CONFIDENTIAL

Final results

Study on the quantification of Demand Response (DR) benefits to electricity suppliers and consumers in Europe in 2030 on its way to achieve deep decarbonisation

January 2021

Presented to: DR4EU DEMAND RESPONSE FOR EUROPE

Sponsored by: Voltalis sympower Energy Pool Smart energy management

Disclaimer

- This presentation has been prepared by FTI France SAS under the name Compass Lexecon ("Compass Lexecon") for DR4EU (the "Client") under the terms of the Client's engagement letter with Compass Lexecon (the "Contract").
- This presentation has been prepared for the benefit of the Client in connection with their vision. No other party than the Client or the Sponsor is entitled to rely on this presentation for any purpose whatsoever.
- Compass Lexecon accepts no liability or duty of care to any person (except to the Client under the relevant terms of the Contract) for the content of the presentation. Accordingly, Compass Lexecon disclaims all responsibility for the consequences of any person (other than the Client on the above basis) acting or refraining to act in reliance on the presentation or for any decisions made or not made which are based upon such presentation.
- The presentation contains information obtained or derived from a variety of sources. Compass Lexecon does not accept any responsibility for verifying or establishing the reliability of those sources or verifying the information so provided.
- Nothing in this material constitutes investment, legal, accounting or tax advice, or a representation that any investment or strategy is suitable or appropriate to the recipient's individual circumstances, or otherwise constitutes a personal recommendation.
- No representation or warranty of any kind (whether express or implied) is given by Compass Lexecon to any person (except to the Client under the relevant terms of the Contract) as to the accuracy or completeness of the presentation.
- The presentation is based on information available to Compass Lexecon at the time of writing of the presentation and does not take into account any new information which becomes known to us after the date of the presentation. We accept no responsibility for updating the presentation or informing any recipient of the presentation of any such new information.
- All copyright and other proprietary rights in the presentation remain the property of Compass Lexecon and all rights are reserved.

CONTENTS

Executive Summary (1/2)

- Europe's Green Deal ambitions to **achieve carbon neutrality continent-wide by 2050**. Announcements by the European Union in December 2020 set a new target of **55% of reduction of CO_2 emissions in 2030**.
- Several recent studies explore the potential for increased ambition for decarbonisation of the power sector and highlight **the role of flexibility and in particular DR as a key enabler for this increased ambition**.
- We use a hourly model of the European power wholesale market and **a realistic DR portfolio of 30 GW in 2030** participating in this market, and we calculate the benefits for all electricity suppliers directly resulting from **the market-wide reduction achieved in their energy sourcing costs, thus benefitting ultimately all electricity consumers.**

Executive Summary (2/2)

- **We find that the direct benefits for electricity suppliers resulting from DR participating in the market amount to 290 M€/year and 190% of the costs for energy suppliers, thus leaving to them and ultimately to all consumers a net benefit,** whereas conservative assumptions lead to underestimate these figures in several cumulative ways:

  1. We suppose thermal capacity remains the same with and without DR, as if there were no disinvestment in thermal peak capacity upon development of DR even though DR would cannibalize revenue over time and push them out of the market (and so would climate policies); hence calculation of benefits of having DR are herein underestimated;
  2. We assume perfect market coupling and cross-border interconnexions development in line with historical trends *and* public announcements; should such investment be delayed, DR would be even more beneficial and even vital to ensure security of supply;
  3. The optimisation model is run on a representative climate year, and does not consider extreme climate cases e.g. featuring extreme cold, which lead to higher benefits of having DR; yet extreme weather already occurred in the past, and climate change may increase this.
  4. We had to use, to run the calculation with our model, a two-step optimisation to spread DR volumes during the year as per higher market prices, and this does not capture all but only part of price spikes in the hourly dispatch especially for short activation durations.
  5. DR revenues, considered as costs for suppliers, are calculated based on spot market prices regardless of the possibility that it would be sold cheaper on forward markets and/or as options, in order for DR aggregators to secure revenues, thus reducing costs.

- In addition to showing DR benefits for suppliers almost twice greater than costs for suppliers, our assessment of DR benefits for a realistic DR portfolio in 2030 demonstrates the following:

  1. **DR is activated when the European power market margins are tight,** thus improving security of supply, another benefit that is not taken into account as such in this study.
  2. Thanks to DR participation, **price volatility** on European spot markets would be lower, i.e. spikes are avoided.
     In France for instance, where some 16% of the DR capacity in Europe was assumed to be located, DR activation allows a **reduction of the highest hourly price of - 40 €/MWh.**
  3. In terms of GHG, the **30 GW DR portfolio avoids 1 Mt/year of CO_2 emissions**, mostly avoiding use of gas generation.

Context and objectives

COMPASS LEXECON

Study context

- The European institutions **have reaffirmed their commitment to accelerate the decarbonisation of the European economy and reach carbon neutrality by 2050** within the Green Deal. As mentioned in the daily news of the 11th of December from the European Commission, EU Heads of State or Government approved a new and more ambitious net greenhouse gas emissions reduction target of at least 55% for 2030 compared to 1990 levels. President Ursula von der Leyen then said:

  "I am delighted that, together with the German Presidency,
  we were able today to reach an agreement on the proposal for a new EU climate target.
  *We will **reduce emissions by at least 55% by 2030**.*
  Today's agreement puts us on a clear path towards climate neutrality in 2050."

- Several recent studies from the European Commission (1), the IPCC (2) and various stakeholders including the IEA (3) have explored the potential for increased ambition for the decarbonisation of the power sector:
  - These studies suggest a **growing role of electricity, from circa 20% of the European final energy consumption in 2015 to more than 40% by 2050** through electrification of transport, heating and cooling and industrial processes.

- This creates **new challenges and opportunities for the power system** and highlights the need for new ways in which the **power sector can meet this ambition whilst ensuring security of supply at the least cost for consumers.** Increasing demand-side flexibility is generally considered as key, not to say necessary, both to improve efficiency and reliability of the power system, and particularly to use more effectively intermittent renewable and distributed resources.

(1): 2050 EU Energy roadmap (2010), EU Reference scenario 2013, 2016, PINC

(2): IPCC: Global Warming of 1.5C, October 2018

(3): World Energy Outlook (IEA, 2018)

Study context and CL Energy mandate

- **Transition towards European carbon neutrality objective will deeply impact the power system, both on the supply and demand side.**
  - Solar and wind capacities will strongly develop by 2030 in line with the National Energy and Climate Plans of member states;
  - Coal and nuclear phase-outs in Europe will drive flexible capacities down by 110 GW in 2040;
  - A higher decarbonisation ambition by 2030 implies an accelerated electrification of transport, heating and cooling leading to additional demand side flexibility potential.

- **In the current market design, increasing RES capacity** in the mix tends to drive wholesale electricity prices down on average, reducing the revenues on the wholesale market for all power plants, but resulting in **a higher volatility of power prices**
  - Consequently, RES capacities often depend on support mechanisms to recover their investment costs.
  - Meanwhile conventional power plants incur a missing money problem that may need be offset by capacity remuneration mechanisms in order to meet criteria for security of supply, an issue that would be minimized with more DR.
  - The lack of resource adequacy would threaten the security of supply and increase the frequency of periods of tension in the market, resulting in higher price spikes. Having DR participate in the market is a way to ensure resource adequacy.

- Considering this background, DR4EU sponsored by Voltalis, Sympower and EnergyPool has mandated CL Energy to provide a robust assessment of DR benefits in 2030 for the interconnected wholesale European power markets.

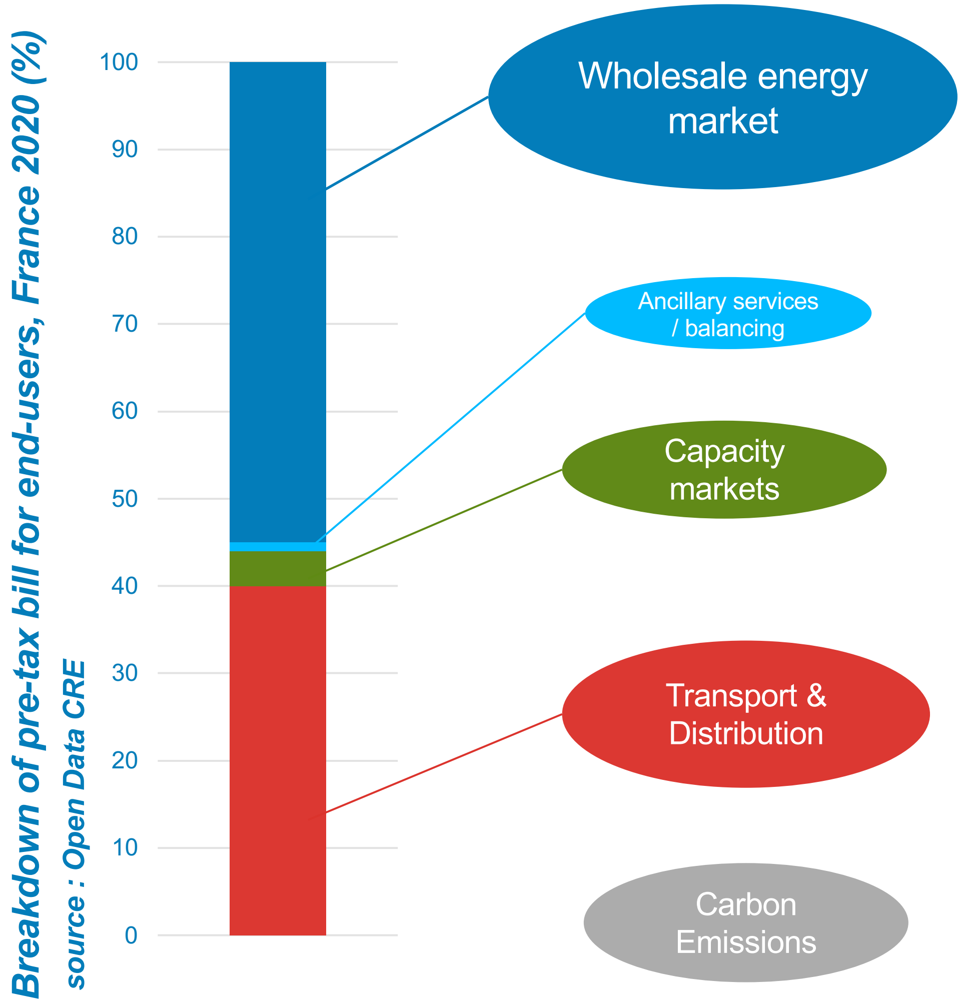
Study scope and modelling approach

COMPASS LEXECON

1. Focusing 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 DSR**



Associated DR benefits

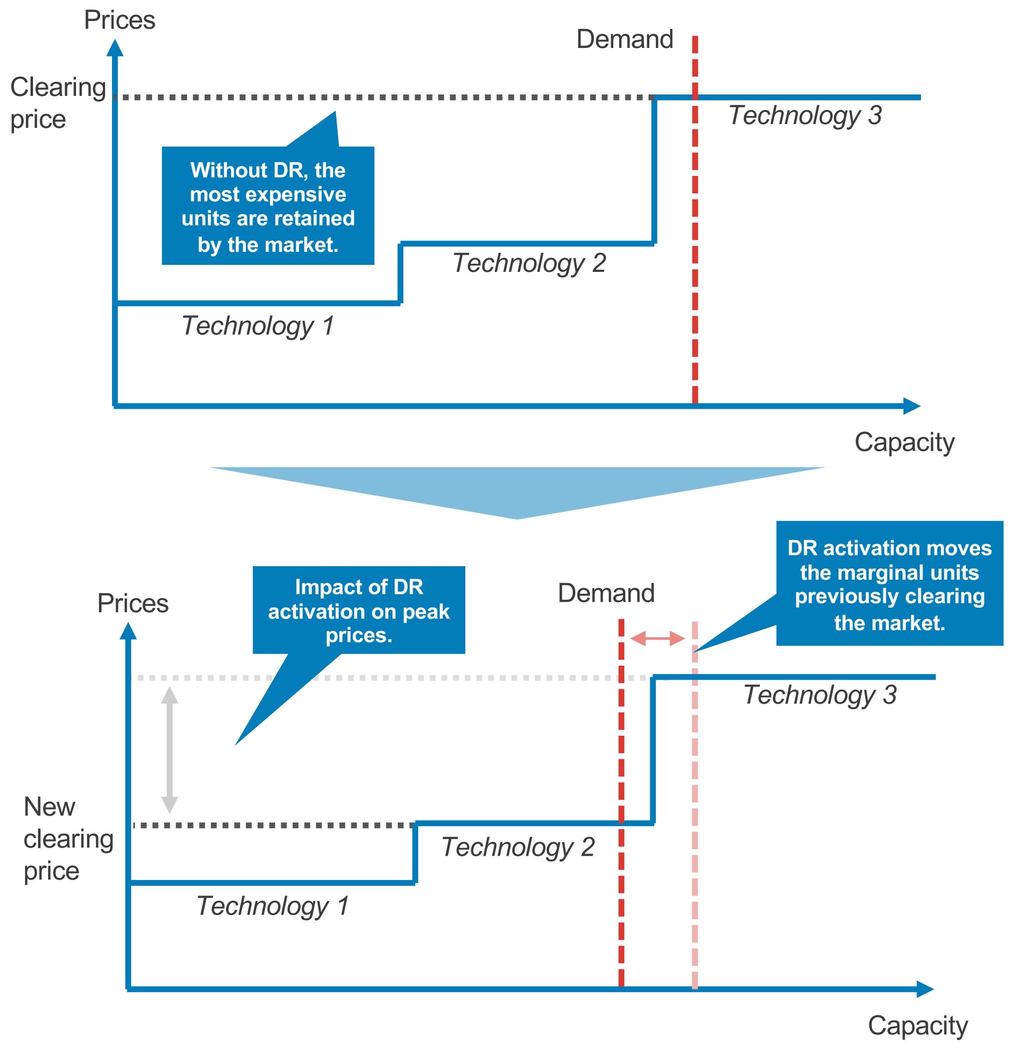
- Reduced price volatility and average price on the wholesale market, in substitution for peaking plants;
- Lower balancing costs, with cheaper flexibility to contain system imbalances and provide ancillary services.
- Reduced need for flexible generation capacity and capacity remuneration mechanism;
- 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 in 2030 for the wholesale power market

- **If we focus on 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.

