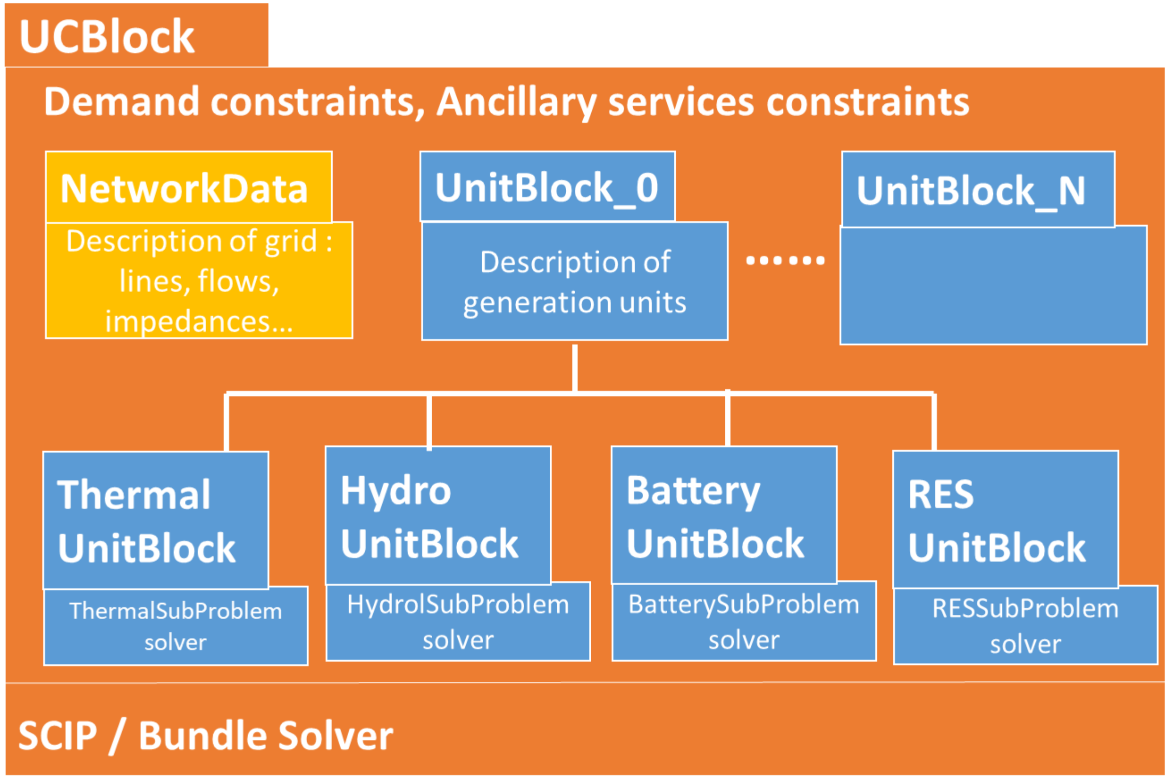


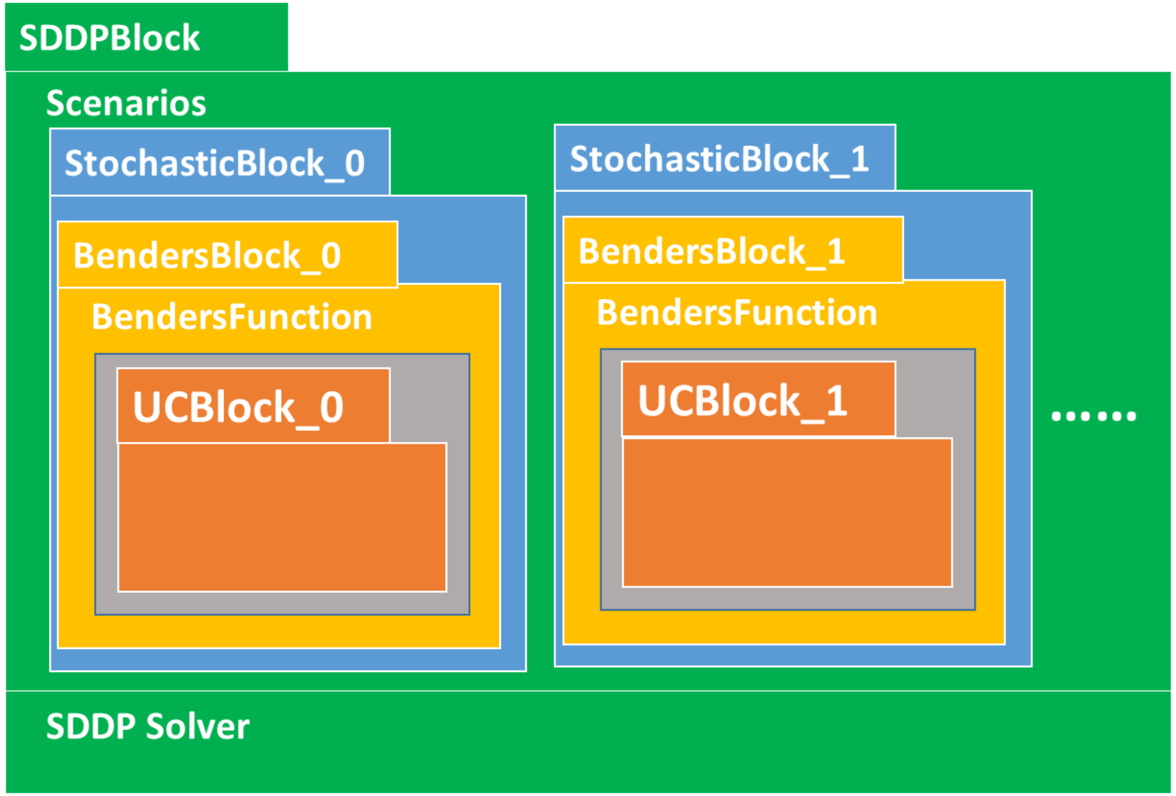
- Very large size, nested structure
- Perfect structure for Stochastic Dual Dynamic Programming[3,4] with multiple EUC inside

