Final results

Study on the quantification of Demand Response (DR) benefits to electricity suppliers and consumers thanks to the reduction of wholesale prices in Europe in winter 2022/2023

Presented to: DR4EU – DEMAND RESPONSE FOR EUROPE

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1.

Executive summary

Executive summary

DR4EU has mandated CL Energy to provide an assessment of DR benefits to electricity suppliers and consumers thanks to the reduction of wholesale prices during one year in Europe

Modelling approach

DR capacity
30 GW
(5% of peak load)

DR volume
10 TWh/year
(0.3% of annual demand)

France, GB, Germany and Italy represent more than half of the European DR capacity

- A total **30 GW of DR capacity** is considered for the period (July 2022 – June 2023) in Europe, accounting for 5% of the European peak load.
- We simulated a realistic DR portfolio of activation hours: capacities are available for various durations, from a few ten hours to 600 hours per year.
- The total volume of DSR amounts to **10 TWh per calendar year,** or 0,3% of EU annual power demand.
- The country allocation of DR capacity is based on existing studies of pan-European DR potential and taking into account the more advanced stage of DR development in France and GB.

DR benefits assessment

DR benefits for suppliers
4700 M€
(1.4% of power sourcing cost)

- The considered DR portfolio reduces energy sourcing costs by approximately **4700 M€** in Europe between July 2022 and June 2023.

DR "costs" for suppliers
1400 M€

- Over the same time horizon, suppliers incur "costs" to buy DR in the market of **1400 M€**, thus providing market-based revenues for DR.

Benefits versus costs
+335%

- Market benefits for suppliers, as they save on their sourcing costs, are **335%** of their "cost" as they buy DR in the market – i.e. 235% net benefit

Price cap at around **150 €/MWh** from an average highest price reduction of up to **-120 €/MWh**

- Thanks to DR participation, price volatility on European spot markets reduces, i.e. spikes are avoided and capped at around **150 €/MWh** thanks to an average reduction of the highest hourly prices of up to -**120 €/MWh**.

CO_2 emission reduction
6.7 Mt
Gas saved
1.5 bcm

- In terms of GHG, the 30 GW DR portfolio avoids **6.7 Mt/year of CO_2 emissions**, mostly avoiding use of natural gas generation (**1.5 bcm**)

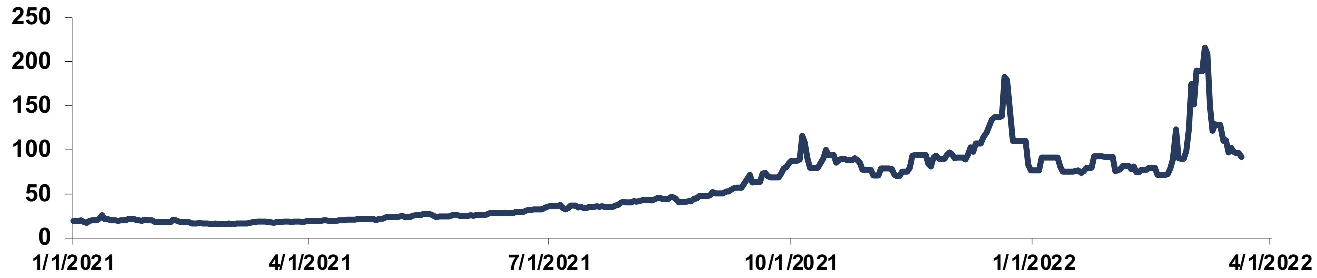
2.

Context and objectives

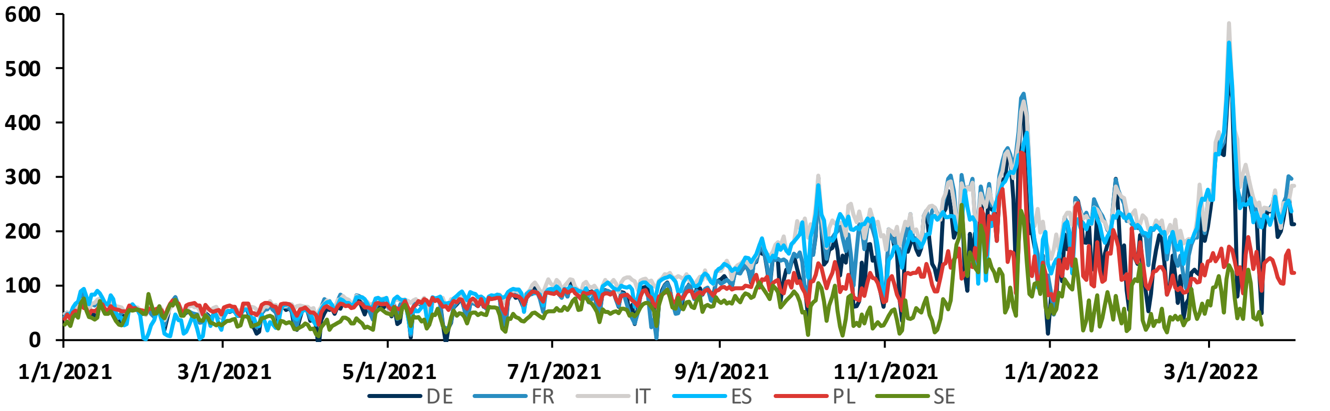
Study context and our mandate

- Since late 2021, Europe has been confronted with an important increase in energy prices combined to a high volatility in energy markets.
  - The increase in global energy demand due to the recovery from the Covid-19 pandemic has caused an increase in electricity prices at the end of 2021.
  - The Russian invasion of Ukraine has recently increased upward pressure on energy prices and led to unprecedented high electricity prices across Europe.
  - These price increases put significant upward pressure on household energy bills and impact economic activities.
- The recent invasion of Ukraine by Russia has also increased the concerns of security of energy supply, pushing the EU to reduce dependency on Russia's fossil fuel supply in the context of so far high dependency on Russian energy imports and already tight energy markets.

Evolution of daily TTF gas prices since January 2021 (EUR_{nom}/MWh)



Evolution of EU power prices since January 2021 (EUR_{nom}/MWh)



Considering this background, DR4EU mandated CL Energy to provide an assessment of DR benefits to electricity suppliers and consumers thanks to the reduction of wholesale prices in Europe in winter 2022/2023, using a similar approach to the previous study on DR benefits in 2030 (link).

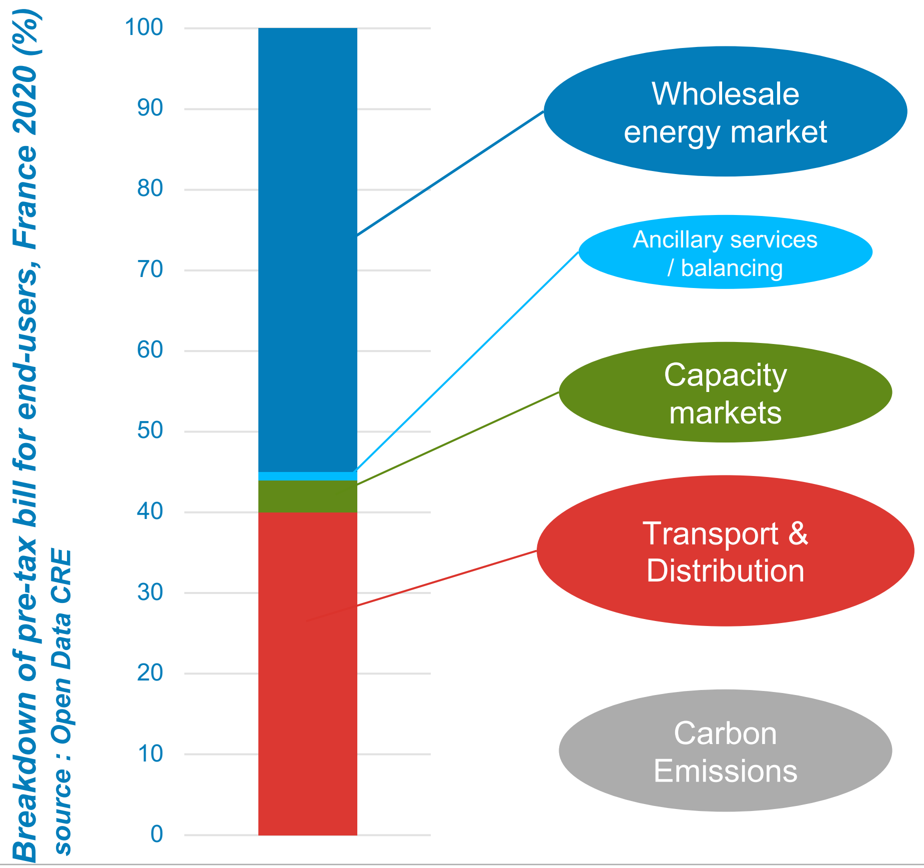
3.1

Study scope and modelling approach

Focus on European power markets

Benefits of Demand Response span over the full range of direct and indirect cost components for end-users

In this study, we focus on the wholesale energy market as it leads to the highest costs for consumers and subsequently the greater market size for DR



Associated DR benefits

- Reduced price volatility and average price on the wholesale market, in substitution for peaking plants;
- Lower balancing costs, with cheaper flexibility to contain system imbalances and provide ancillary services.
- Reduced need for flexible generation capacity and capacity remuneration mechanism;
- Lowering the magnitude of load peaks and participating in local flexibility operations, DR could lead to lower needs for network reinforcements
- In substitution for peaking carbon intensive generation technologies, DR can lower overall CO_2 emissions of power systems*