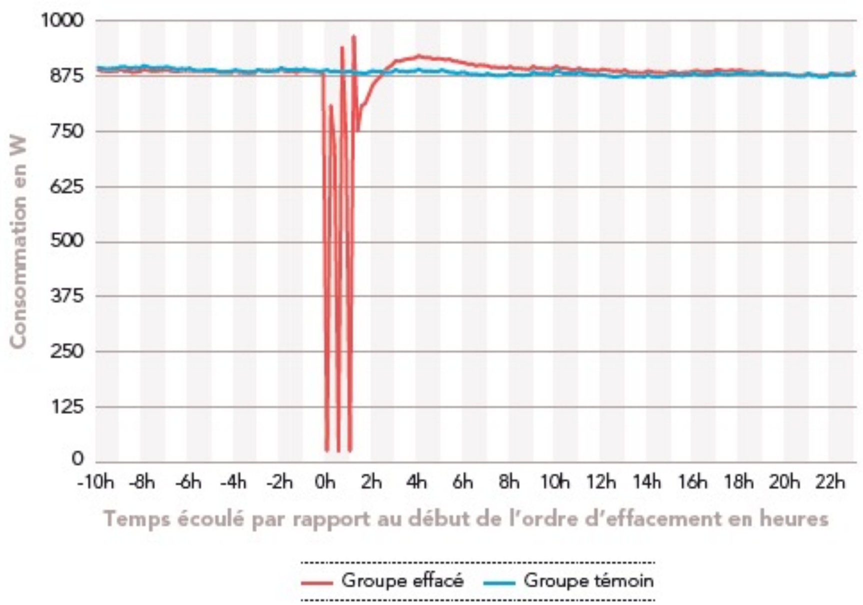
The DR activation in the wholesale market will decrease prices



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.

Source : RTE, 2016, *Évaluation des économies d'énergie et des effets de bord associés aux effacements de consommation*

DR benefits assessment methodology relies on simulating the dispatch with a realistic DR portfolio

Simulation in CL Dispatch Model

- **The analysis performed by CL focuses on DR benefits for the wholesale power market in 2030.**
- **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 EC, IEA or with market data to be in line with recent trends
  - 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 energy (activation hours) is chosen to model a representative DR portfolio
  - Several sensitivities are performed: RES development, DR capacity, DR activation hours.

Study scope and modelling approach

COMPASS LEXECON

2. Modelling the power dispatch in Europe

CL 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

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	■ Meet EU objective of 56% RES-E penetration share by 2030 ■ CAPEX and OPEX outlook based on latest data from EC and E3M (June 2018)	■ Capacity dynamically optimised thereafter based NPV of anticipated costs and revenues ■ 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 (June 2018)	■ Capacity dynamically optimised in the longer term based on NPV of anticipated costs and revenues ■ Dispatch optimized by hourly dispatch model
Storage technologies	■ CAPEX and OPEX outlook based on latest data from EC and E3M (June 2018)	
Commodity prices		
Gas	■ Forwards until 2020, converge to IEA WEO 2019 New Policy by 2030	■ Fixed set as an input
Coal ARA CIF	■ Forwards until 2021, converge to IEA WEO 2019 New Policy by 2030	■ Fixed set as an input
CO_2 EUA	■ Forwards until 2021, converge to EUCO33 by 2025, EUCO30 by 2030/35	■ Fixed set as an input
Interconnections		
Interconnection	■ ENTSO-E TYNDP 2018 outlook for new and existing interconnections	■ Fixed set as an input

(1) MAF: Medium term adequacy forecast; (2) TYNDP: Ten Years Network Development Plan; (3) WEO: International Energy Agency World Energy Outlook

Assumptions contribute to a conservative assessment of DR benefits

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

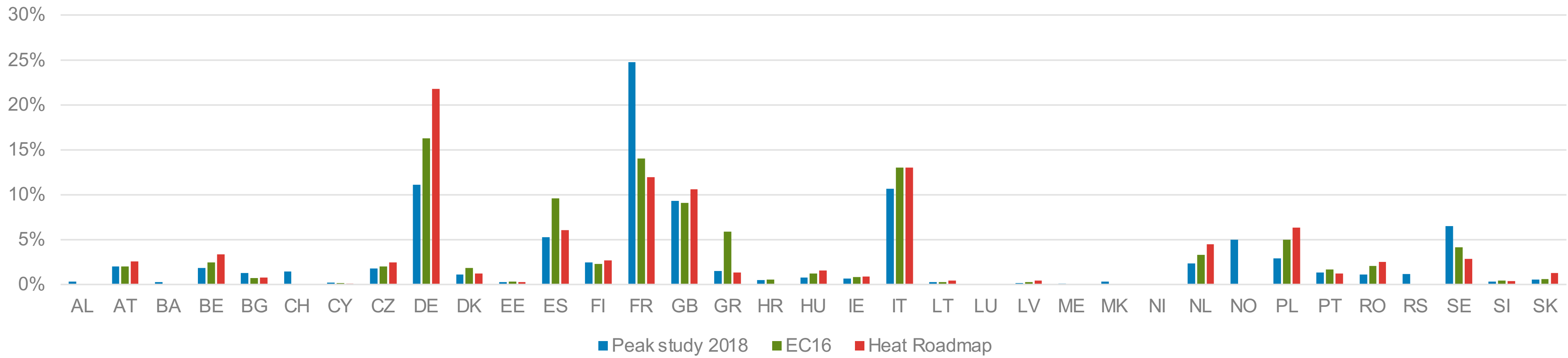
- **Thermal capacities are assumed to be the same in scenarios with or without deployment of DR, thus limiting the benefits resulting from having DR**
  - Beyond announced coal phase-outs, it is considered there would be no disinvestment in thermal peak capacity thanks to the development of DR in the 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.
- **Interconnexion 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 interconnexion would limit price convergence between price zones and lead to higher upward volatility of prices, and greater benefits of having DR
- **The optimisation runs on a representative climate year, and does not consider extreme climate years featuring extreme cold spell.**
  - DR benefits would be even higher when such events occur, and they do, and may tend to occur more frequently with climate change,
- **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 "generation".

Study scope and modelling approach

3. 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)



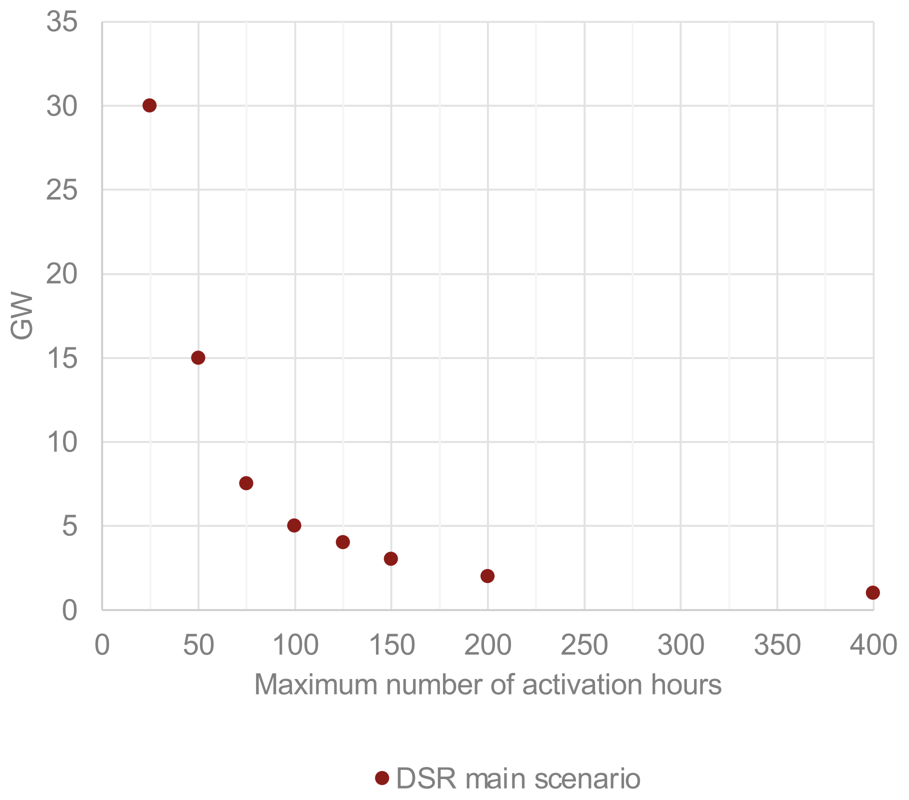
- **The country distribution of the DR potential is considered in this study as an average based on three main sources/studies:**
  - European Commission, 2016, Impact assessment study on downstream flexibility, price flexibility, demand response & smart metering
  - Heat Roadmap for Europe
  - Peak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

- We assume a conservative capacity of **DR in Europe in 2030: 30GW representing only roughly 20% of the 160 GW potential for 2030** as mentioned by the European Commission in their impact assessment**.**

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 conservatively based on 20% of the 160 GW potential mentioned by EC 2016.
  - 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, 1 GW potential is considered available 400h/year.
- **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 estimated as the revenue of DR on the spot market when activated
  - This includes all suppliers, hence all consumers, but does not consider additional benefits specific to participating consumers
- **The definition of DR costs above contributes to maximising the costs for, in practice, some DR capacity could be sold on the forward market lowering its costs for suppliers**
- **In the following, we present:**
  - First, the results for the selected distribution
  - Then, a sensitivity to RES penetration
  - Finally, the results of sensitivities performed

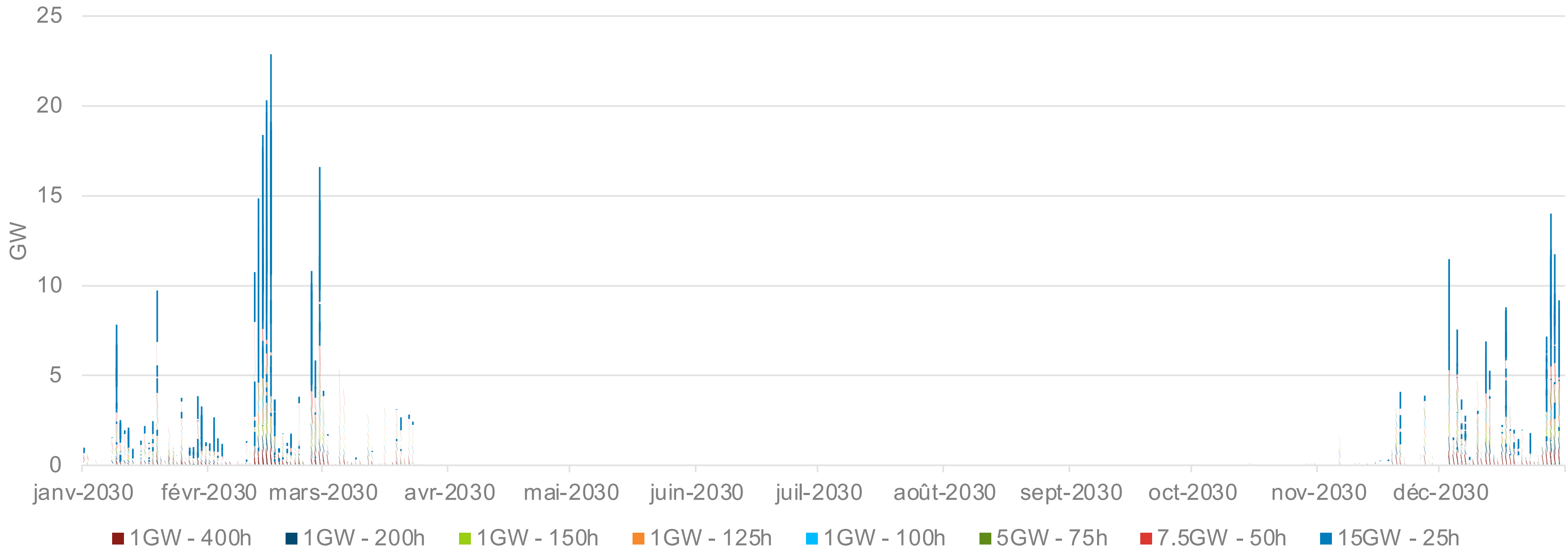
DR potential distribution



DR benefits assessment

DR helps the European system during periods of tension

Profile – DR Central Scenario –EU 2030



- **As a consequence of the assumptions made (particularly on interconnections and market coupling), the activation of DR mostly appears during winter periods to provide margins to the system when capacity is scarce.**
  - The most important share of capacity is used in last resort as it grasps an important share of value
  - Peak prices are not necessarily simultaneous all over Europe, hence the total 30GW might not ever be activated fully
  - For the highest peak hours, DR impacts the price downward of about 40€/MWh
- **With this distribution, no activation occurs from April to September.** Since we assumed perfect market coupling, summer demand peaks in southern Europe can benefit from nuclear and renewables generation in northern Europe.
- **Assuming an imperfect market coupling** (interconnexion outages, congestions, etc), power prices could spike during summer demand peaks and lead to some DR activation in summer as well, with **additional benefits of having DR in the market**.