[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++



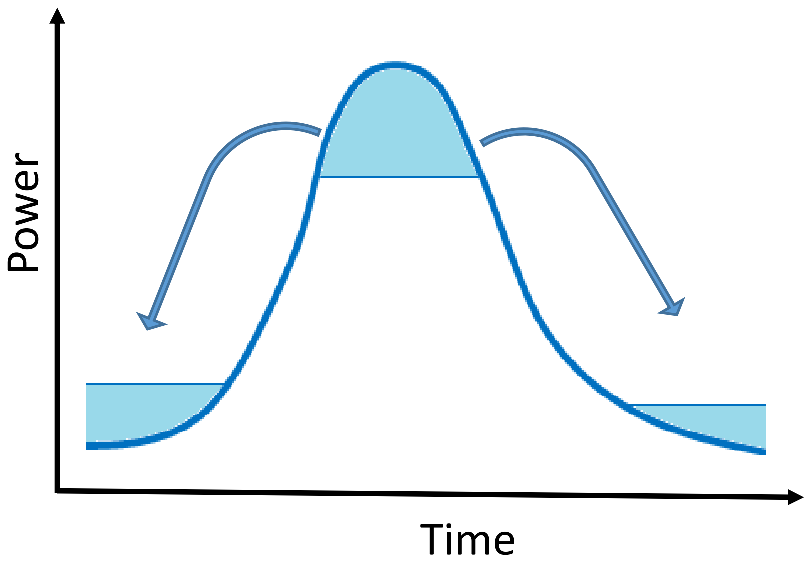


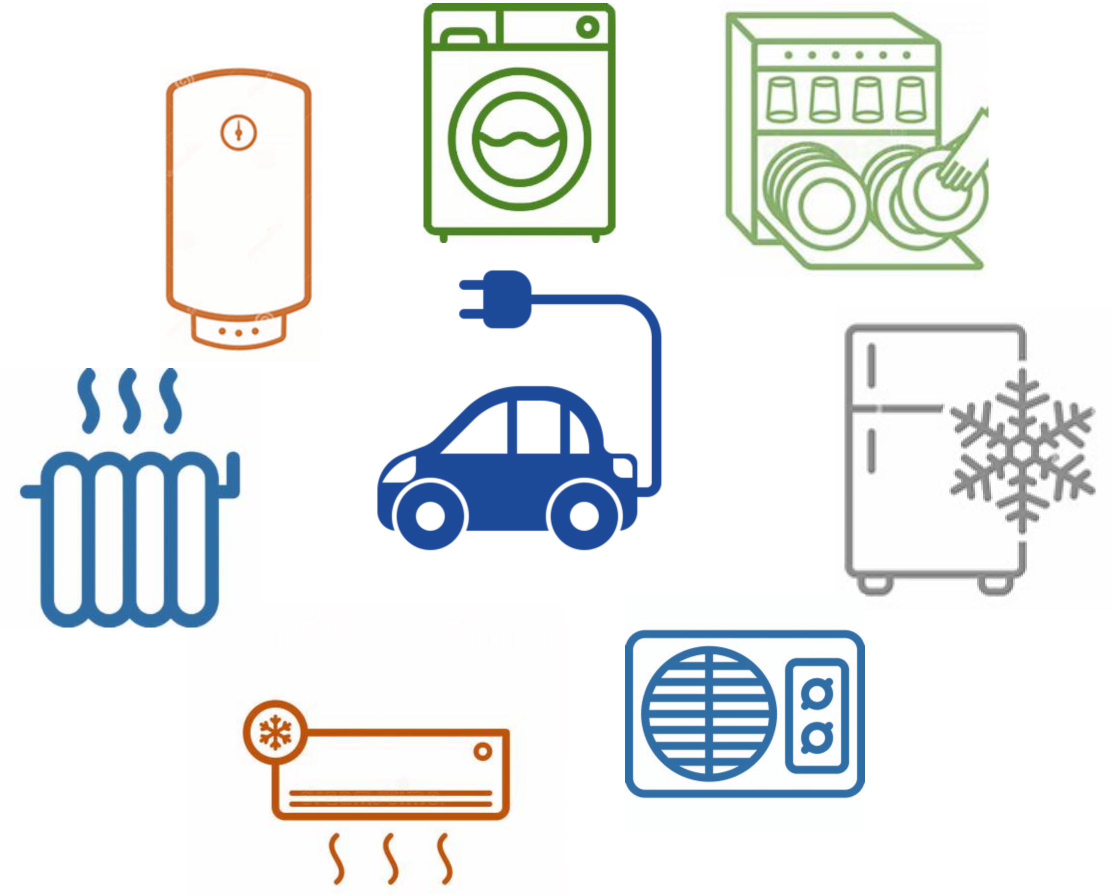
3

Case Study: what is the value of residential load shifting for the electricity system?

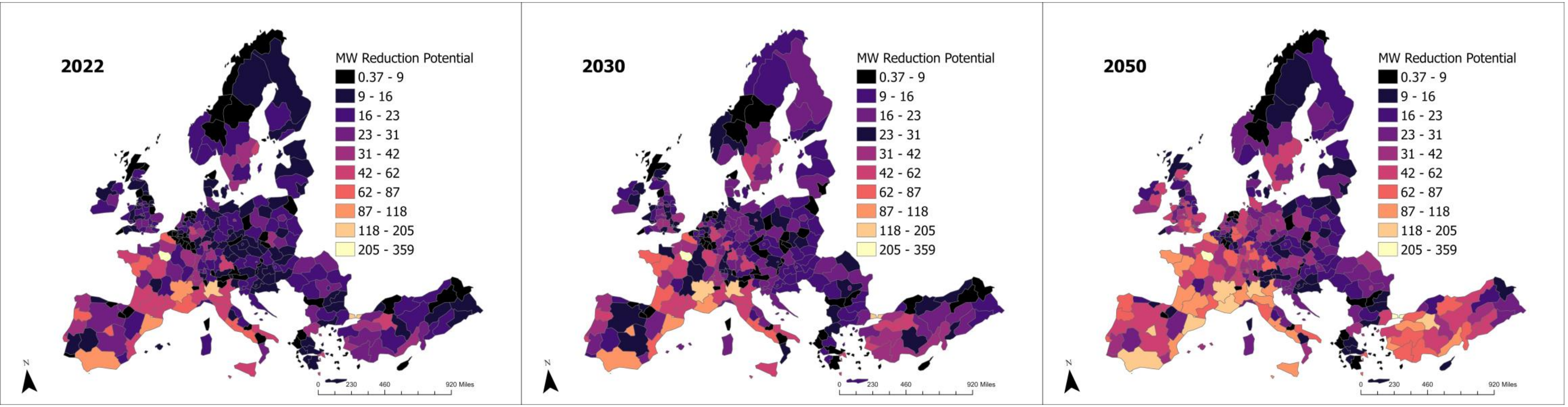
Demand Response in household electricity use

- What is the potential flexibility from demand response from household consumers taking into account the willingness of the population?
- Which impact on the integrated European electricity system operation and cost?
- Can it reduce investment needs?