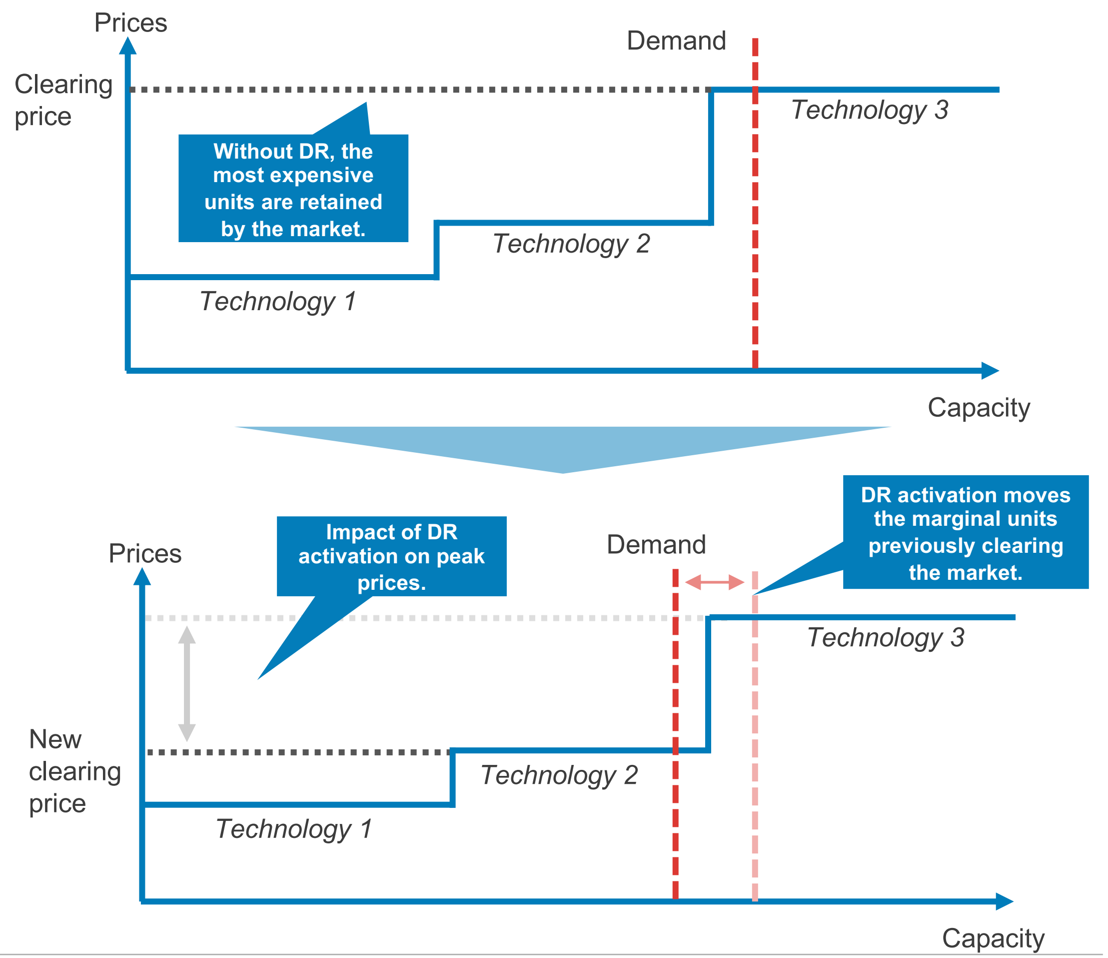
** In the study CO_2 avoided costs are considered to be included in the wholesale market costs*

The study aims at assessing the benefits of DR from July 2022 to June 2023 for the wholesale power market

- Regarding the wholesale market, **the impact of DR on peak prices can be explained by a change in clearing marginal unit when activated**.
- Hence **the resulting clearing price of the market is lower than without DR**, which results in avoided costs for electricity suppliers.

- **To evaluate the benefits entailed by DR to the system, several indicators can be analysed:**
  - Benefits on a market-wide basis, for all electricity suppliers, hence ultimately for all customers,
  - Costs to the suppliers, on a similar basis for the same reason,
  - Benefits to cost ratios (i.e. sourcing costs that electricity suppliers avoid thanks to DR compared to costs for them);
  - Spot price volatility,
  - Peak prices and average prices,
  - CO_2 emissions, etc.

The DR activation in the wholesale market will decrease prices

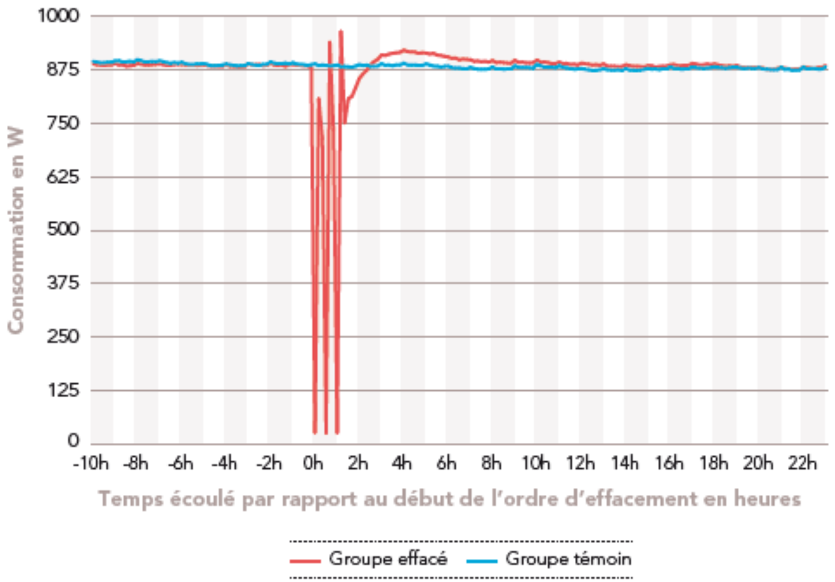


Study scope and modelling approach

The rebound effect does not affect benefits assessment

- In the wholesale market, the impact of DR on peak prices is a reduction of clearing marginal unit when activated.
- Depending on the source of DR, a rebound effect following the activated decrease in load may occur:
  - For electric vehicles, the rebound effect may be considered as 100% as far as mobility needs remain unchanged by a delay in charging;
  - For electricity usage in industrial processes, the rebound effect is harder to determine and depends on many parameters such as, in the case of heat or cold, the thermal efficiency of processes and buildings, the efficiency of processes after a load decrease, duration of load decrease, etc.;
  - For heating and cooling in buildings the rebound effect is also difficult to assess but a study in 2016 by RTE on a large scale (45,000 homes) suggests, even without any mitigating action, it could be limited and spread on a long duration, thus minimizing impact on the system.

Illustrative rebound effect before mitigating measures



- **In any case, a management of demand flexibility allowing to smooth the rebound effect is possible all the more when using multiple sites (aggregation).** For instance, impact of rebound can be either smoothed or delayed to catch low prices and/or RES generation (for instance with EV charging), allowing to leave wholesale prices basically unchanged.
- Hence, the load shifting would tend to occur mainly during hours of low prices, thus leading to a very small change on wholesale market price, if any. The overall net benefits are thus marginally affected by the rebound effect in most cases.
- Therefore, the rebound effect is not modelled in this study which assumes that DR happens as a simple load-shedding.

DR benefits assessment methodology relies on simulating the dispatch with a realistic DR portfolio for the interconnected European power markets

Simulation in CL Dispatch Model

- **The analysis performed by CL focuses on DR benefits for the wholesale power market from July 2022 to June 2023.**
- The modelling relies on the CL Energy Pan European model
  - **Input** :
    - installed capacities per technology, share of RES, level of demand in countries are all in line with the latest announcements of member states
    - commodities are updated with market data to be in line with recent trends (using futures as of 22/03/2022)
  - **Simulation** :
    - hourly dispatch of generation
    - hourly cross border flows
    - hourly power prices

DR approach

- **To efficiently determine DR benefits in this market, it is required to set upstream the key parameters of DR**
  - DR capacity is distributed between EU countries
  - DR capacity is calibrated to represent a possible potential in Europe
  - a realistic mix of capacity and delivered volumes (activation hours) is chosen to model a representative DR portfolio
  - DR volume is distributed over the time horizon* :
    - In 2022, we assume that half of the annual DR volume is activated between July and December.
    - In 2023, the model optimises the distribution of the annual DR volume over the whole year.
  - Sensitivity is performed on the volume and allocation of DR

Note : Necessary step needed because CL Energy's power market model optimises DR activation by calendar year:

3.2

Study scope and modelling approach

Modelling the power dispatch in Europe

Our European power market dispatch model covers all European power markets

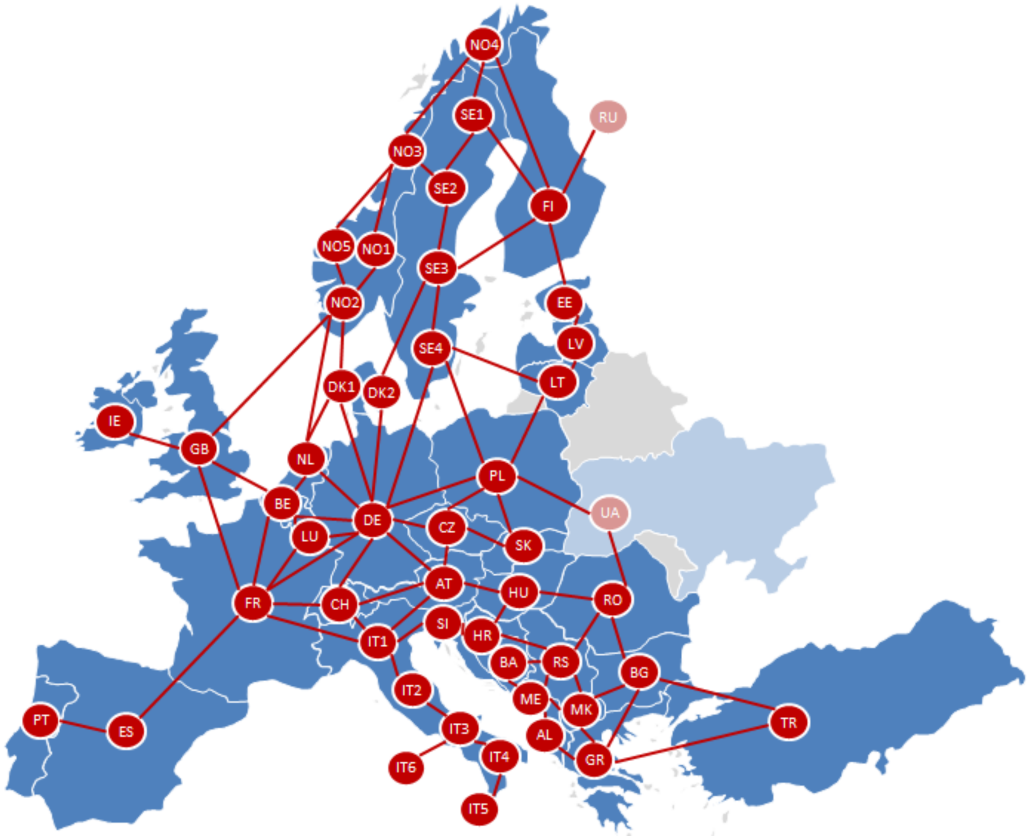
Overview of CL Energy power market model