DR helps reduce spikes in wholesale prices

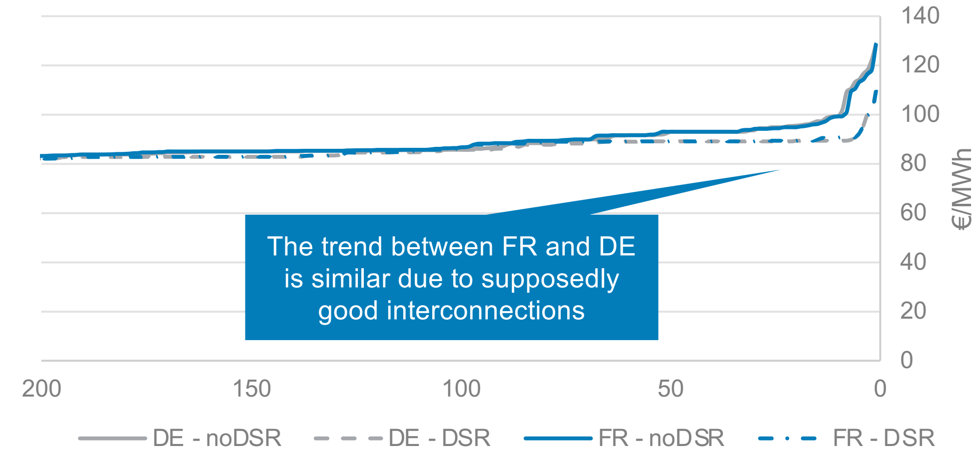
- **DR gives the maximum benefit to the system during peak hours as the marginal units lead to a steep supply curve**.

- **In this study, it is taken into consideration that prices can be reduced thanks to DR activation abroad and not only on the national market (/price zone).**
  - Activation of DR in neighbouring countries can be simultaneous
  - Less often, it can also happen that activation in one country answers a neighbour's needs
  - For the highest 50h, when DR is activated in France it is also activated in Germany and in other countries across EU.

- Below, a focus is given for France:
  - The change in French prices over the activation for the 50 highest hours is a diminution of an average of -7.5€/MWh
  - For other hours the spread between situations with and without DR decreases as the supply curves is not as steep
  - For the highest peak price, the DR activation allows to decrease the price of almost - 40 €/MWh.

- **The comparison analysis between France and Germany shows that due to the supposedly well interconnected market, the results are similar for both countries.**

Prices evolution – DR Central Scenario – FR / DE 2030



Note : The chart is for the 200 highest prices of the monotone

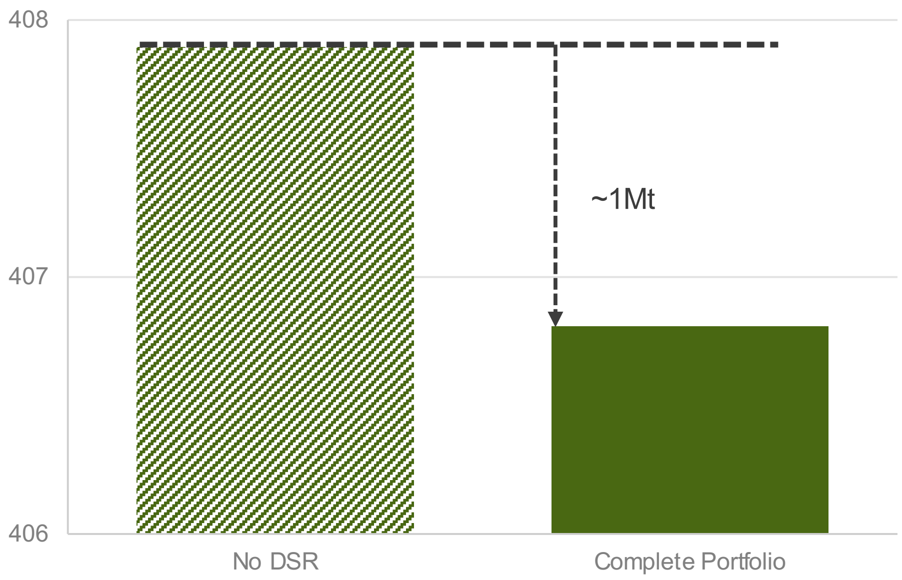
Comparison of prices for the 50 first hours of activation in France

€/MWh	No DR	DR
Average prices	*97.7*	*90.1*
Highest price	*128.8*	*89.1*

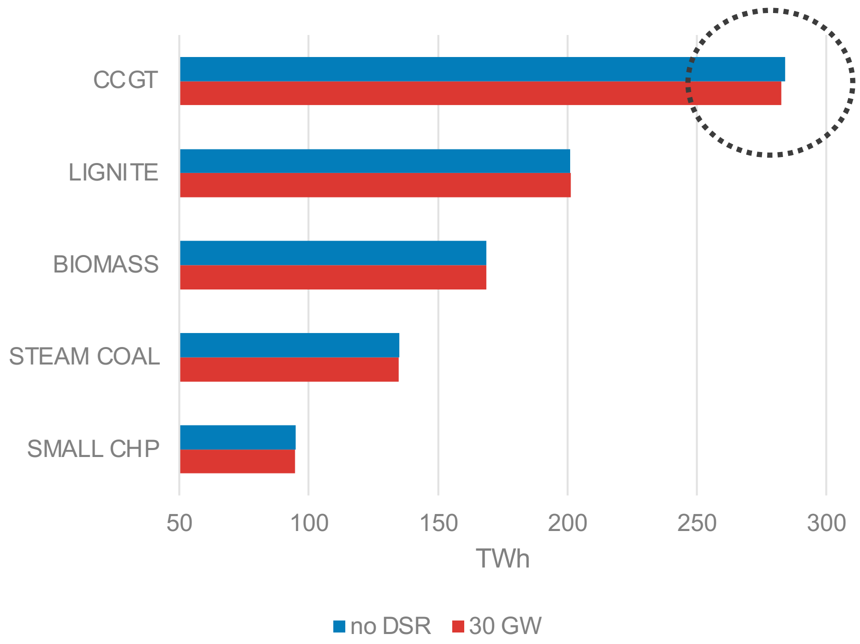
A reduction of 40€/MWh for the peak price in France

DR avoids electricity generation with carbon intensive technologies

CO_2 Emissions (Mt) - Sensitivity



Generation (TWh) – Central Scenario

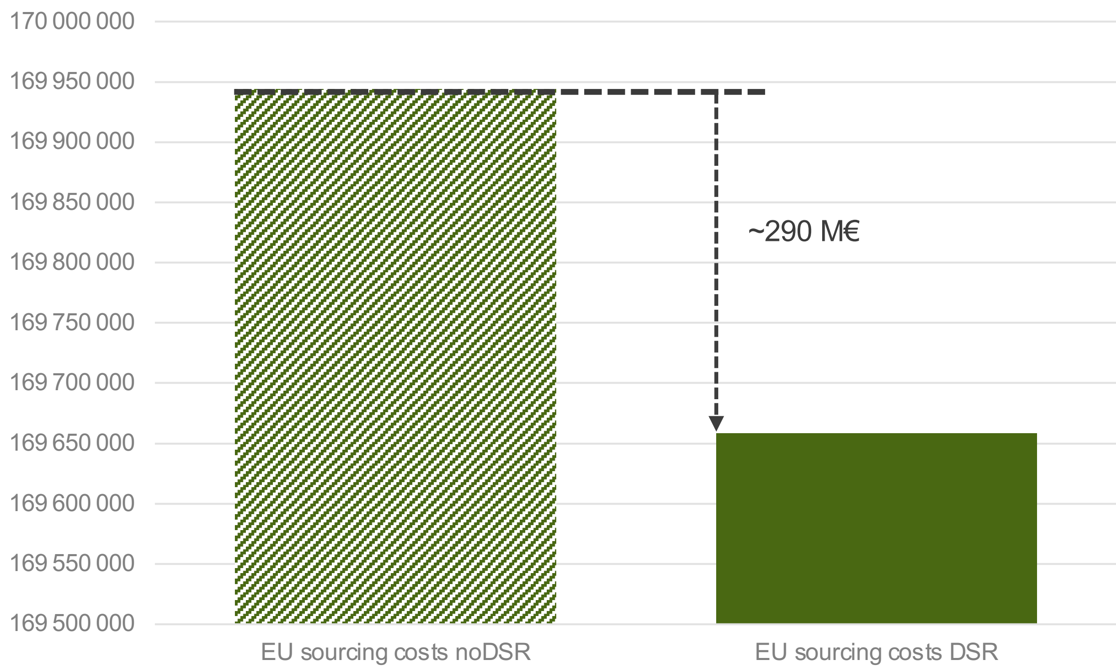


- **Our realistic DR portfolio allows a reduction in CO_2 emissions of more than 1 $MtCO_2eq/y$ in 2030**
- **This DR portfolio has a total available volume of 2 TWh. It mostly replaces CCGT production during peak hours.**
  - This is due to the DR country repartition considered. Indeed, as DR capacity is maximum in countries with completed coal-phase outs, the peaking capacity is now CCGT. If DR was deployed in countries with more coal power plants, CO_2 emissions avoided could be higher.

DR portfolio reduces energy sourcing costs of about 290 M€ in Europe, benefitting all suppliers, hence ultimately all end-users

- **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 290M€.
  - 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

Impact of DR in wholesale market for the portfolio (000€) – EU 2030



Several assumptions contribute to a conservative assessment of benefits:

- No disinvestment of in thermal peak capacity even though DR could cannibalize revenue over time and push them out of the market
- Perfect market coupling and cross-border interconnexions 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
- Benefits of a better resource adequacy (e.g. via savings on capacity mechanisms) are not taken in to account here

With the 30 GW DR portfolio, market benefits for suppliers in their energy sourcing are 190% of DR market costs for suppliers

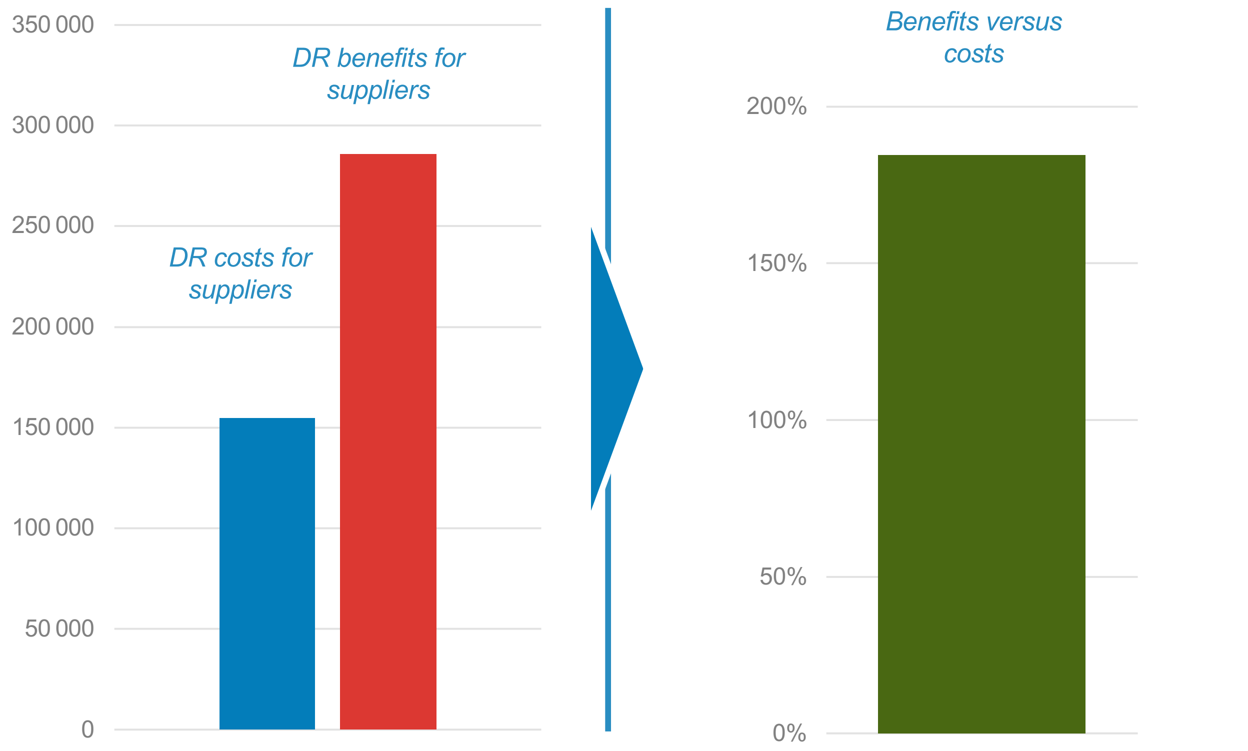
- Gross market-wide benefits are defined as the reduction in suppliers' sourcing costs in the wholesale energy market (i.e. the drop in prices allowed by DR activation multiplied by the load the same hour, *see previous slide*), not taking into account indirect benefits e.g. on capacity markets/mechanisms.