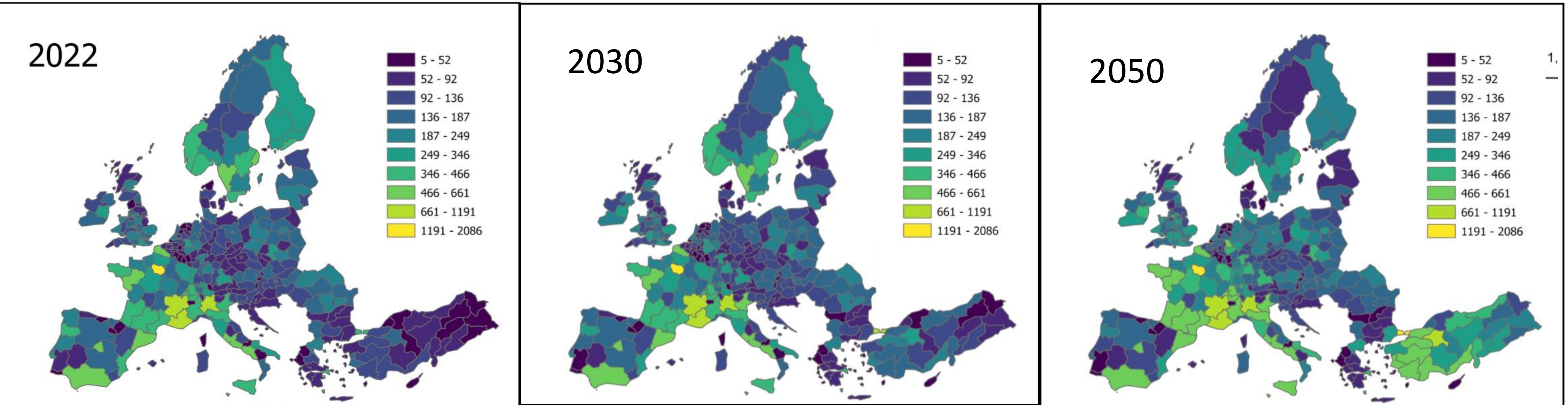


Load shifting potentials



Delay

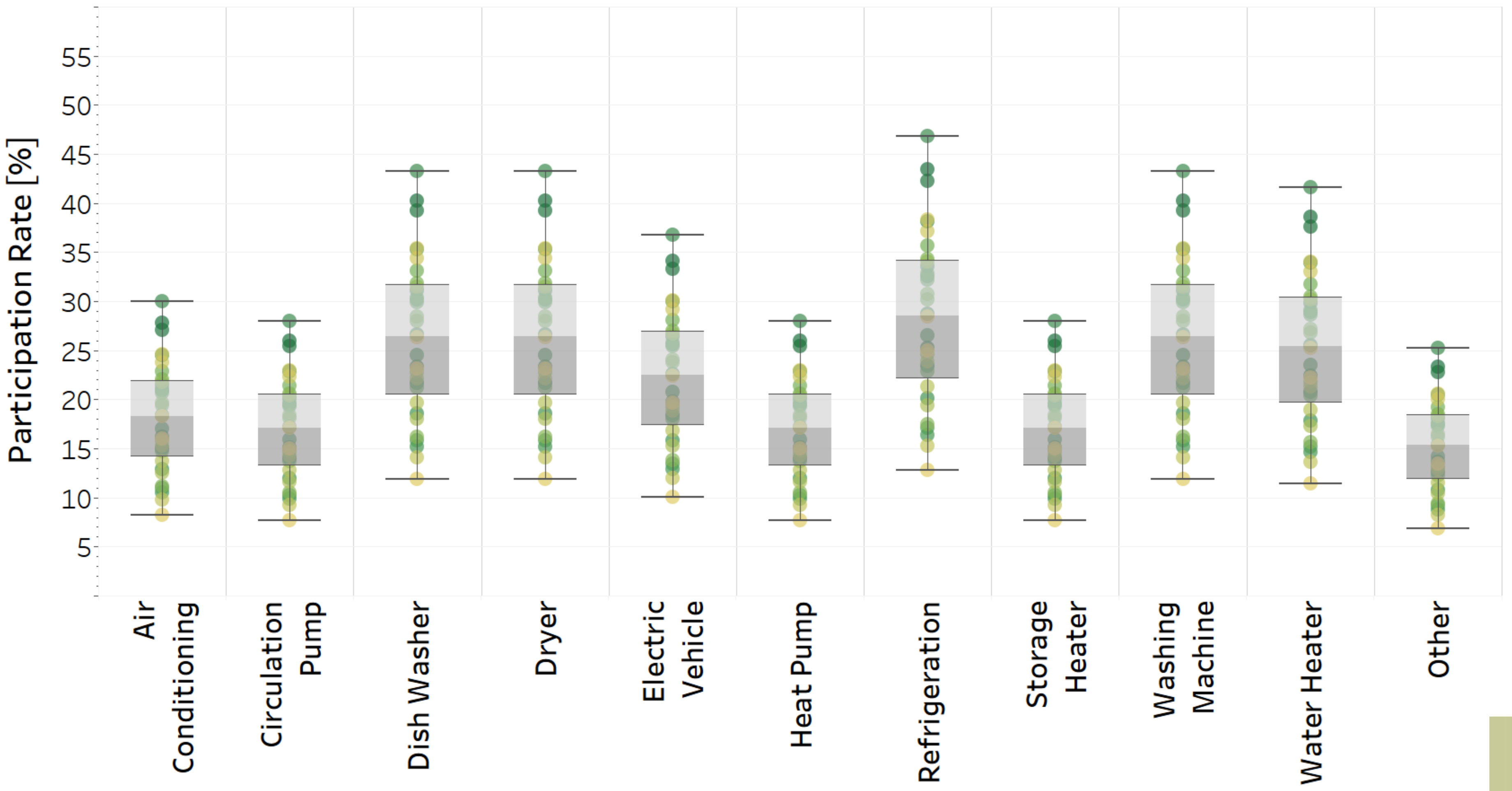
7 ↗ 12 GW



Anticipate

51 ↗ 67 GW