- GB and Ireland
- France, Germany, Belgium, Switzerland, Austria and the Netherlands
- Spain, Portugal and Italy
- Nordic and Baltic countries
- Poland
- Eastern Europe and Greece, as well as Turkey

Model structure

- The model constructs supply in each price zone based on individual plants.
- Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies
- Takes into account the cross-border transmission and interconnectors and unit-commitment plant constraints
- The model is run on the commercial modelling platform Plexos® using data and assumptions constructed by FTI-CL Energy

Geographic scope of the model



Study scope and modelling approach

The power market model is set up with a range of inputs derived from latest announcements from TSOs, regulators and market players

Key power price driver	Sources	Optimization
Demand		
Power demand	■ Long term electrification based on decarbonisation scenario	■ Fixed set as demand to be met
Supply		
RES capacity	■ CAPEX and OPEX outlook based on latest data from EC and E3M (July 2021)	■ End of Feed-in-Tariffs for new capacities, no <0 prices
Nuclear capacity	■ Latest National plans on phase-down or phase-out ■ Latest announcement on plants' life extension and new projects	■ Dispatch optimized by hourly dispatch model
Thermal capacity	■ Latest announcements from operators and National plans on phase-out or conversion to biomass ■ Latest announcement on refurbishment and new projects in the short-term ■ CAPEX and OPEX outlook based on latest data from EC and E3M (July 2021)	■ Dispatch optimized by hourly dispatch model
Storage technologies	■ CAPEX and OPEX outlook based on latest data from EC and E3M (July 2021)	
Commodity prices		
Gas	■ Forwards until 2023 (as of 22/03/2022)	■ Fixed set as an input
Coal ARA CIF	■ Forwards until 2023 (as of 22/03/2022)	■ Fixed set as an input
CO2 EUA	■ Forwards until 2023 (as of 22/03/2022)	■ Fixed set as an input
Interconnections		
Interconnection	■ ENTSO-E TYNDP 2021 outlook for new and existing interconnections	■ Fixed set as an input

(1) E3M: Energy-Economy-Environment Modelling Laboratory ; (2) TYNDP: Ten Years Network Development Plan

Our assumptions contribute to a conservative assessment of DR benefits

A range of assumptions for modelling tend to lead to conservative assessment of DR benefits:

- **The optimisation runs on a representative climate year, and does not consider extreme climate years featuring extreme cold spell or Dunkelflaute**.
  - DR benefits would be even higher when such events occur, and they do, and may tend to occur more frequently with climate change,
- **Interconnection development is supposed to follow historical trends and TSO's announcements with a perfect market coupling**
  - A delayed development of new projects or outage of some cross-border interconnection would limit price convergence between price zones and lead to higher upward volatility of prices, and greater benefits of having DR
- **Thermal capacities are assumed to be the same in scenarios with or without deployment of DR, thus limiting the benefits resulting from having DR**
  - Beyond announced coal phase-outs, it is considered there would be no disinvestment in thermal peak capacity thanks to the development of DR in the system;
  - As a result, the difference in price peaks depending on the scenario (with or without DR) is limited due to the availability in both scenarios of peaking capacity up to the level that is necessary to ensure security of supply without DR.
- **A two-step optimisation to solve a complex dispatch modelling issue**
  - For mathematical reasons, the dispatch optimisation problem is solved in two-step
    - First a simplified all-year optimisation occurs, with low resolution (6h blocks) to determine optimal dispatch of capacity with intertemporal arbitrages such as hydro, storage, P2G and DR
    - Second, a detailed hourly dispatch optimisation selects the best mix of generation to minimise costs at every hourly step
  - The existence of the first simplified optimisation, although necessary, does not allow to catch systematically all price spikes as the model selects hours when to allocate DR deliveries.

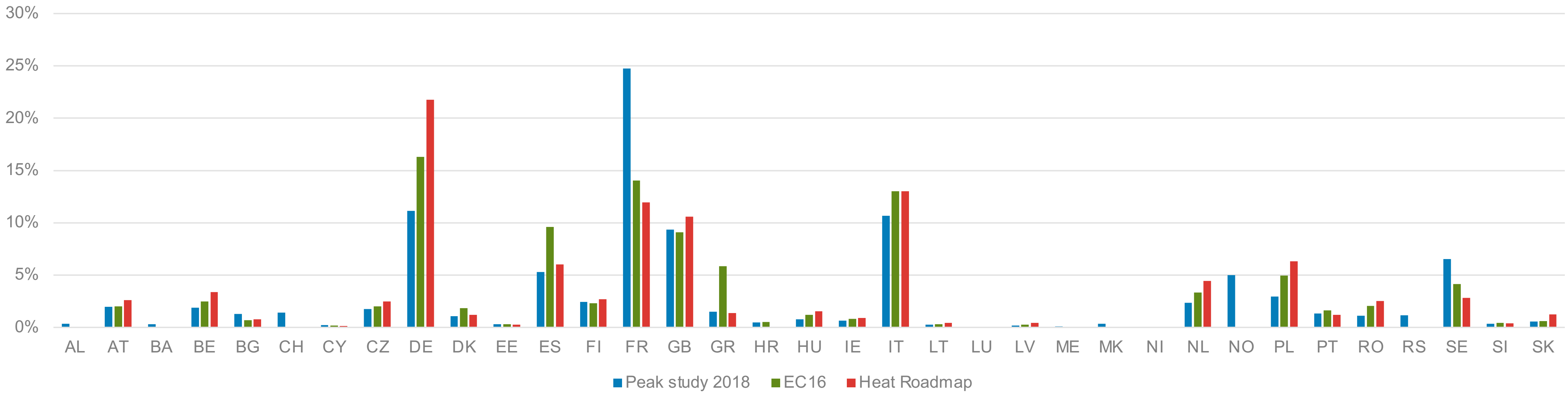
3.3

Study scope and modelling approach

Building a realistic DR portfolio spread over both space and time

The modelling of country by country distribution of DR capacity is based on existing studies of pan European DR potential

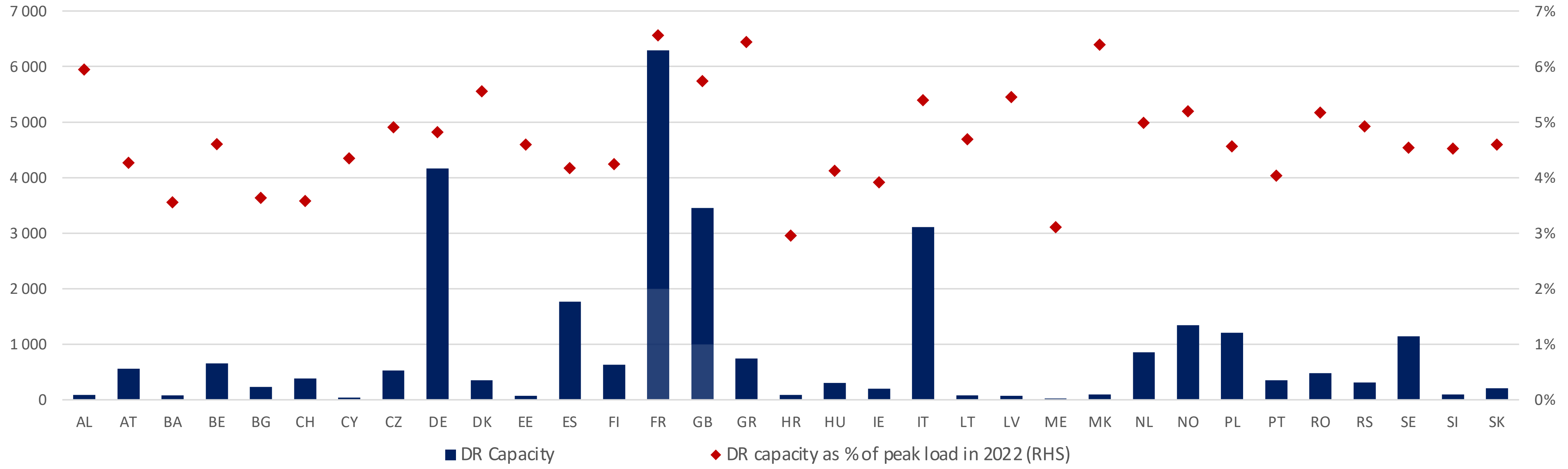
DR distribution in Europe (% of overall DR considered capacity)



- The country distribution of the DR potential is considered in this study as an average based on three main sources/studies:
  - European Commission, 2016, Impact assessment study on downstream flexibility, price flexibility, demand response & smart metering
  - Heat Roadmap for Europe
  - Peak study with ENTSO-E data for 2018
- We assume 30 GW of DR in Europe in 2022/2023

The modelling of country by country distribution of DR capacity is based on existing studies of pan European DR potential

DR distribution in Europe (MW)