- On the other hand, suppliers incur extra costs related to DR. They can be considered either as :
  - Market costs : DR being offered as "production" on the market it receives the market clearing (i.e. the energy provided by DR multiplied by the clearing price on the wholesale market the same hour)
  - Or, indirect costs : DR being activated leads to lower consumption of participating clients hence to lower revenue for suppliers.

- Indirect costs can be approximated at 100M€.
- Our modelling precisely estimates market 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 twice the market costs**

Costs of energy sourcing with DR (€) and benefits versus costs analysis for DR portfolio - Central Scenario - EU 2030



The 30 GW DR portfolio brings benefits to the power system, and eventually to final consumers

- The study of a DR portfolio of 30GW in the wholesale power market resulted in in the quantitative assessment of the range of benefits DR brings to power systems, under a range of several conservative assumptions (detailed p.16). Results show that:
- **DR activation happens during periods of tension:** DR brings margins into the system when winter consumption peaks create adequacy issues;
- **DR helps reduce spikes in wholesale prices** up to 40 €/MWh in some cases;
- **DR avoids electricity generation with carbon intensive technologies:** by 2030, 30 GW of DR could reduce CO2 emissions by 1MtCO2;
- **DR portfolio reduces energy sourcing costs**: about 290 M€ of cost reduction in Europe, benefitting all suppliers, hence ultimately all end-users
- **DR benefits always exceed costs**: with the 30 GW DR portfolio, market benefits for suppliers in their energy sourcing are 190% of DR market costs for suppliers. With other DR portfolios, the ratios benefits over costs is always over 100% (see. Annex 2).

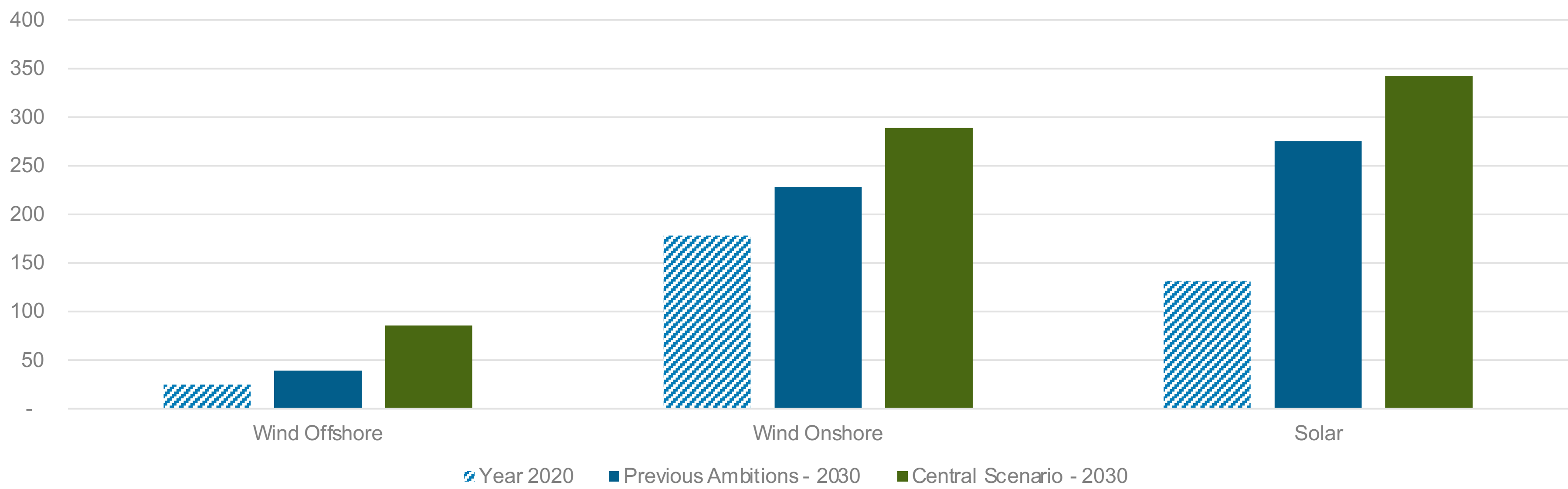
With this DR portfolio of 30 GW and the assumptions previously described (slide 16), about 0.1% of annual European load is managed resulting in a reduction of 0.2% in pan-European energy sourcing costs.

DR is a no regret option for European power systems.

Annex 1 : Benefits are the same with limited RES development

RES deployments in EU for Previous Ambitions and Central scenarios are not so radically different in 2030 (yet)

Capacity mix without DR in Previous and Revised Scenarios – EU 2030



Central scenario

- Central scenario presented in the previous slides is designed to comply with the latest scenario of ambitions of the European Commission EUCO3232.5.

Previous Ambitions scenario

- **In order to capture the sensitivity to RES development, we design a second scenario labelled Previous Ambitions, based on the previous EUCO27 ambitions.**
  - In the Central Scenario, variable renewable energy sources account for 40% of electricity generation in 2030;
  - In the Previous Ambitions scenario, they account for 30% of energy produced;
  - In 2019, they represented 20% of total European electricity mix.

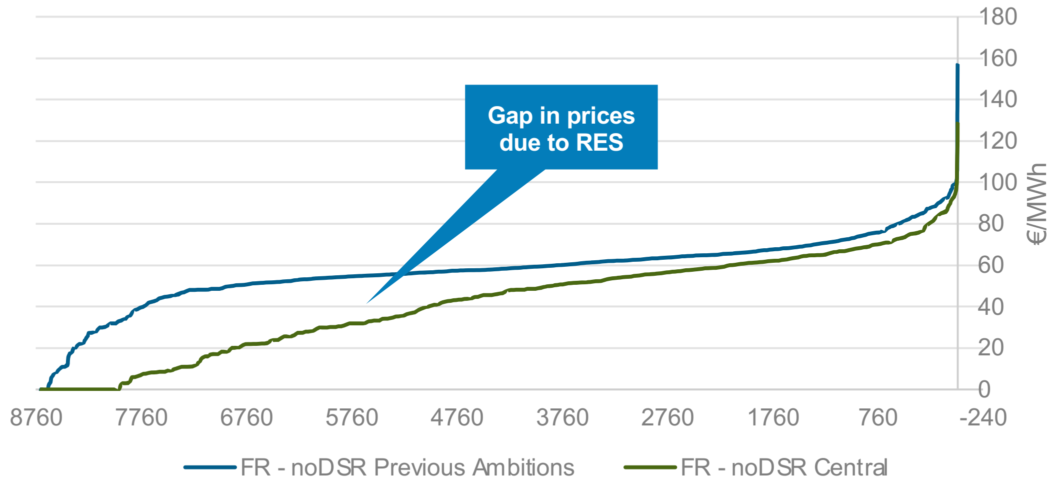
With a higher share of RES in the system, prices are more volatile but most of the impact is on the low prices

- **In our model, the Central trajectory adds RES capacity without supposedly closing units.**
  - Therefore, even if RES do not produce, there is no problem on the adequacy demand and supply.
  - The introduction of DR then moves the supply curve and substitutes expensive units in the market when called.
- **RES increase the volatility of prices - however, this variation in volatility only concerns low prices.**
  - The impact of RES is to add low prices capacity to the market. An important fluctuation might then appear between prices when RES are producing and when they are not.
  - On the other hand, peak prices occur in the absence of RES generation, when peaking plants are used.
- **The addition of RES has an impact on market prices**
  - More RES means lower prices in peak hours, even if the RES produces only a few in peak prices. In the scenario without DR, the changes in peak prices imputable to RES is around 28€/MWh.
  - On average, this impact for the most expensive hours is around 8€/MWh

Selected prices for DR 30GW – FR 2030

	Central Scenario		Previous Ambitions	
	No DR	DR	No DR	DR
Average prices	*97.7*	*90.1*	*103.4*	*95.4*
Highest price	*128.8*	*89.1*	*157.1*	*98.1*

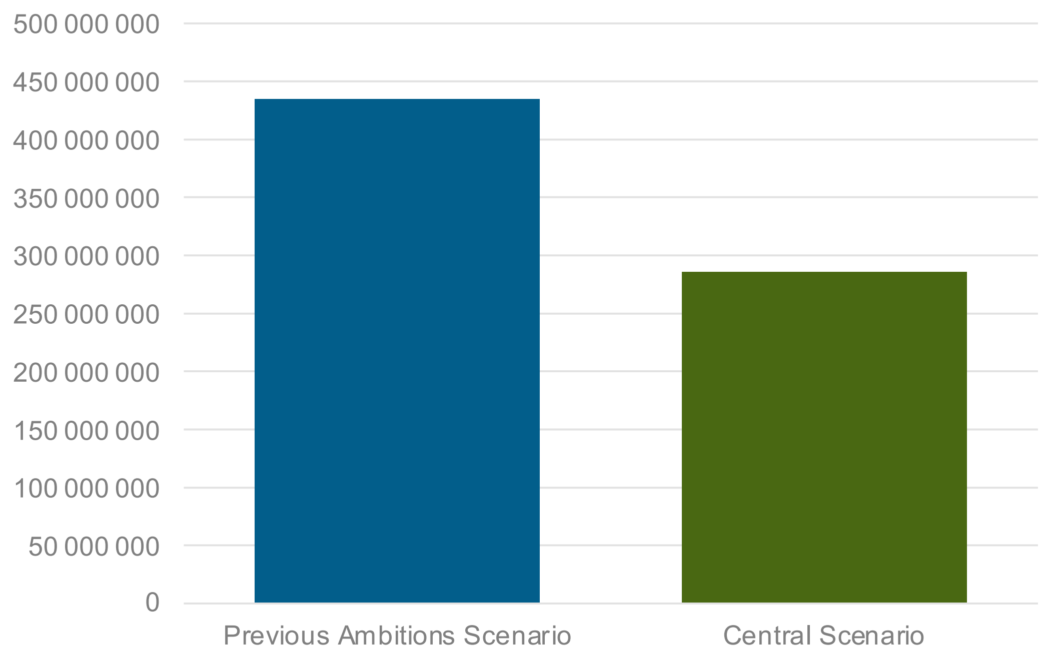
Prices monotone for DR 30GW – FR 2030



Uncertainty regarding RES penetration in 2030 should not materially impact DR benefits on energy sourcing costs

- **The uncertainty regarding the success of RES deployment in 2030 should not materially impact the value of DR for the system.**
  - In the central scenario, DR benefits in terms of energy sourcing costs amount to 290 M€ ;
  - In the Previous Ambitions scenario, DR benefits in terms of energy sourcing costs amount to 430 M€

Sensitivity to scenarios for DR Central and Previous Ambitions scenarios – EU 2030



In addition, it is expected that DR benefits for other purposes than the wholesale market will grow with higher RES penetration.

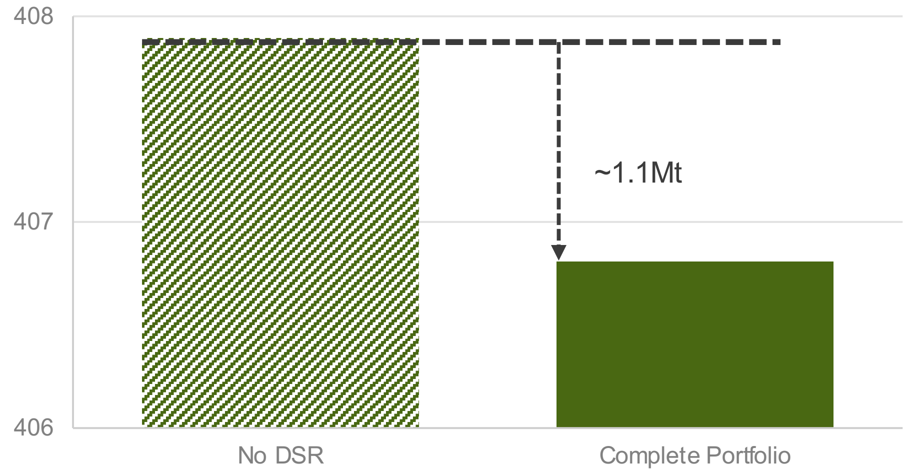
- **RES low prices reduces conventional technologies revenues that are only supported through Capacity Remuneration Mechanisms.** DR allows to replace these technologies in periods of scarcity, saving on thermal plants investment costs.
- RES intermittency fosters higher network management costs that can be mitigated with the help of demand flexibility;
- RES are supported through public incentives, managing demand to fit solar and wind generation curves can lead to lower support mechanisms costs.