Demand Response in household electricity use: participation rates

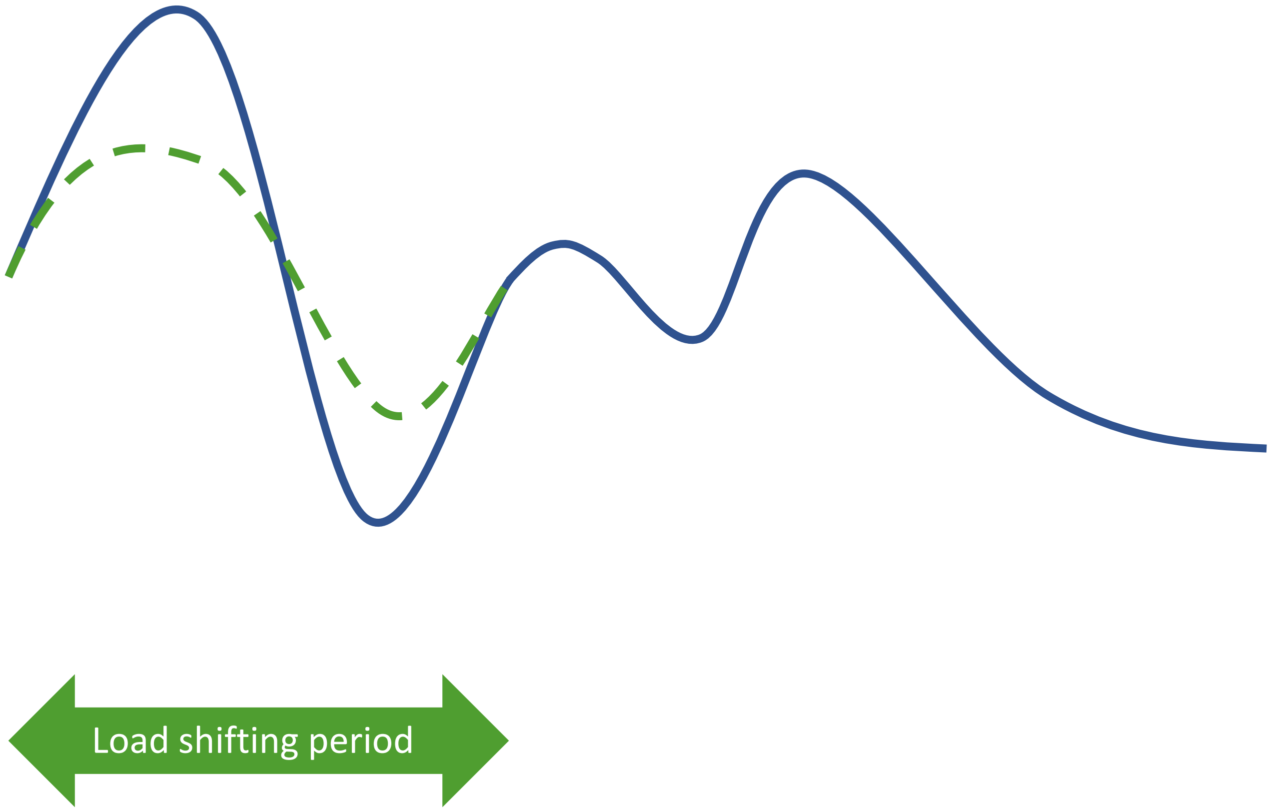


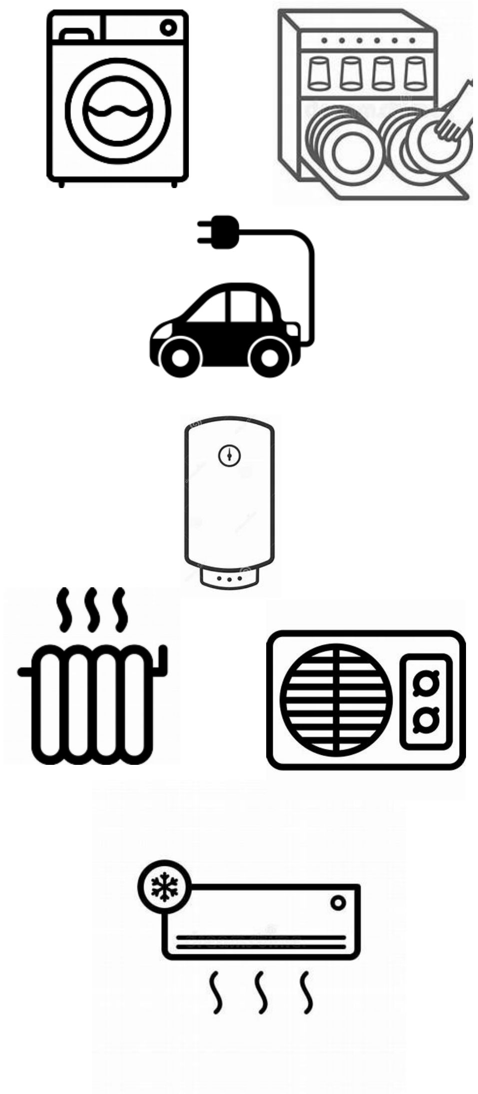
open ENTRANCE

echoes
Energy union comes to life.