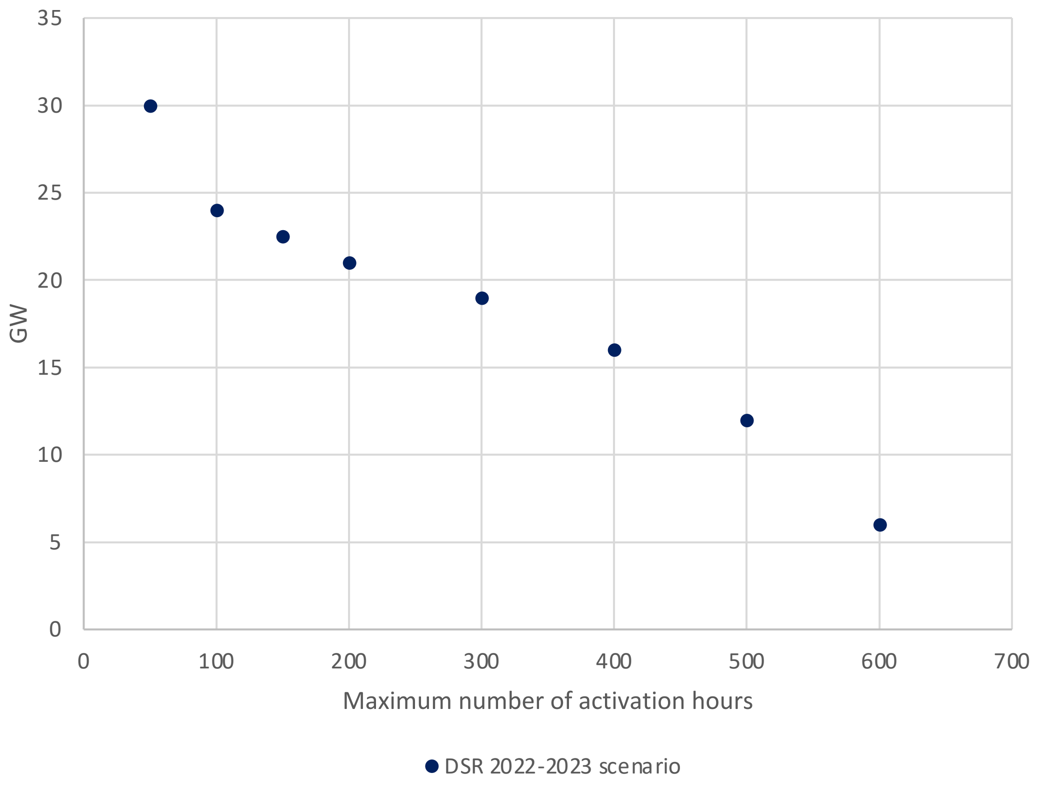
- We assume 30 GW of DR in Europe in 2022/2023
  - We allocate 27 GW of DR capacity to European countries according to the previous distributions.
  - We allocate an additional 2 GW to France and 1 GW to GB, to reflect their more advanced stage in DR development. Some other countries are also advanced, which is supported by the selected distribution (Finland, Italy ..)
- The allocated DR capacities range between 3% and 7% of the national peak load, with an average of 5% across countries

Study scope and modelling approach

DR durations of activation to consider a realistic DR portfolio

- We simulated a selected realistic DR client type portfolio of activation hours and capacities
  - A total **30 GW of maximum capacity** is considered for the winter 2022/2023
  - Capacities are available for various durations: not all can be used at all times. Some are available only a few tens of hours per year.
  - At most, 6 GW potential is considered available 600 h/year.
- The total volume of DSR amounts to **10 TWh per calendar year,** or 0,3% of EU power demand
- We calculated benefits and costs for electricity suppliers (hence ultimately for all consumers) with:
  - Benefits estimated as the avoided costs of energy sourcing in all modelled national markets
  - DR “costs” for suppliers estimated as the revenue of DR delivered in the spot market
  - This includes all suppliers, hence all consumers, but does not consider additional benefits specific to participating consumers
- The assessment of DR costs as defined above contributes to maximising them. In practice, some DR volumes could be sold in the forward market lowering its costs for suppliers

DR potential distribution

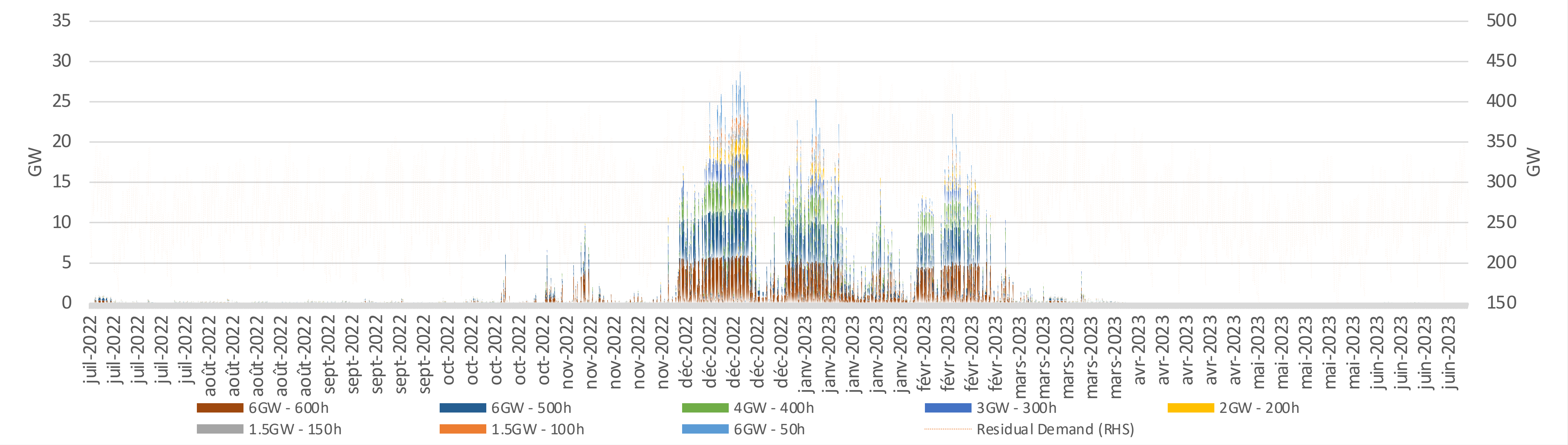


4.

DR benefits assessment

DR helps the European system during periods of market tightness resulting from high levels of residual demand to be met by dispatchable plants

Hourly profile of activation – EU from July 2022 to June 2023 – Total DR activation : 10.7 TWh



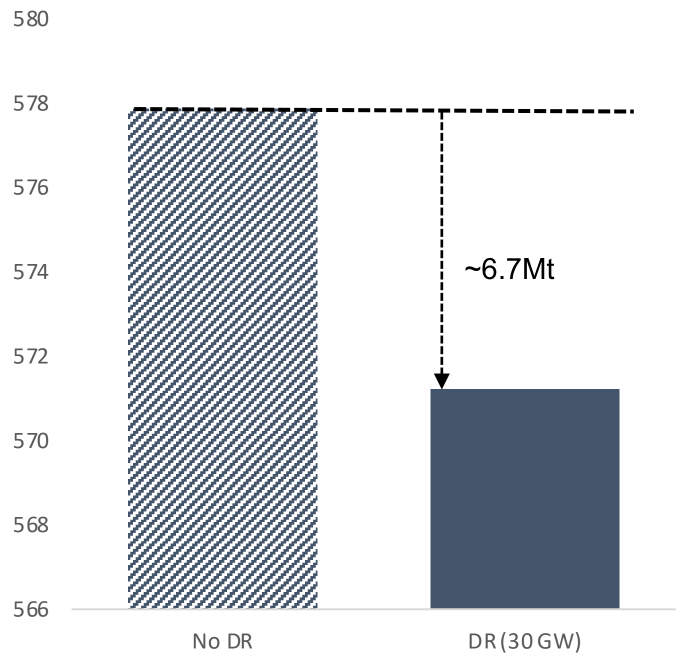
- As a consequence of the assumptions made (particularly on interconnections and market coupling), the activation of DR mostly appears during winter periods to provide flexibility to the system when capacity is scarce.
  - The majority of DR is used at periods of overall EU market tightness to maximise the benefits to the wholesale markets.
  - However as peak prices are not necessarily simultaneous all over Europe, the maximum DR capacity of 30 GW is never fully activated.
- With this distribution, almost all activations occur from November to March. Since we assumed perfect market coupling within the available interconnection capacity, summer demand peaks in southern Europe can partially benefit from nuclear and renewables generation in northern Europe.

Note : Residual demand is defined as final customer demand minus renewable generation
CL Energy's power market model optimises DR activation by calendar year:
- *In 2022, we assume that half of the annual DR volume (5 TWh) is activated between July and December.*
- *In 2023, the model optimises the distribution of the annual DR volume (10TWh) over the whole year. It sets more volume in H1 2023 (5,7 TWh) than in H2 2023 (4.3)*

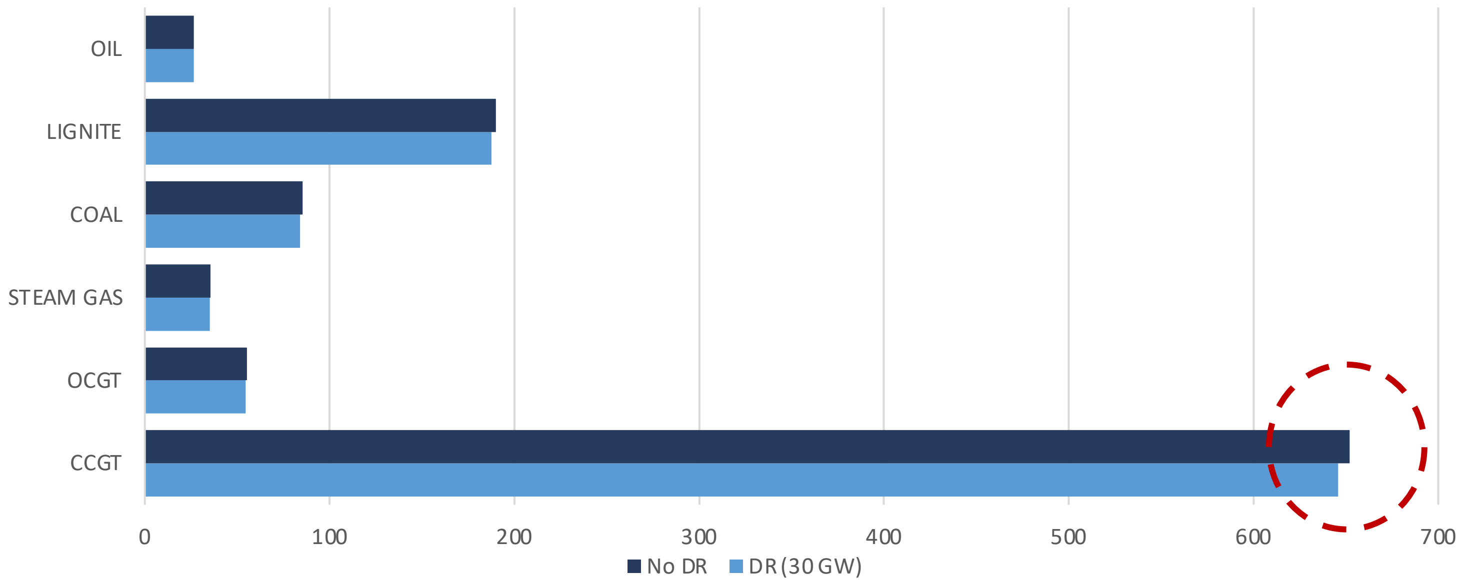
DR benefits assessment

DR avoids electricity generation from carbon intensive technologies

CO2 Emissions (Mt)