Avoided CO_2 emissions are of the same magnitude in both scenarios

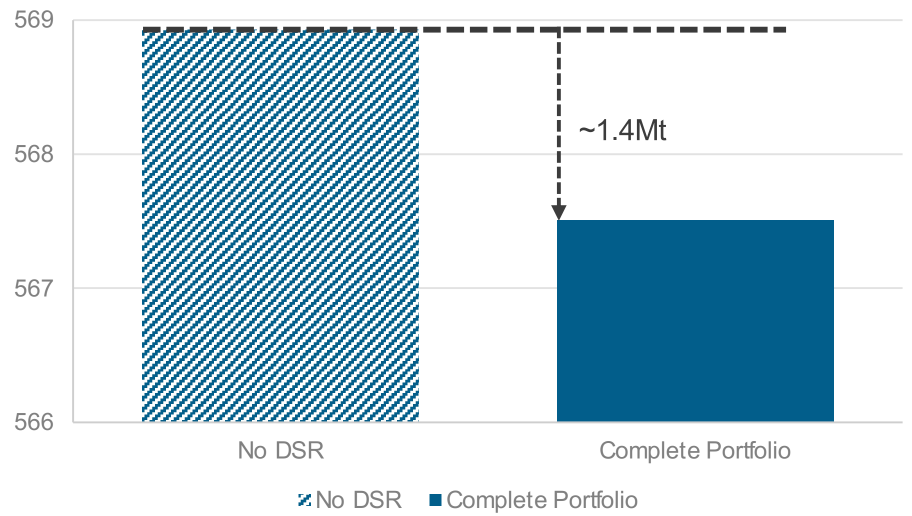
- **Savings on CO_2 emissions are of the same magnitude in both Central and Previous Ambitions Scenarios.**

- **When activated at full energy and capacity, DR avoids the generation of 2TWh mainly from CCGT**
  - It allows a reduction in CO_2 emissions of more than 1 $MtCO_2eq/y$ in 2030
  - The main reduction in generation concerns CCGT which are not the most expensive nor the most peaking plants.
  - This is due to the distribution of DR in EU countries, the highest capacities of DR are distributed in countries where coal phase-outs have made CCGTs the last flexible units.

CO_2 Emissions (Mt) - sensitivity for DR 30GW – EU 2030 / Central Scenario



CO_2 Emissions (Mt) - sensitivity for DR 30GW – EU 2030 / Previous Ambitions Scenario



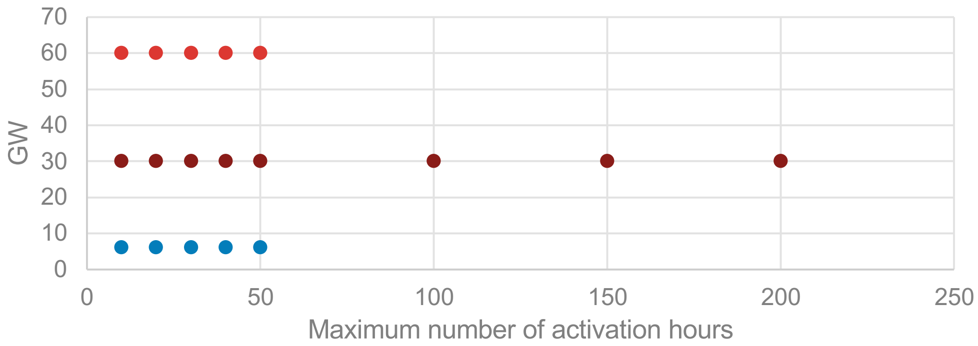
Annex 2 : Sensitivity analysis on DR portfolio

Sensitivity analysis on DR portfolio

Other DR capacities and durations yield benefits/costs ratios that stay superior to 100%

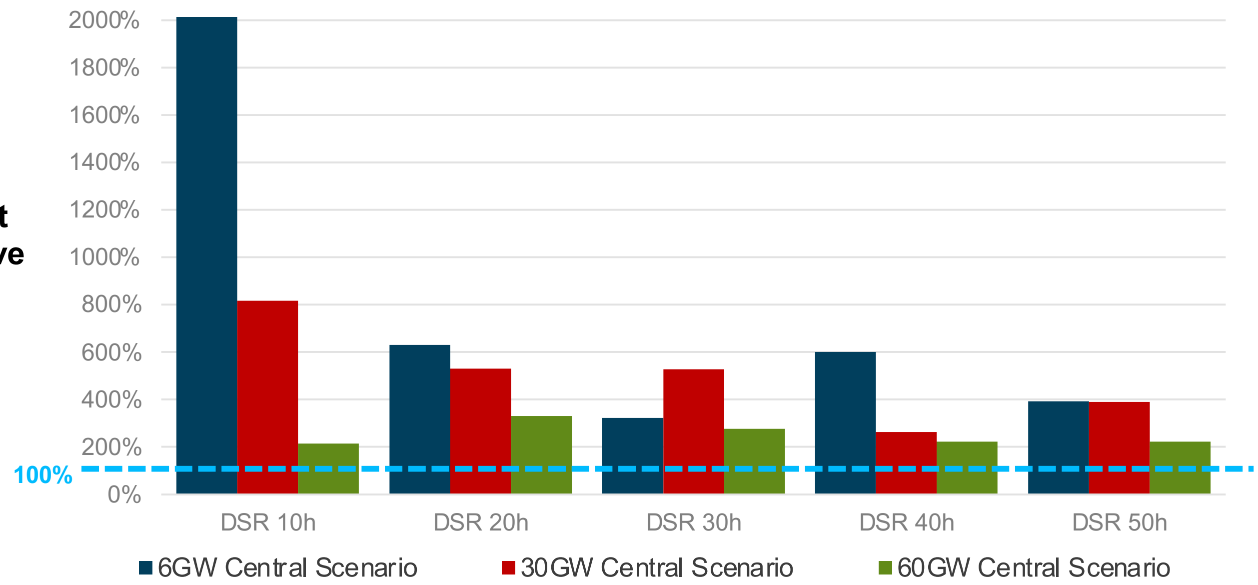
- **Further analysis estimating the impact of DR in a variety of situations was conducted:**
  - Total DR potential tested are 6GW, 30GW, 60GW;
  - Each time with activation duration form 10 to 50h or more;

DR configurations tested as sensitivities



- **With benefits at least equal to costs, DR is a no regret option for the system.**
  - While benefits to costs ratio is a decreasing function of both capacity and available hours, i.e. a natural law of diminishing returns, it should be emphasized that **total benefits is a growing function of both, as well as net benefits**, because the **benefit/cost ratio remains above 100% in all scenarios**.
  - With a higher capacity of DR in the system, additional benefits stemming from capacity mechanisms grow as less thermal capacity is needed.

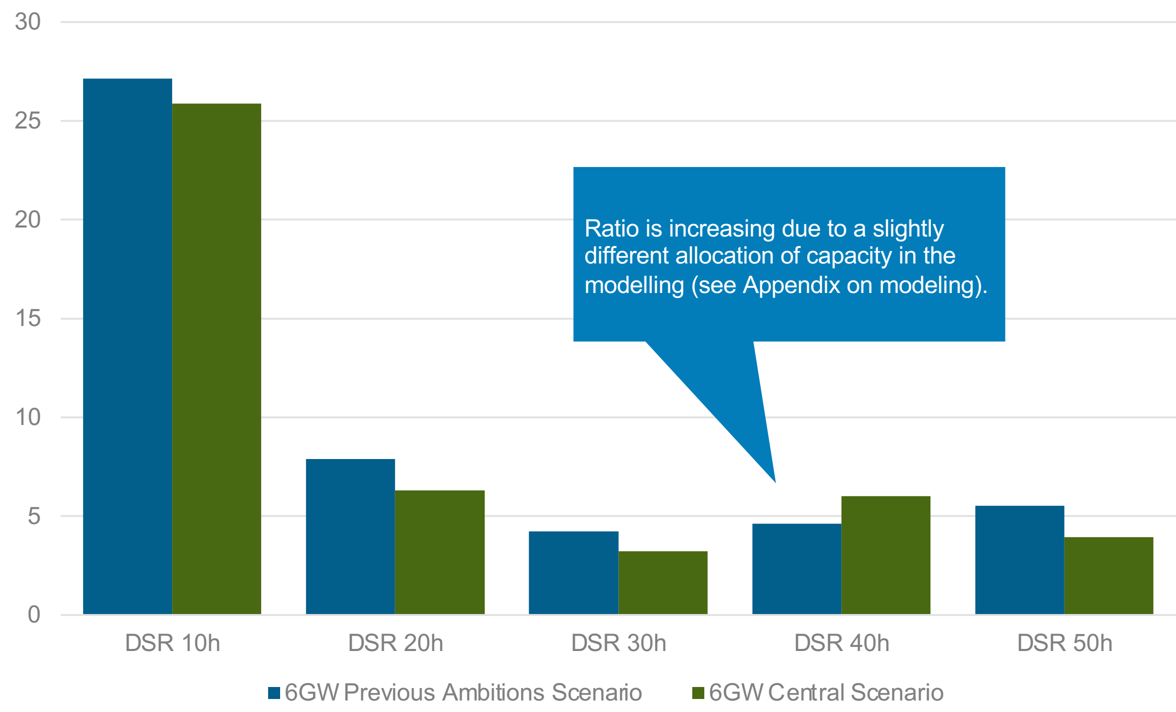
Benefits to costs for different DR capacities – EU 2030 / Central Scenario



With 6 GW of DR and 50h of activation, benefits for suppliers are superior to 500% of costs for suppliers

- With 6 GW of DR capacity, and the country by country distribution already mentioned (slide 18), results in both Previous Ambitions and Central RES deployment scenarios confirm the very low impact of RES in 2030 on DR benefits to costs analysis.
- As for all DR capacity modelled, as the delivered volume (i.e. number of hours of activation) increases the ratio decreases.
- With only 6GW of DR capacity deployed in Europe by 2030, DR volumes delivered remain relatively low, hence a limited decrease in ratios.
- **Even with 50 hours of activation the benefits to costs ratios are still around 5.**

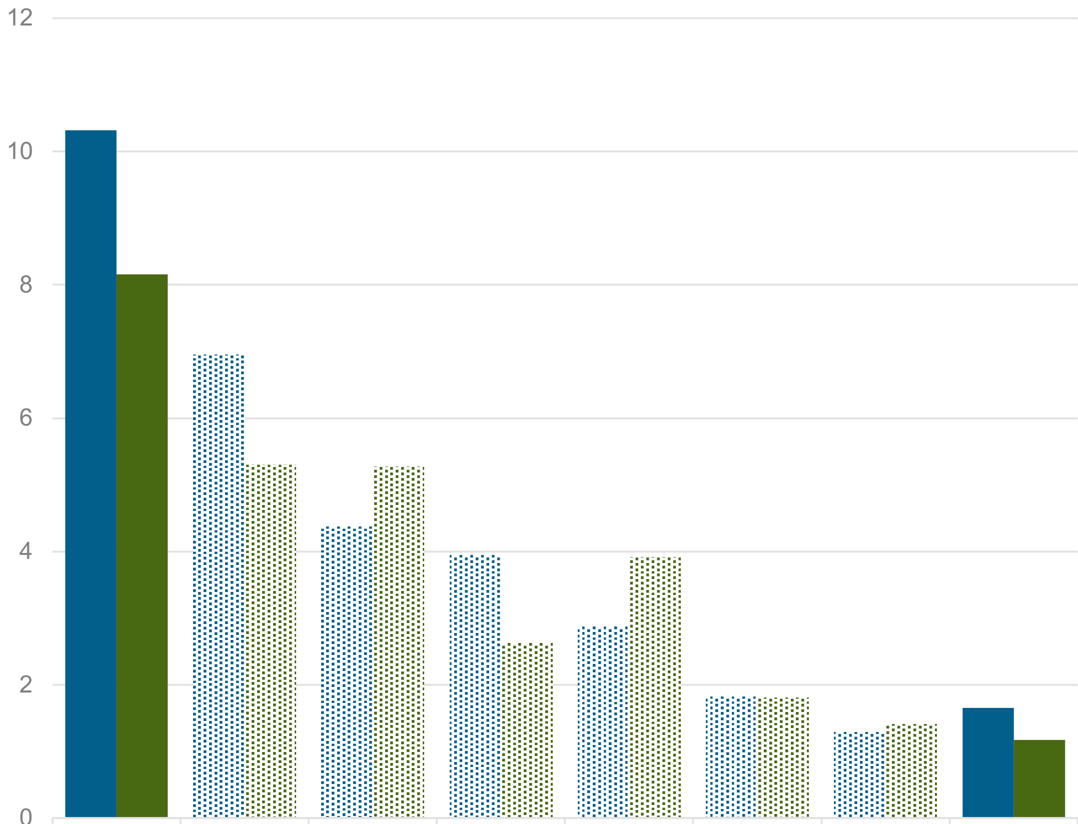
Sensitivity to running hours for DR 6GW – EU 2030



30 GW sensitivities show benefits greater than costs and twice greater for all activations of less than 100h

- If we focus on the 30GW DR capacity for the previously established scenarios, respectively Central and Previous Ambitions, the modelling comforts the trend.
- RES deployment in 2030 has limited impact on DR benefits to costs analysis
- **With a capacity of 30GW, benefits account for twice the DR costs in energy sourcing on the power market if hours of activation are less than 100h.**