EDF

Demand Response in household electricity use





6 hours

4 hours

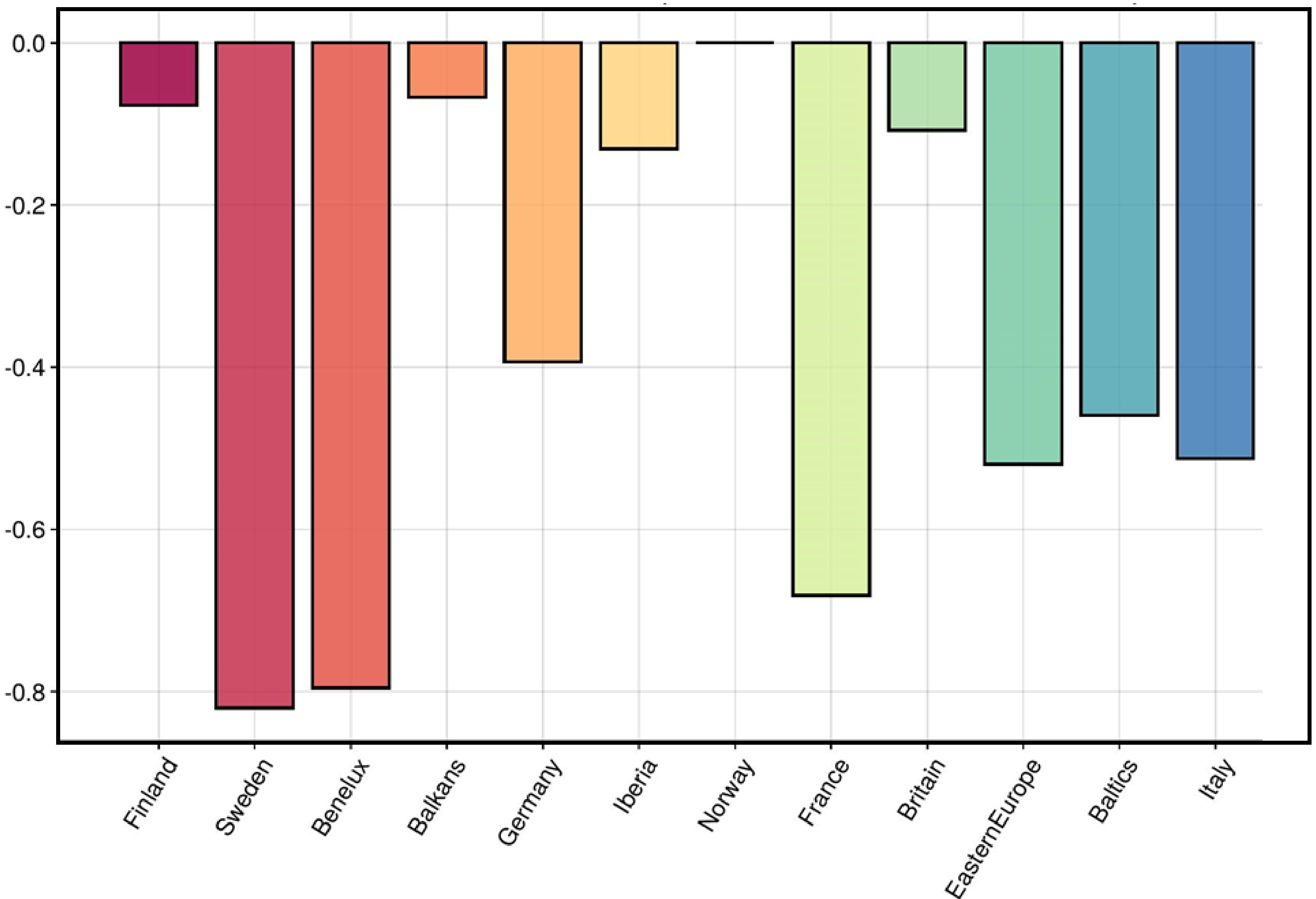
12 hours

2 to 12 hours

2 hours

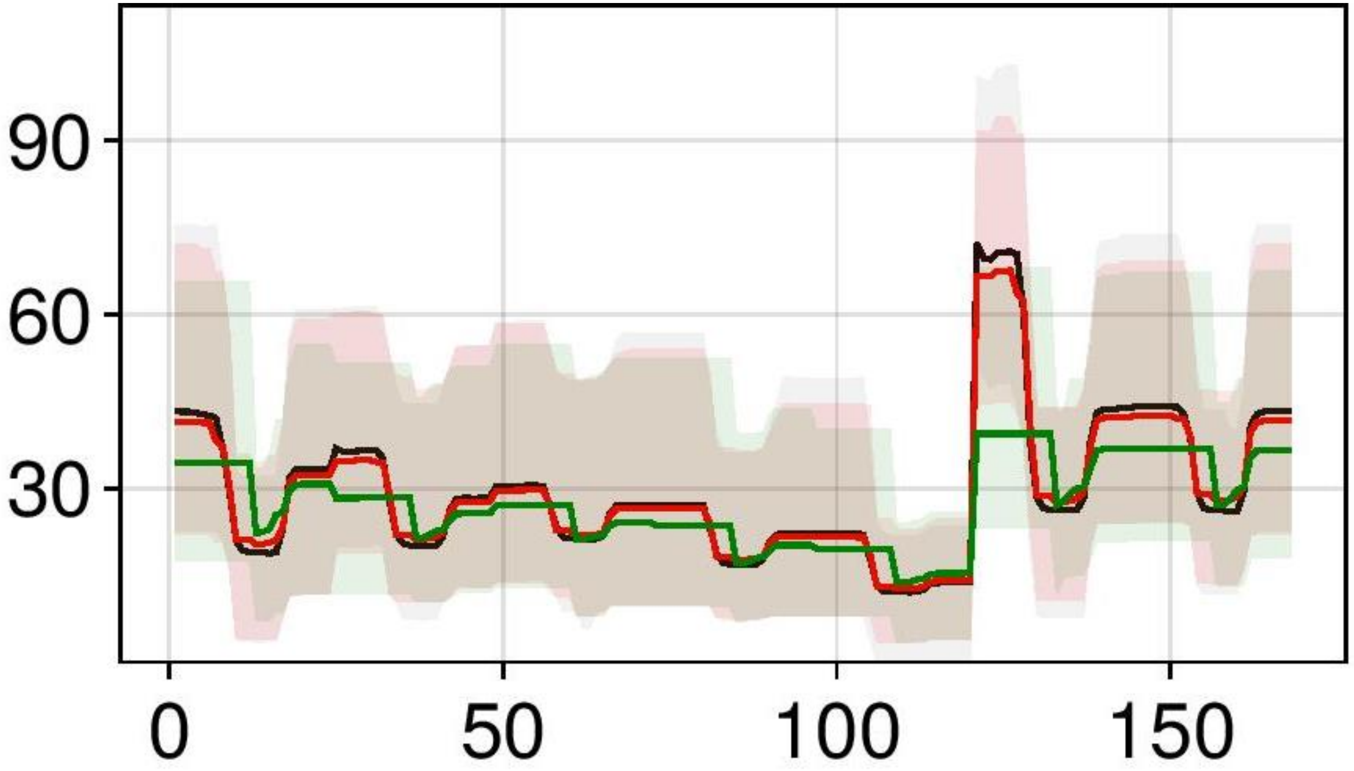
Demand Response in household electricity use

Household demand response reduces the operation costs by ~1%
(2.5% with 100% participation) *(average on 40 climatic scenarios, 2050)*