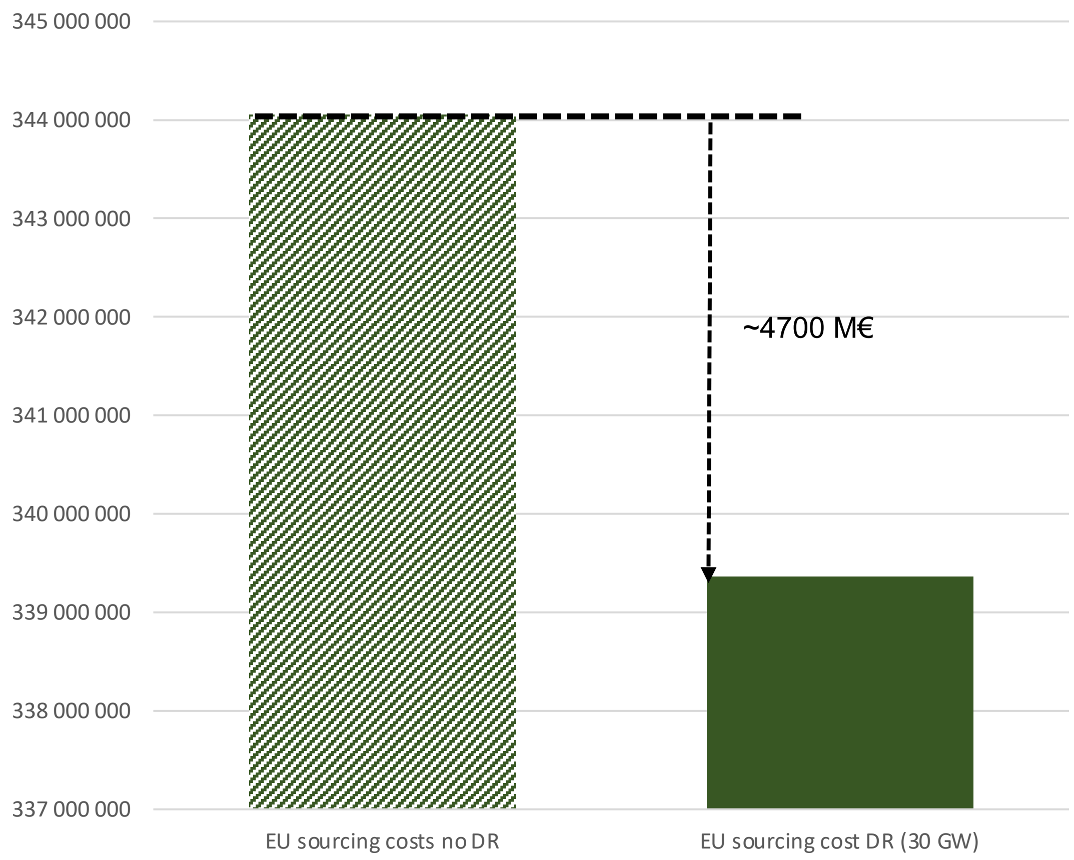
Power generation (TWh)



- **DR participation in the market as an alternative to generation allows a reduction in CO_2 emissions of more than 6.7 $MtCO_2eq$ /y.**
- **The DR portfolio considered has a total available volume of 10 TWh per calendar year (10.7 TWh during the period July 2022 - June 2023). It mostly replaces CCGT production during peak hours**.
  - This is a conservative assessment due to the DR country repartition considered. Indeed, as DR capacity is maximum in countries with advanced coal-phase outs, the marginal technology is modelled to be CCGT. If DR was deployed in countries with more coal power plants, CO_2 emissions avoided could be higher.
  - The volume of gas saved amounts to around **15 TWh, equivalent to 1.5 bcm**.

DR portfolio reduces energy sourcing costs of about 4700 M€ in Europe between July 2022 and June 2023

Impact of DR in wholesale market for the portfolio (000€) – EU from July 2022 to June 2023



Gross benefits of the chosen DR portfolio are defined as the avoided costs of sourcing energy on the market for suppliers.

- We define the sourcing costs as the cleared market price applied to energy demand. We do not consider any transaction costs.
- In our model, DR allows a reduction in sourcing costs of about 4700M€, which represents a **1.4% reduction in power sourcing costs**.
- These costs are incurred by end-users through suppliers, lowering them is beneficial to all suppliers, hence ultimately all customers.

The net between these total benefits and costs for suppliers will be passed on to all customers through the energy bill – see next slide

Several assumptions contribute to a conservative assessment of benefits:

- Perfect market coupling and cross-border interconnections development
- Representative climate year, no extreme events
- The two-step optimisation in the modelling might not catch all the price spikes for the short activation duration
- No disinvestment of in thermal peak capacity even though DR could cannibalize revenue over time and push them out of the market
- Benefits of a better resource adequacy (e.g. via savings on capacity mechanisms) are not taken in to account here, nor via ancillary services

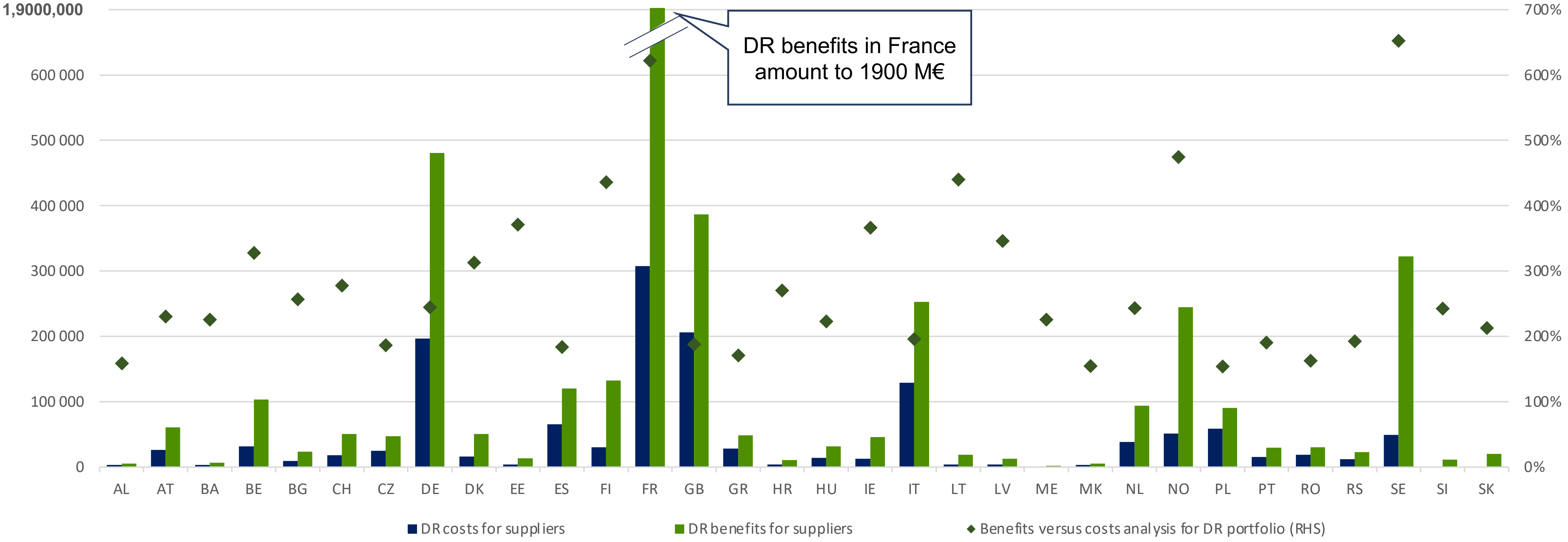
With the 30 GW DR portfolio, market benefits for suppliers in their energy sourcing are 335% of DR market costs for suppliers

- Gross market-wide benefits are defined as the reduction in suppliers' sourcing costs in the wholesale energy market (i.e. the drop in prices allowed by DR activation multiplied by the load the same hour, see previous slide), not taking into account indirect benefits e.g. on capacity markets/mechanisms nor ancillary services.
- On the other hand, suppliers incur extra costs related to DR. They can be considered either as :
  - Market costs: DR being offered as "supply" in the market it receives the market clearing price (i.e. the volume provided by DR multiplied by the clearing price on the wholesale market that hour)
  - Or, 'opportunity costs': DR being activated leads to lower consumption of participating clients hence to lower revenue for suppliers.
- Our modelling precisely estimates market costs (likely to be higher than 'opportunity costs'), the following is based on these results.
- **With several assumptions leading to a prudent estimation of market wide gross benefits (i.e. for all suppliers) and maximising the market costs of DR, benefits account for more than three times the market costs**

Costs of energy sourcing with DR (000€) and benefits versus costs analysis for DR portfolio – EU from July 2022 to June 2023

Most countries feature a benefit/cost ratio between 1.5 and 2.5, France has a higher ratio due to the exceptional situation for next winter

Distribution of avoided sourcing costs in Europe (000€)



- The ratio of DR benefits for suppliers to DR market costs for suppliers is between 1.5 and 2.5 for most European countries.
- This ratio reaches 620% for France, due to its exceptional situation next winter (low nuclear generation available)

Note : Nordic countries show high Benefits vs Costs ratio as the two step modelling approach allows the model to optimise and reduce the water value of hydro in the Nordic countries with DR compared to the scenario without DR