Sensitivity to running hours for DR 30GW – EU 2030

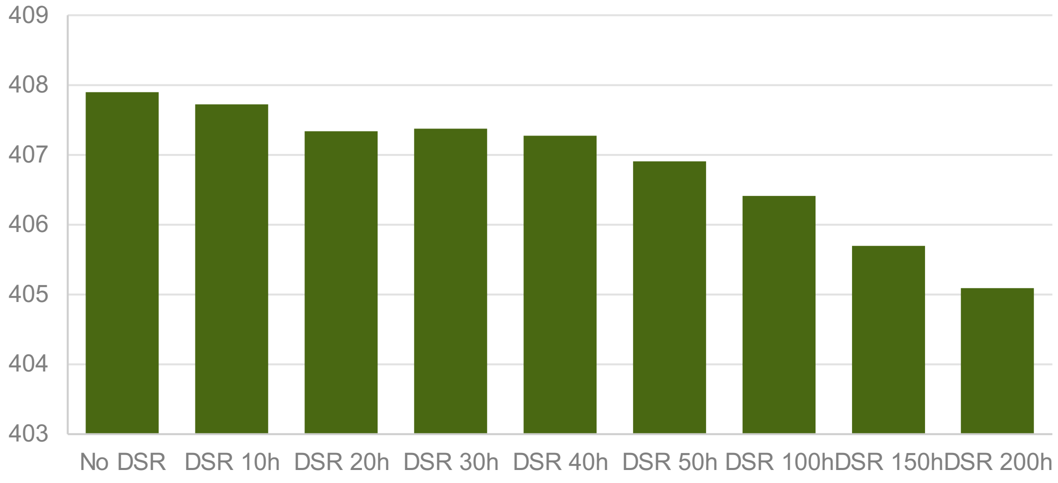


	DSR 10h	DSR 20h	DSR 30h	DSR 40h	DSR 50h	DSR 100h	DSR 150h	DSR 200h
Previous Ambitions Scenario	10,3	7,0	4,4	3,9	2,9	1,8	1,3	1,7
Central Scenario	8,2	5,3	5,3	2,6	3,9	1,8	1,4	1,2

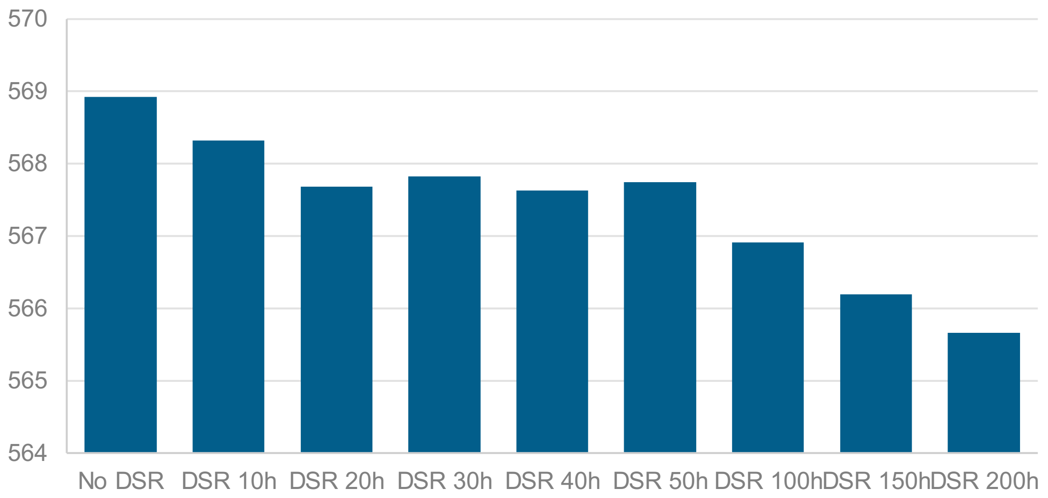
Emissions of 1MtCO_2 avoided for 30 GW over 50h

- Savings on CO_2 emissions are of the same magnitude in both Central Scenario and Previous Ambitions Scenarios.
- **When activated 50h, 30 GW DR avoids the generation of 1,5 TWh mainly from CCGT**
  - It allows a reduction in CO_2 emissions of more than 1 MtCO_2eq/y in 2030
- **When activated 200h, 30 GW DR avoids the generation of 5 TWh from CCGT, 1 TWh from OCGT and 1 TWh of COAL**
  - It allows a reduction in CO_2 emissions of 3 MtCO_2eq/y in 2030
- The main reduction in generation concerns CCGT which are not the most expensive nor the most peaking plants.
- This is due to the distribution of DR in EU countries, the highest capacities are in countries where coal phase-outs have made CCGTs the last flexible units.

CO2 Emissions (Mt) - sensitivity for DR 30GW – EU 2030 / Central Scenario

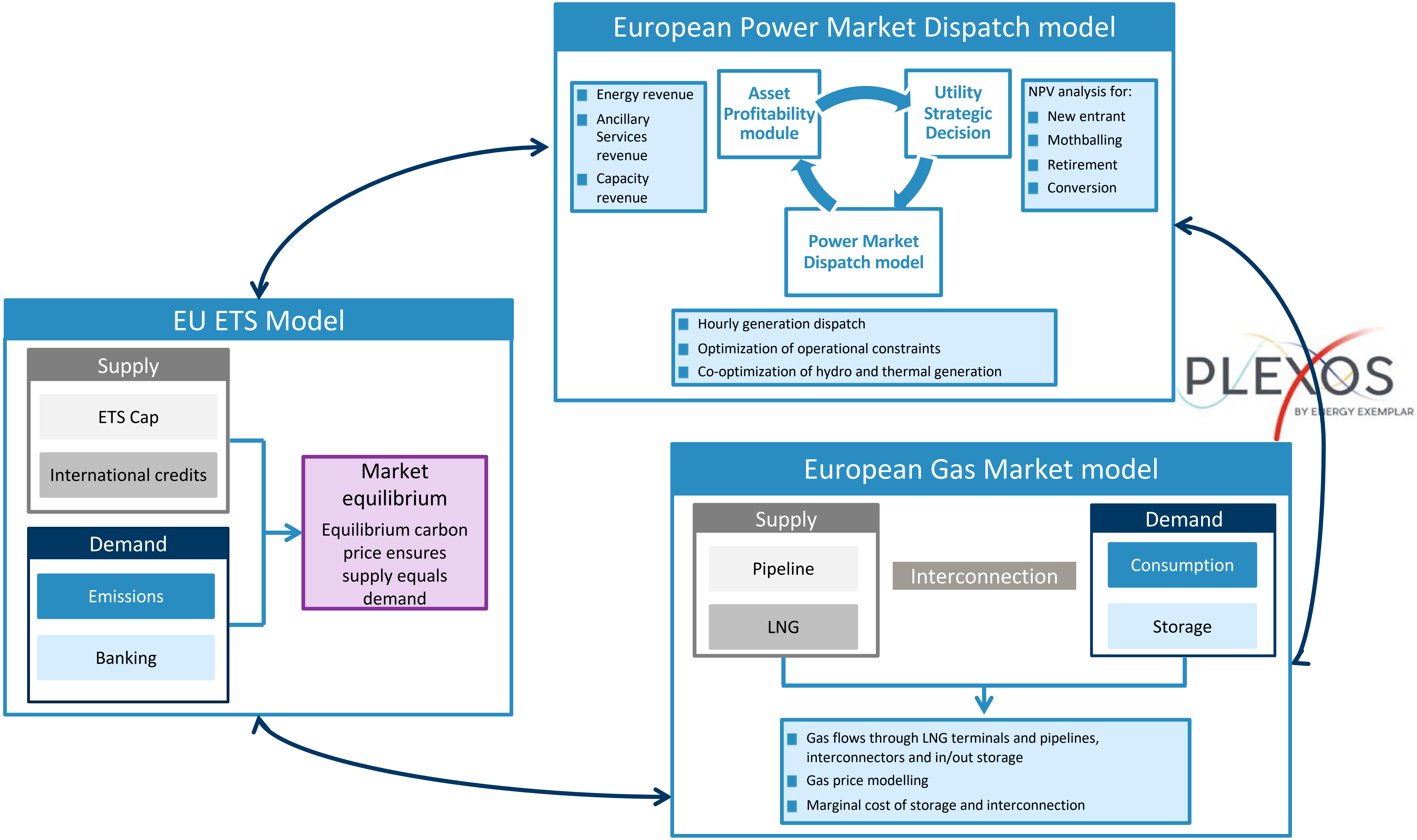


CO2 Emissions (Mt) - sensitivity for DR 30GW – EU 2030 / Previous Ambitions Scenario



Annex 3
Detailed modelling approach and assumptions

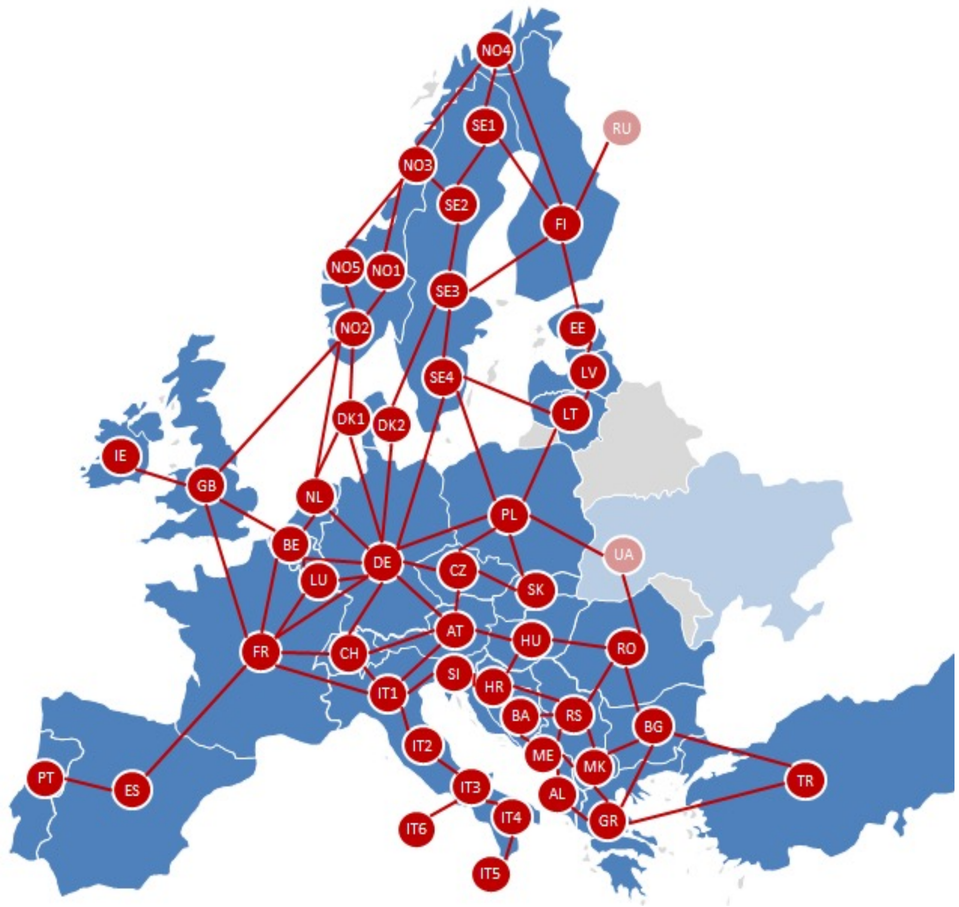
FTI-CL energy has developed integrated proprietary models of electricity, gas and CO_2 markets



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

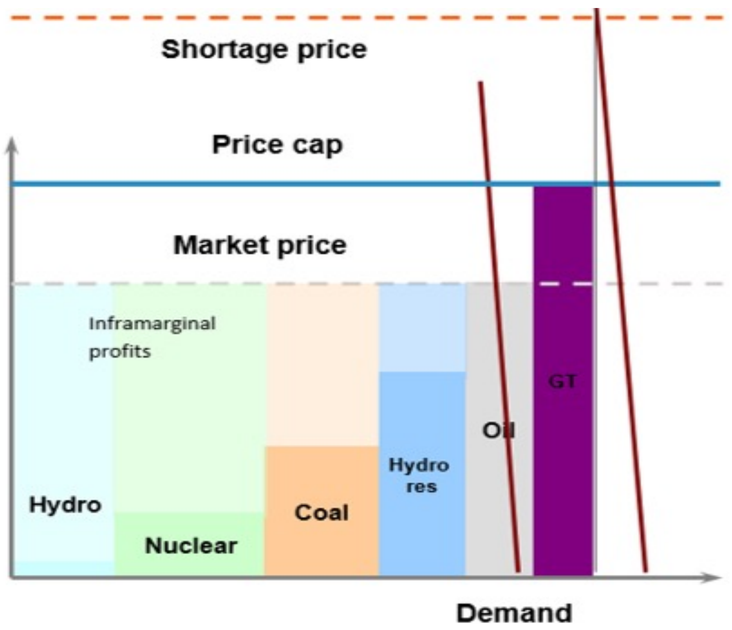


Source: CL Energy

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



Source: CL Energy

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.