Demand Response in household electricity use

Household demand response reduces Marginal Costs Peaks and dispersion



Marginal Cost Level

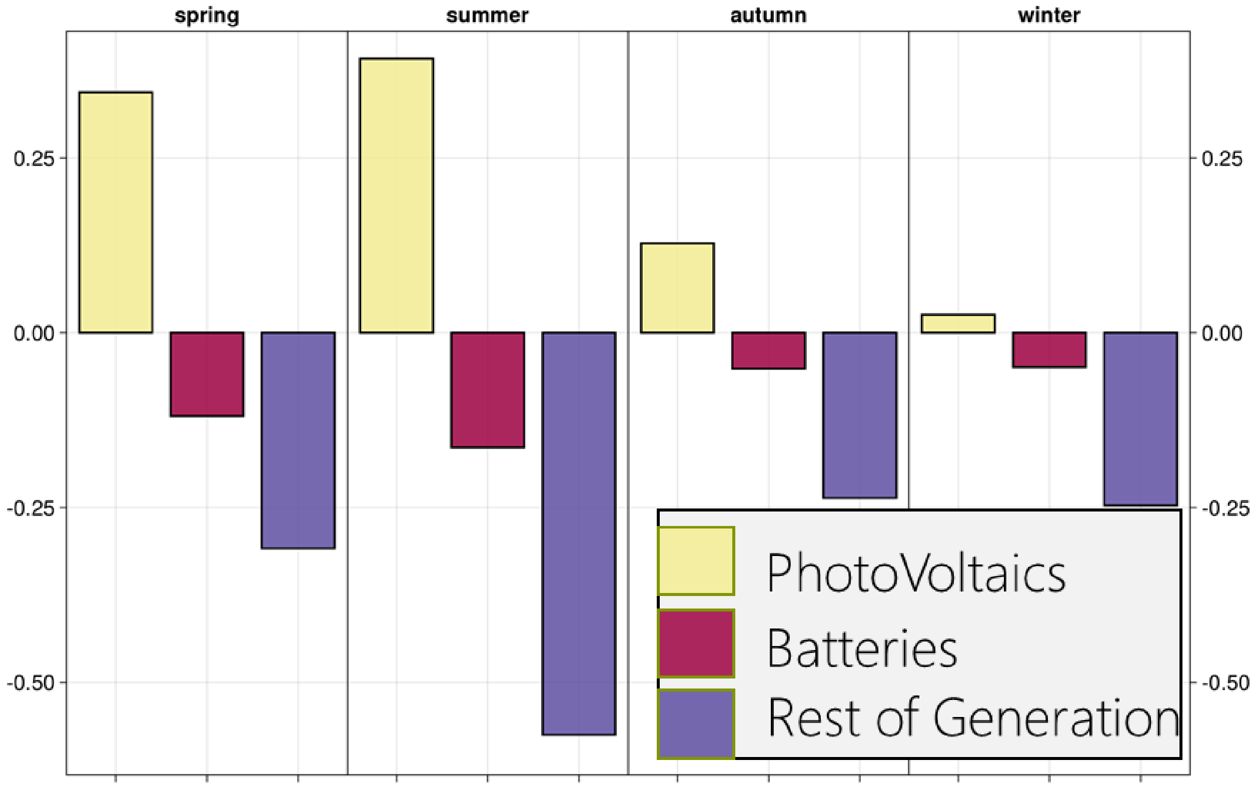
Up to -30%

Marginal Cost Dispersion

-10%

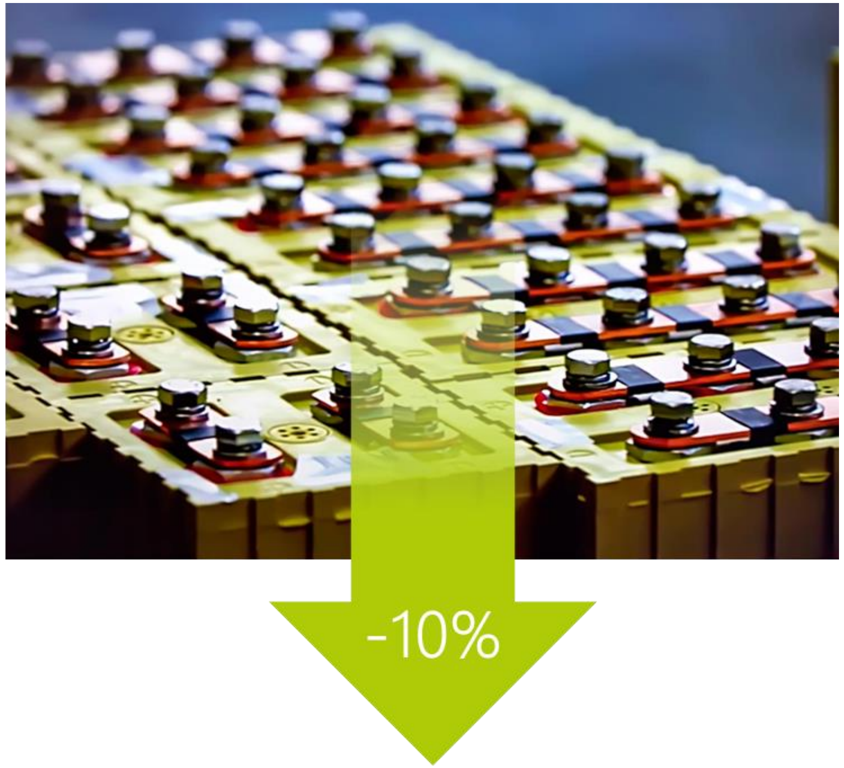
Demand Response in household electricity use

Household demand response reduces PhotoVoltaic generation curtailment



Demand Response in household electricity use

Household demand response reduces the need for battery storage and traditional power generation



https://zenodo.org/communities/plan4res

https://zenodo.org/communities/openentrance

https://gitlab.com/smspp/smspp-project

www.openentrance.eu

www.plan4res.eu

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Thank you