Annex A1

DR as a shield to protect suppliers and consumers by shaving price spikes

DR helps to cap wholesale price spikes and reduce average prices

Average prices change for the 50 first hours of activation

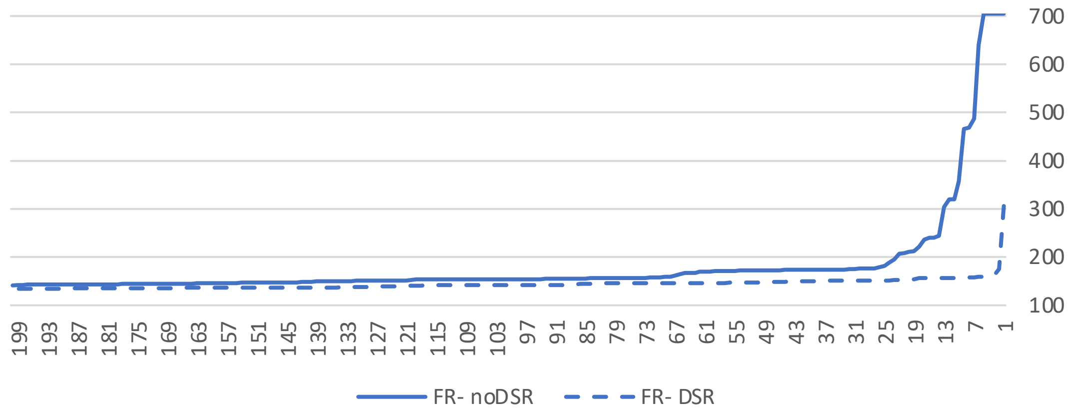
€/MWh	No DR	DR	Difference
DE	159	149.5	9.5
FR	276.5	156.6	120
GB	196.4	176.3	20.1
ES	156.7	151.4	5.3
ITN*	159.4	151.4	8
PL	300	224.2	15.5
NL	158	148	10
BE	193.6	152.2	41.4

- DR gives the maximum benefit to the system during peak hours as the marginal units lead to a steep supply curve.
- DR activation helps to cap wholesale prices spikes, it acts as **a shield for consumers** capping wholesale price at around 150 €/MWh in most European countries.
- Across European countries, the average price decrease over the activation for the 50 highest hours of up to -120 €/MWh.
- For other hours the spread between situations with and without DR decreases as the supply curves is not as steep
- In this study, it is taken into consideration that prices can be reduced thanks to DR activation abroad and not only in the national market (price zone).

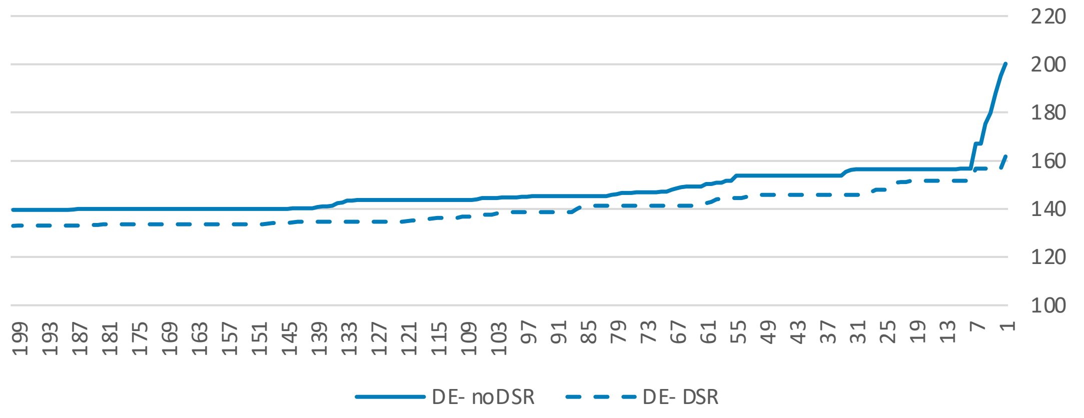
**Italy North*

DR helps to cap wholesale price spikes and reduce average prices

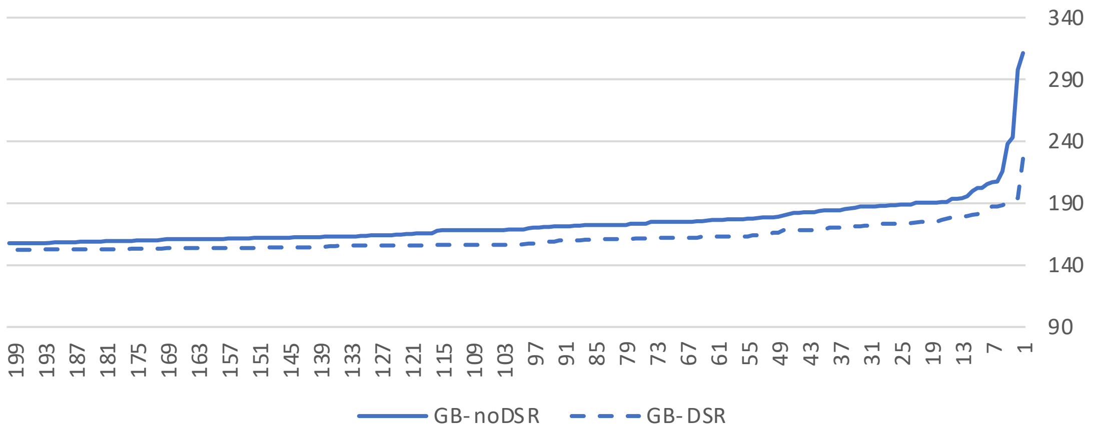
Prices evolution (€/MWh) – FR – from July 2022 to June 2023



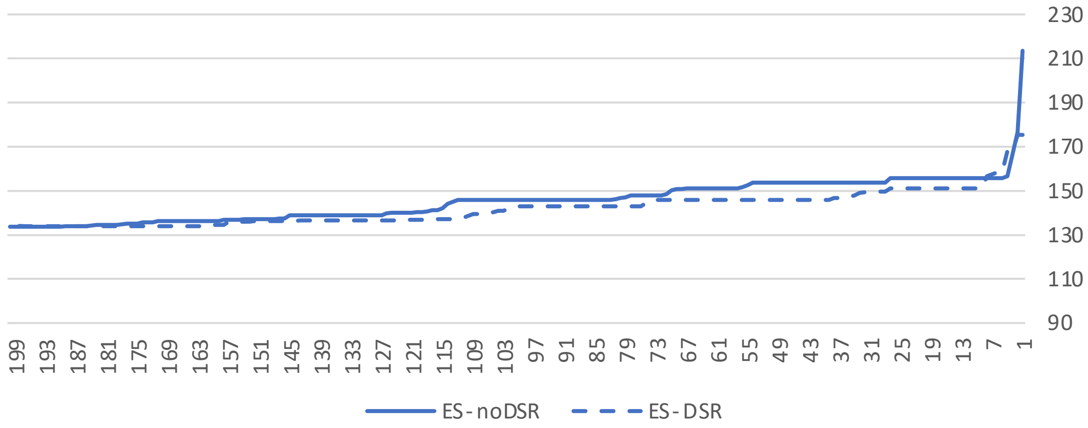
Prices evolution (€/MWh) – DE – from July 2022 to June 2023



Prices evolution (€/MWh) – GB – from July 2022 to June 2023



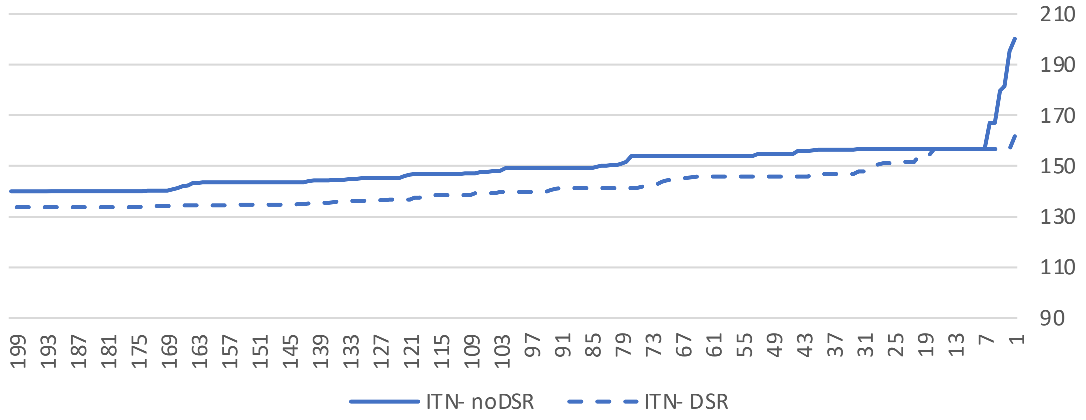
Prices evolution (€/MWh) – ES – from July 2022 to June 2023



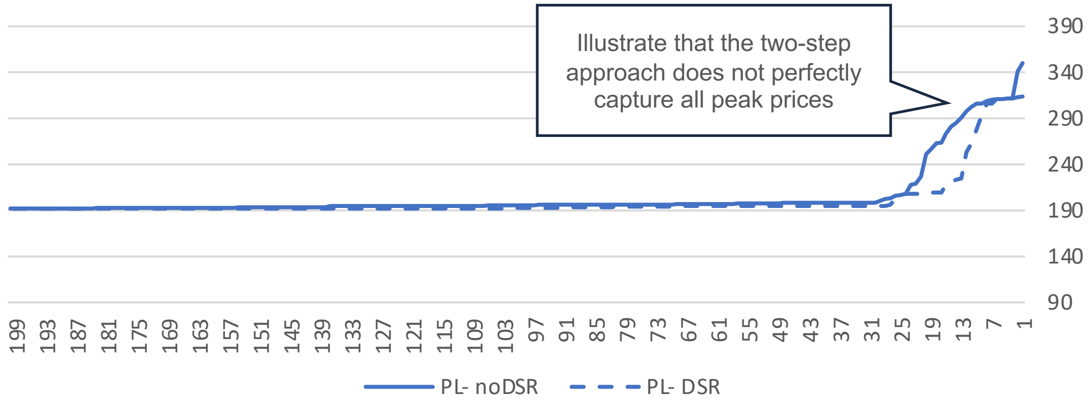
Annex A1 : DR as a shield to protect suppliers and consumers by shaving price spikes