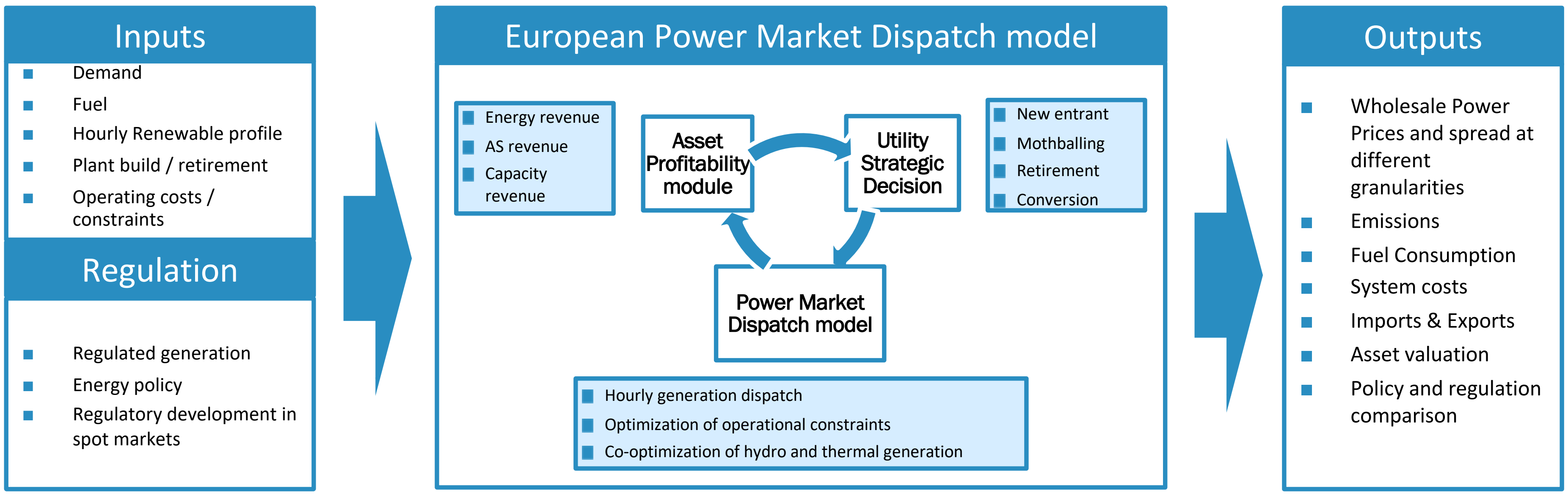
  It contributes to underestimating benefits in DR assessment

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

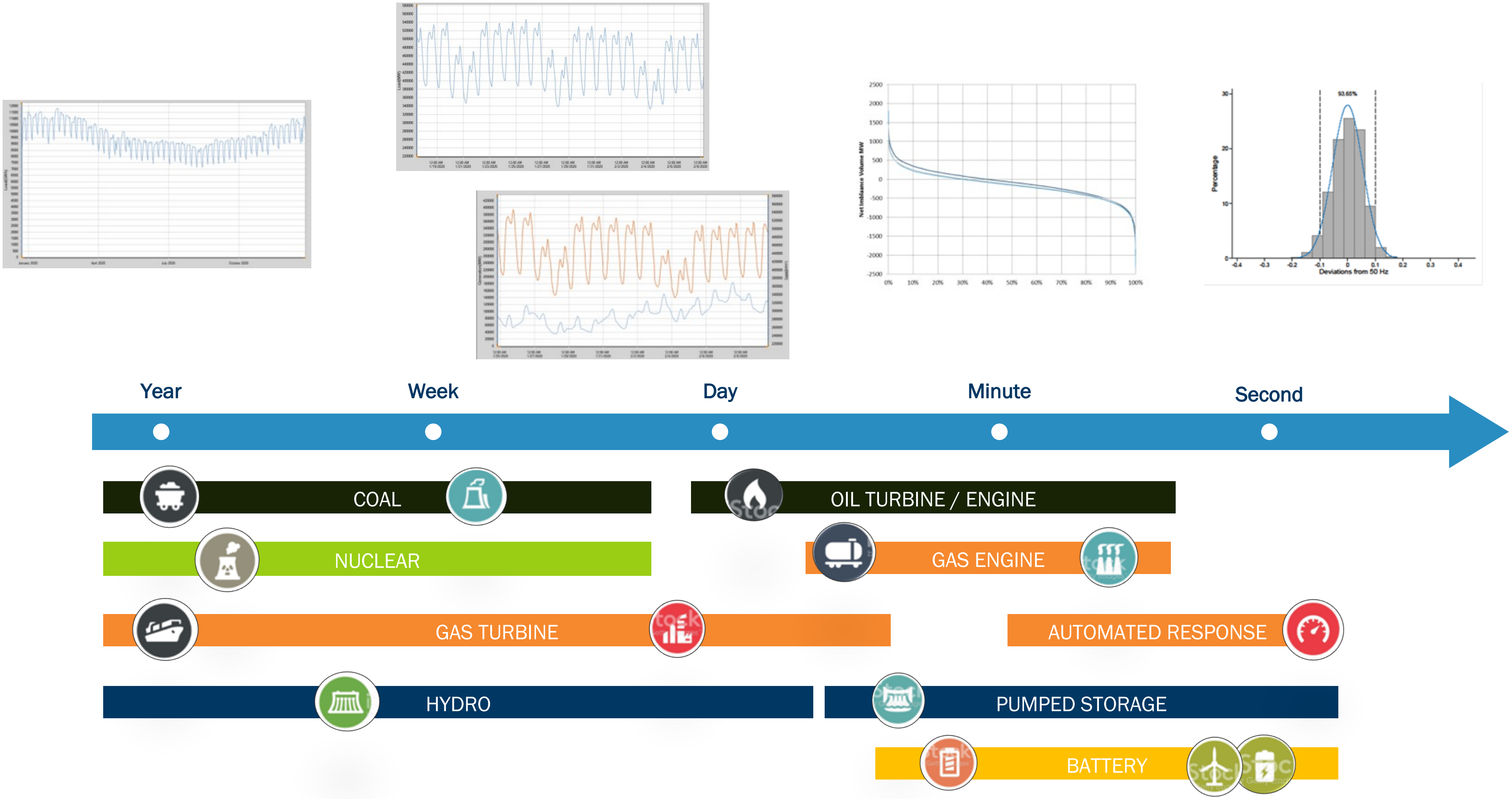
Dispatch optimisation based on detailed representation of power market fundamentals

- 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)



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



Coal phase-outs in Europe will drive flexible capacities down by 110 GW in 2040

Many European countries committed to close coal facilities by 2030: from 120 GW today, lignite/coal capacity will be reduced to **52 GW in 2030 and 14 GW in 2040**.

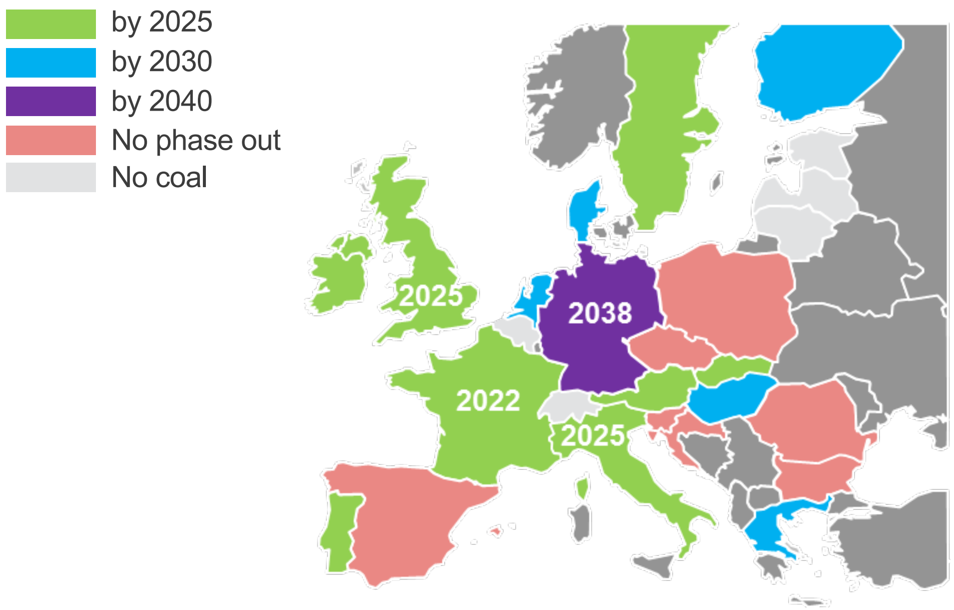
Flexible gas power plants capacities should also decrease significantly towards 2050, through :

- **regulatory compliance**, as in France where the Multiannual Energy Plan prevents the construction of new thermal capacities,
- **economic environment,** such as CO2 prices detrimental to those technologies.

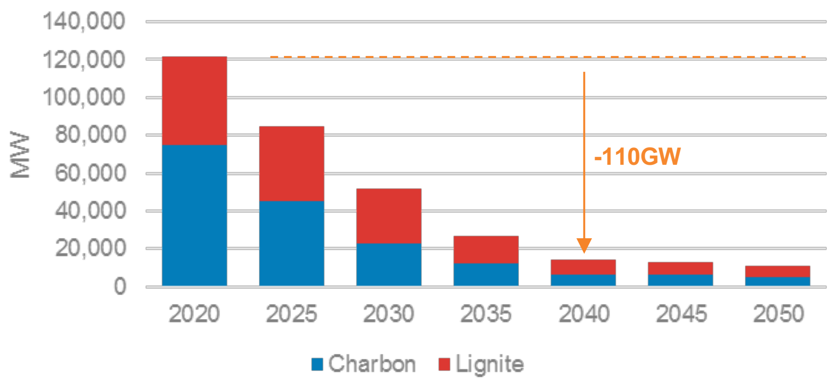
These phase outs will **sharply reduce flexible capacities** in Europe, and **stress issues related to renewables' intermittency** and **need for flexibility.**

For the scenario with or without DR, the same phase-outs plan are considered. With the development of DR, the coal phase-out might be accelerated.

Coal phase out plan in Europe[1]



EU-28 coal/lignite capacity evolution[1]

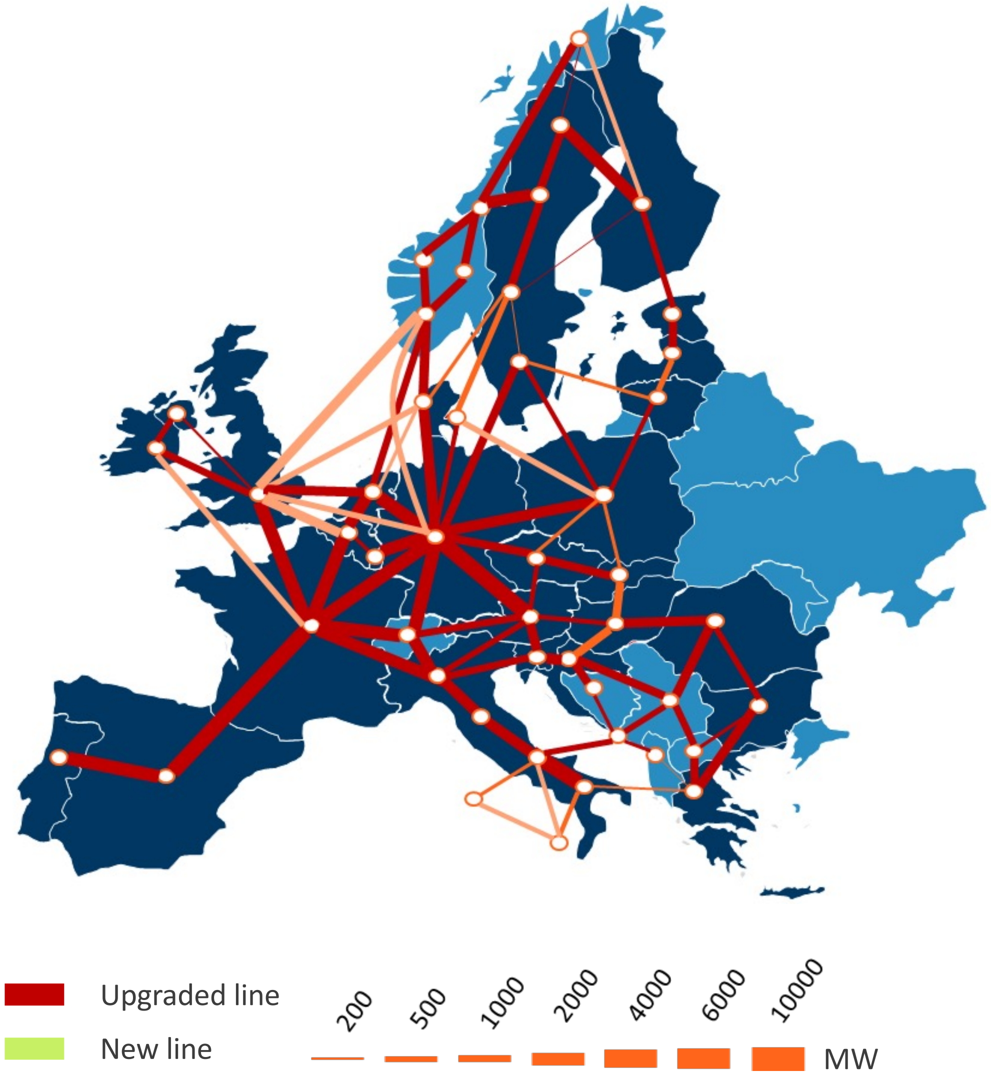


1. Analyse Compass Lexecon des NECP

Our interconnection NTC development is based on ENTSOE TYNDP 2018 development plan featuring a doubling of NTC by 2050

Network in 2015 **NTC: 225 GW**

Network in 2050 **NTC: 439 GW**



Note: NTC stands for Net Transfer Capacity

The European carbon neutrality objective by 2050 will deeply impact the power system, both on the supply and demand side

The **Green Deal** announced by the new Commission has for objective to reach **carbon neutrality in 2050**, with an intermediate objective of **reducing emissions by 55% in 2030.**