DR helps to cap wholesale price spikes and reduce average prices

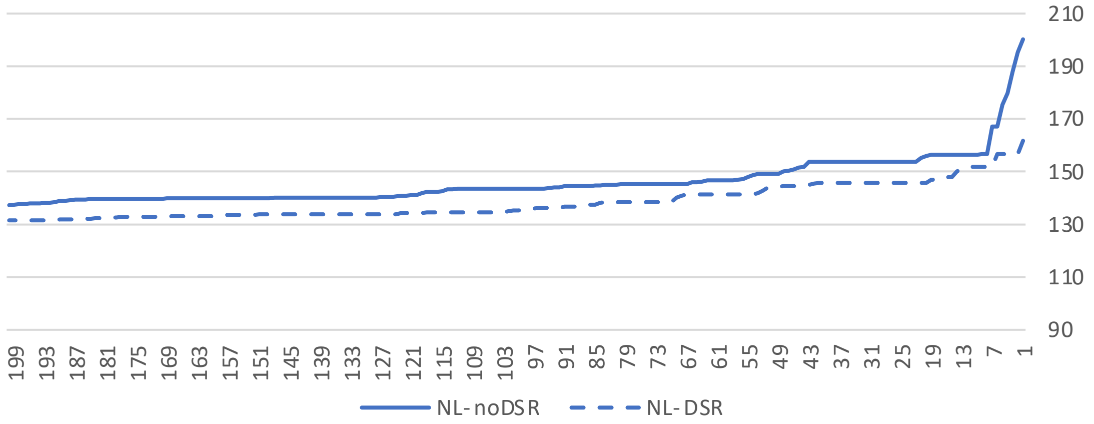
Prices evolution (€/MWh) – ITN – from July 2022 to June 2023



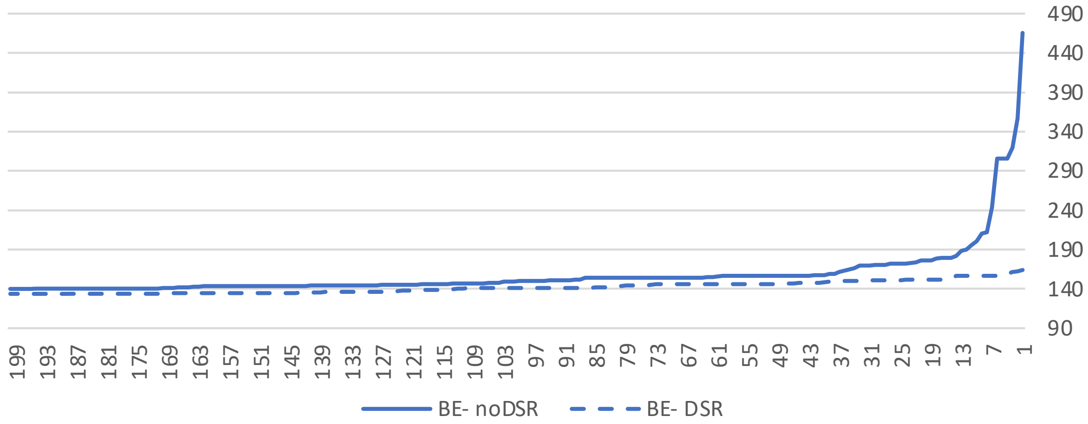
Prices evolution (€/MWh) – PL – from July 2022 to June 2023



Prices evolution (€/MWh) – NL – from July 2022 to June 2023



Prices evolution (€/MWh) – BE – from July 2022 to June 2023



Annex A2

Sensitivity analysis on DR volume

Annex A2: Sensitivity analysis on DR volume

By limiting the volume of DR to 10 TWh from July 2022 to June 2023, the benefits for suppliers decrease by a maximum of 270M€

- CL Energy's power market model optimises DR activation by calendar year. The central scenario presented in the previous slides is defined as follow:
  - In 2022, we assume that half of the annual DR volume (5 TWh) is activated between July and December.
  - In 2023, the model optimises the distribution of the annual DR volume (10TWh) over the whole year. It sets more volume in H1 2023 (5,7 TWh) than in H2 2023 (4.3)
  - Therefore, **DR activation from July 2022 to December 2023 amounts to 10.7 TWh**.
- In order to assess the impact of DR volume and allocation in benefits, we design three additional sensitivities limiting the DR volume to 10 TWh over the considered horizon :
  - Configuration 1: We assume that the annual volume of DR is split equally between H2 2022 and H1 2023 (5TWh in each half year).
  - Configuration 2: We assume that only 4.3 TWh are activated during H2 2022, leaving H1 2023 unchanged.
  - Configuration 3: We assume that 6 TWh are activated in H2 2022 and 4 TWh in H1 2023.

Configuration	Activation H2 – 2022	Activation H1 – 2023	Total activation	Benefits	Reduction in benefits compared to central scenario	
#	*TWh*	*TWh*	*TWh*	*M€*	*M€*	*%*
Central scenario	5	5.7	10.7	4700		
1	5	5	10		490	-10.4%
2	4.3	5.7	10		270	-5.7%
3	6	4	10		350	-7.4%

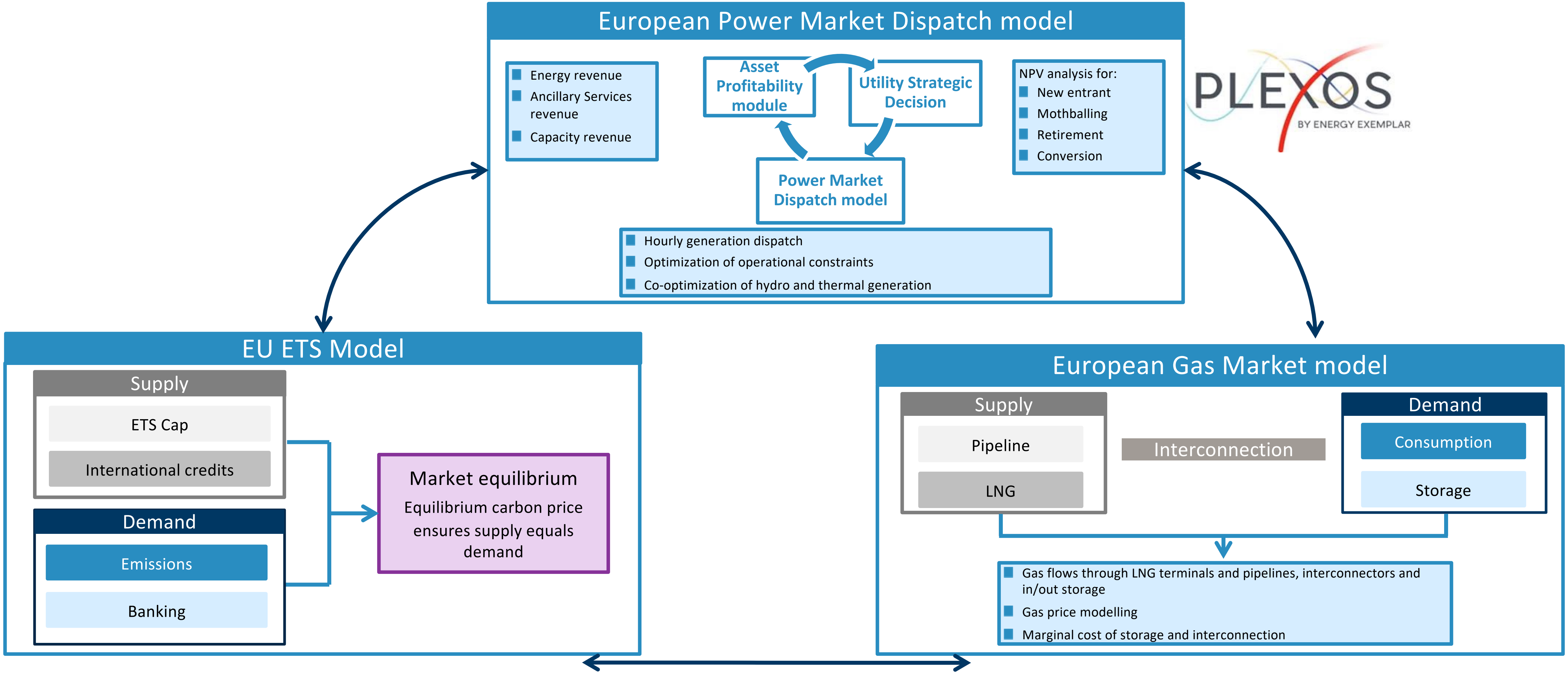
- Configuration 2 is a reasonable approximation of the optimum if a constraint of 10 TWh from July to June and not per calendar year was applied.

Annex B

Detailed modelling approach and assumptions

Annex B: Detailed modelling approach and assumptions

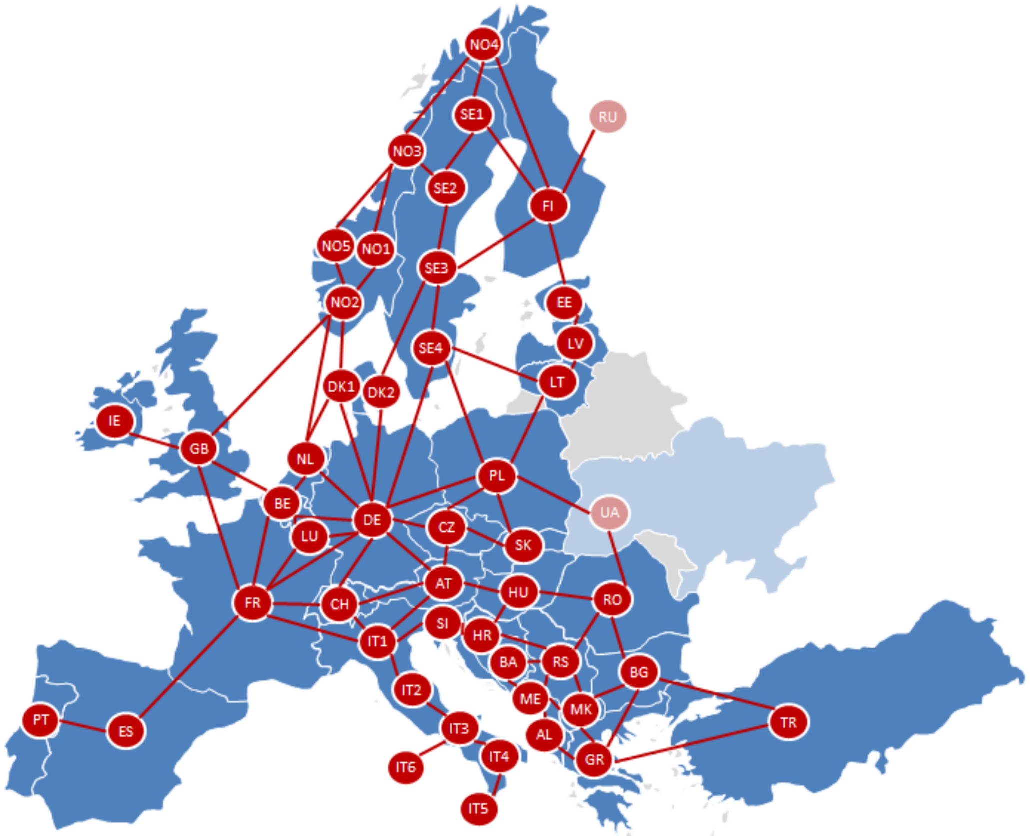
CL energy has developed integrated proprietary models of electricity, gas and CO2 markets



CL European power market model covers the power markets of EU27+ with fine granularity

- CL Energy's power market model covers **the EU-28 countries as well as the UK, Switzerland, Norway, the Balkans and Turkey**.
  - Countries beyond this geographic scope are modelled at an aggregate level.
  - The model is run on a commercial modelling platform Plexos® using data and assumptions constructed by CL Energy for demand, supply, commodity price and interconnection.
- CL Energy's power market model constructs **supply in each price zone based on individual plants and simulates the market with hourly resolution**
  - European power plants database containing technical parameters of all thermal European plants
  - Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies.
  - Model takes into account cross-border transmission and interconnectors and unit-commitment plant constraints.

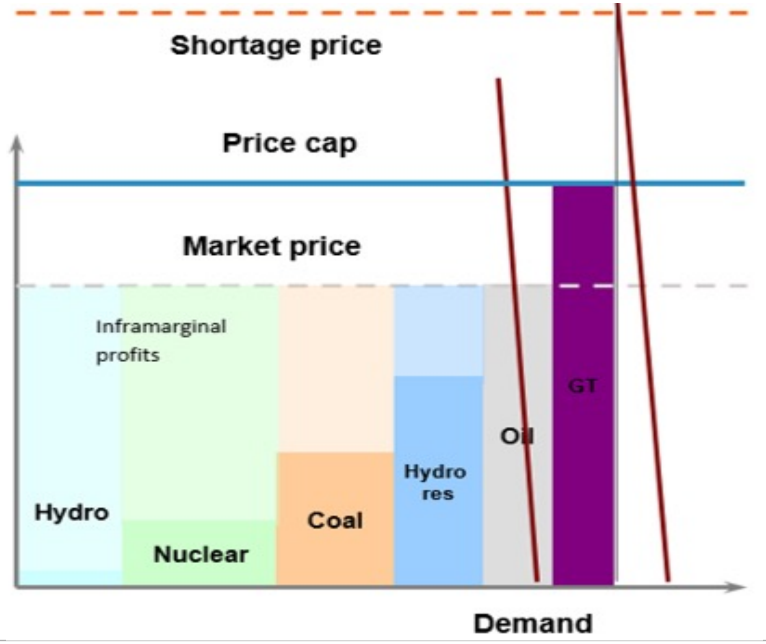
Geographic scope of the model



CL model relies on a dispatch optimisation software applied to short to long term capacity scenarios

Dispatch optimisation for a given time period

- **Model constructs supply hourly in each price zone based on individual plants unit commitment constraints:**
  - European power plants database containing technical parameters of all thermal European plants
  - Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies
  - Model takes into account cross-border transmission and interconnectors



A two-step problem solving

- **In order to be able to simulate intertemporal arbitrages allowed by hydro generation, storages, and DR, with acceptable computational time, the optimisation problem needs two steps of calculation:**
- First, the Medium-Term Schedule solves the annual optimisation problem by:
  - reducing the number of simulated periods by combining together dispatch intervals in the horizon into 'blocks;
  - optimizing decisions over this reduced chronology; then
  - decomposing medium-term constraints and objectives into a set of equivalent short-term constraints and objectives.
- Second, the Short-Term Schedule is designed to emulate the dispatch and pricing of real market-clearing engines with the full desired resolution (e.g., hourly).

  MT Schedule thus simplifies input data for intertemporal arbitrages. The allocation of storage energy (hydro, DR, batteries) is an approach with an interval that might differ from a perfect allocation.

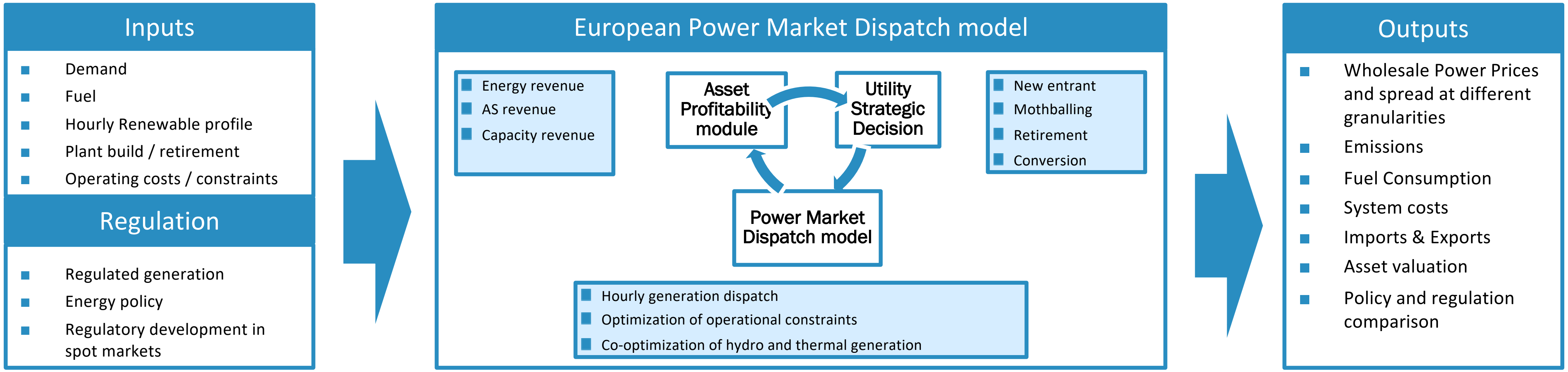
  It contributes to underestimating benefits in DR assessment

CL energy's power market model relies on a dispatch optimisation software with detailed representation of market fundamentals

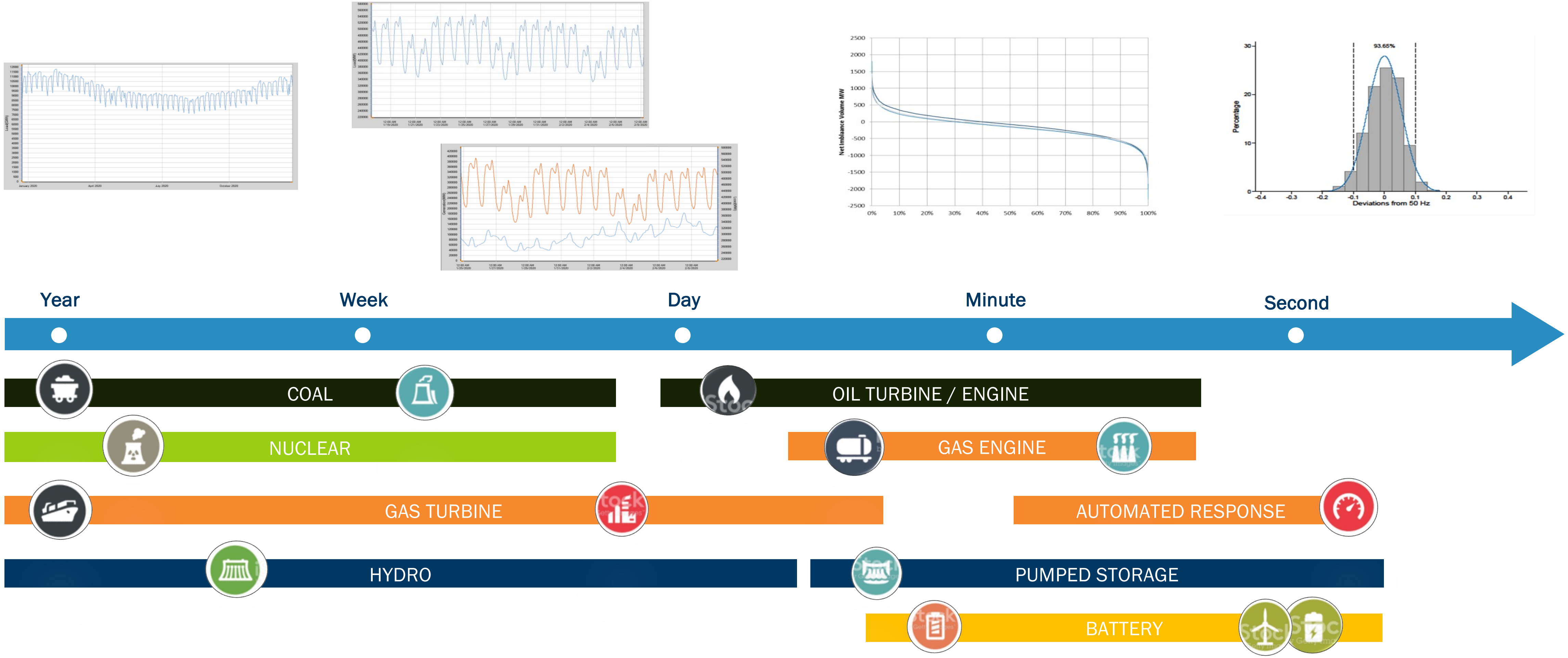
Dispatch optimisation based on detailed representation of power market fundamentals

- At the heart of FTI-CL Energy's market modelling capability lies a dispatch optimisation software, Plexos®, based on a detailed representation of market supply and demand fundamentals at an hourly granularity. Plexos® is globally used by regulators, TSOs, and power market participants.
- FTI-CL Energy's power market model is specifically designed to model renewable generation:
  - Wind: Hourly profiles are derived from our in-house methodology that converts consolidated wind speeds into power output.
  - Solar: Hourly profiles are derived from our in-house methodology that converts solar radiation into power output.
  - Hydro: Weekly natural inflows are derived from our in-house methodology that convert rainfall, ice-melt and hydrological drainage basin into energy. Generation is derived from a state-of-the-art hydrothermal co-optimization algorithm embedded at the heart of Plexos®.

FTI-CL Energy's modelling approach (input, modules and output)



CL energy's power market suite allows to capture the flexibility and market arbitrage values on short time frames



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