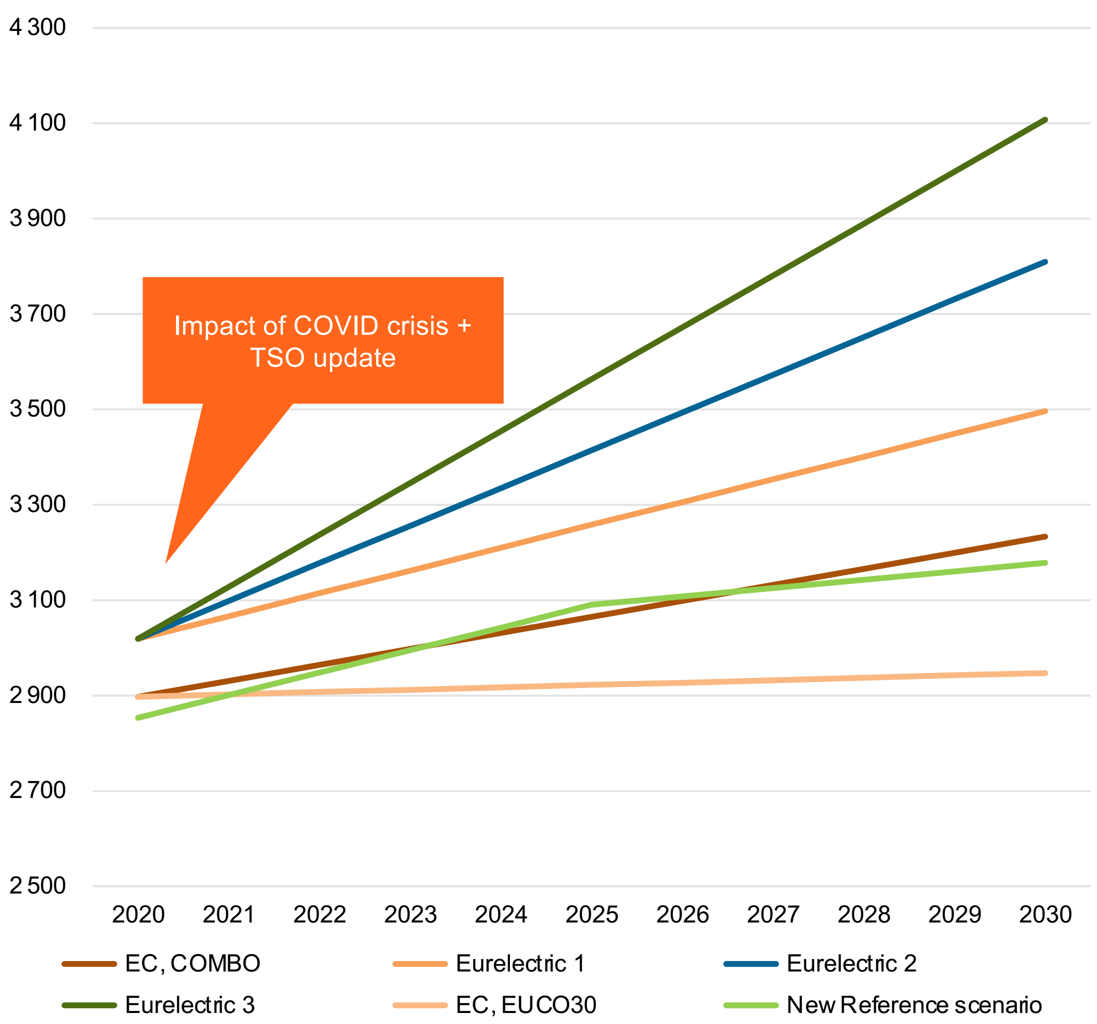
This ambitious decarbonisation target will deeply impact the European power sector:

- **On the supply side**, with a progressive coal phase out and an accelerated development of renewable energies (RES)
- **On the demand side,** with increased controllability and electrification of the economy through sector coupling leading to an increase in consumption
- **On the network and flexibility side,** which will be needed in order to integrate large amounts of variable energy into the system

Targets of GHG emissions reductions in Europe

To meet net zero, European electricity demand is projected to rebound strongly by 2030

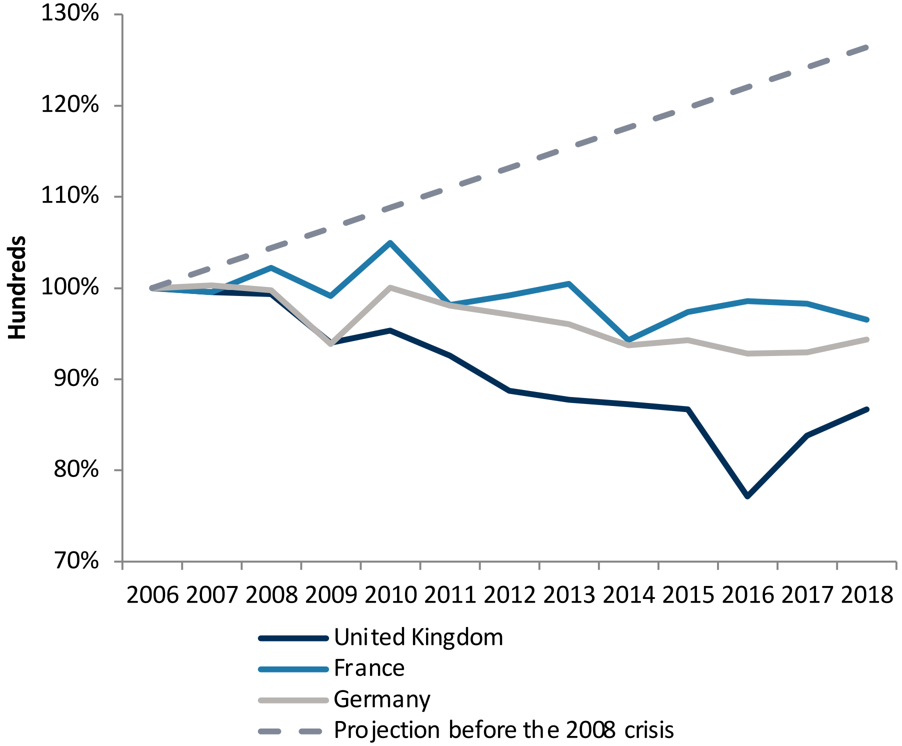
Annual Demand Outlook (TWh), Europe



- The objectives of 2030 carbon neutrality targets are:
  - Improve energy **efficiency** (with the objective of a 32.5% reduction)
  - A cut of 46% of **greenhouse gas emissions** from 1990 levels
  - Electrification of the economy, in particular the **transport sector** via EVs, and **buildings** through heat pumps (direct electrification).
  - A variety of final energy carriers, with the emergence in particular of Hydrogen, and the use of electricity to produce these energy carriers via Power-to-X (H2, CH4, e-fuels etc.) - indirect electrification.
- Different trajectories are possible on a European scale, depending on the relative weight of each of the energy carriers.
- **Our reference scenario assumes a 2030 demand at 3200TWh, assuming a partial direct or indirect electrification of industry.**

Power demand: a structural break from 2008

Index of historical power consumption (base 100 in 2006)



Sources: EC. ENTSO-E, BP RTE 2007.

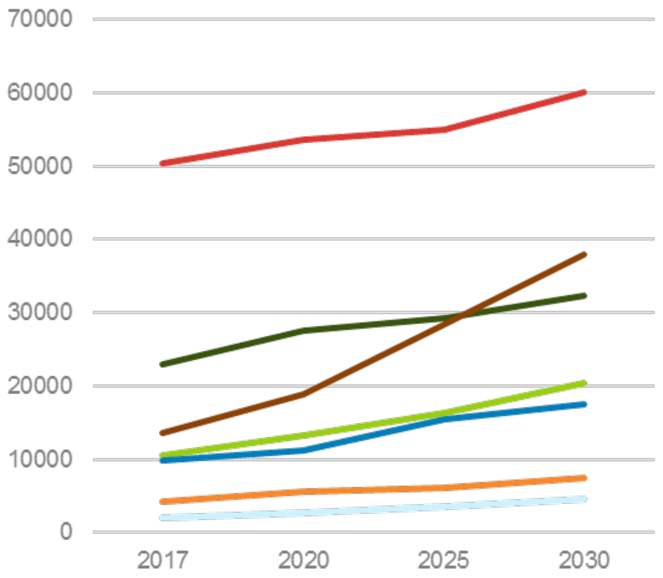
- Before the 2008-crisis, electricity demand was projected to increase at a 2%/year rate on average in Europe, driven by the economic growth expectations
- The economic crisis led to power demand destruction, mainly in the industrial sector
- More importantly, since the crisis, electricity demand has experienced **structural changes** as it started showing signs of **decoupling from the economic growth**, explained mainly by:
  - The development of tertiary services, which tend to replace the energy-intensive secondary sector (creating one unity of added value requires about 4 to 5 times more energy in the industry sector than in the tertiary one)
  - The energy efficiency improvements (European directives to reach the 20% energy efficiency target by 2020)
- Consequently, several countries have not yet recovered the pre-crisis consumption level and a **constant, or even declining, demand** is observed and expected to continue in the following years

European power demand has experienced a structural break from 2008. Added to the impact of the 2008-crisis, energy efficiency improvement and development of tertiary services (instead of industry) have resulted in constant or even declining demand.

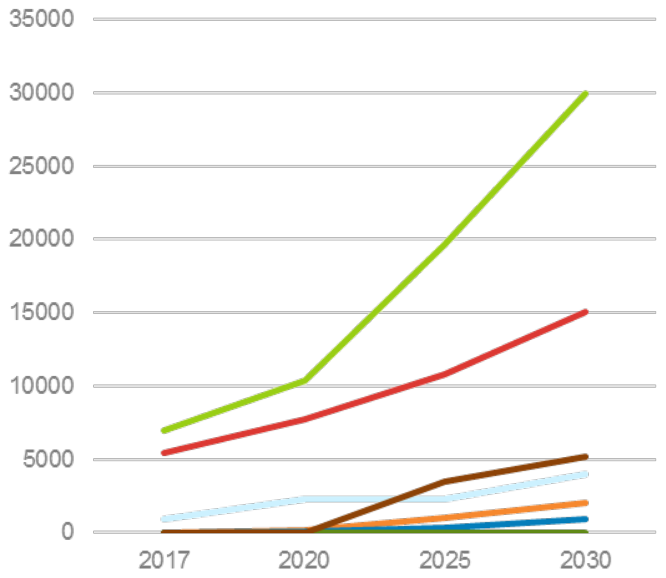
Solar and wind capacity will develop steeply in European countries by 2030

To reach the objectives for RES development by 2030 (32% of final energy versus 17.6%* in 2017 and 56% of electric demand versus 30.7%* in 2017), the NECPs submitted in December 2018 to the European Commission plan to continue or even accelerate RES roll-out (mainly onshore/offshore wind turbines and solar PV).

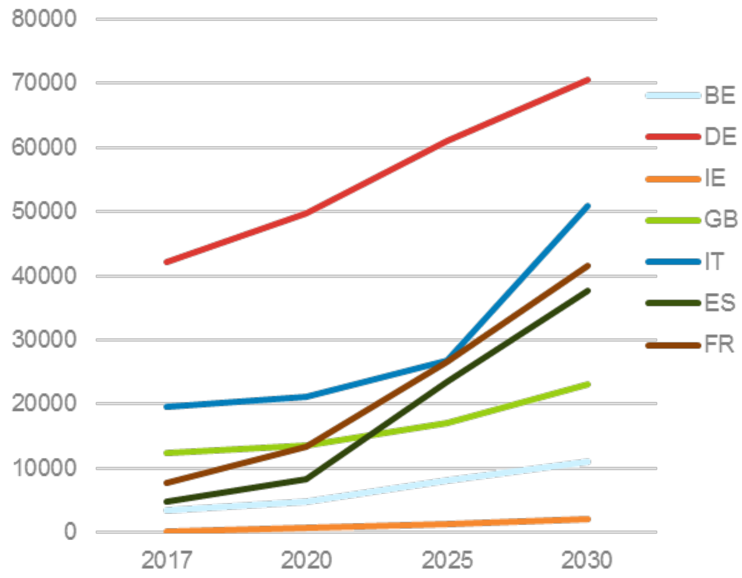
Onshore wind development in Europe (MW)



Offshore wind development in Europe (MW)



Solar PV development in Europe (MW)



*Source: European Environmental Agency – Share of renewable energy in gross final energy consumption in Europe

Gas and coal prices have experienced cycles since 2008

Index of historical commodity prices (base 100 in 2008)

- Since power prices are largely driven by short-run marginal costs of thermal plants based on the fuel and CO_2 prices, the evolution of commodity prices has a direct impact on power prices
- In particular, **from 2008 to 2016, commodity prices collapsed** by around 65% for coal and 45% for gas, which explains partly the power price drop seen over this period

- The decrease in coal prices from 2011 is mainly explained by the global oversupply of coal, resulting from the **shale gas revolution** in the US:
  - Cheap shale gas replaced the use of coal in the US resulting in an oversupply of coal in the US
  - Exportations to Europe increased and plummeted coal prices

- Regarding the gas market, after years of increase, gas prices have declined in 2014, following the fall in oil prices.

- For both commodities prices have started rising again from 2016 **followed by a sharp decrease in 2019.**
- The recent drop in prices is driven by Covid-2019 crisis and economic slowdown.

Gas and coal have experienced price cycles in the past decade: Since 2018, prices have declined following the surplus of LNG.
The gas market is expected to have reached a cycle low in summer 2020

Source: Energymarket prices

After a period of low prices between 2012 and 2017, CO2 prices have recently increased following the reform of the ETS market

Evolution of CO_2 price (€/tonne, nominal)

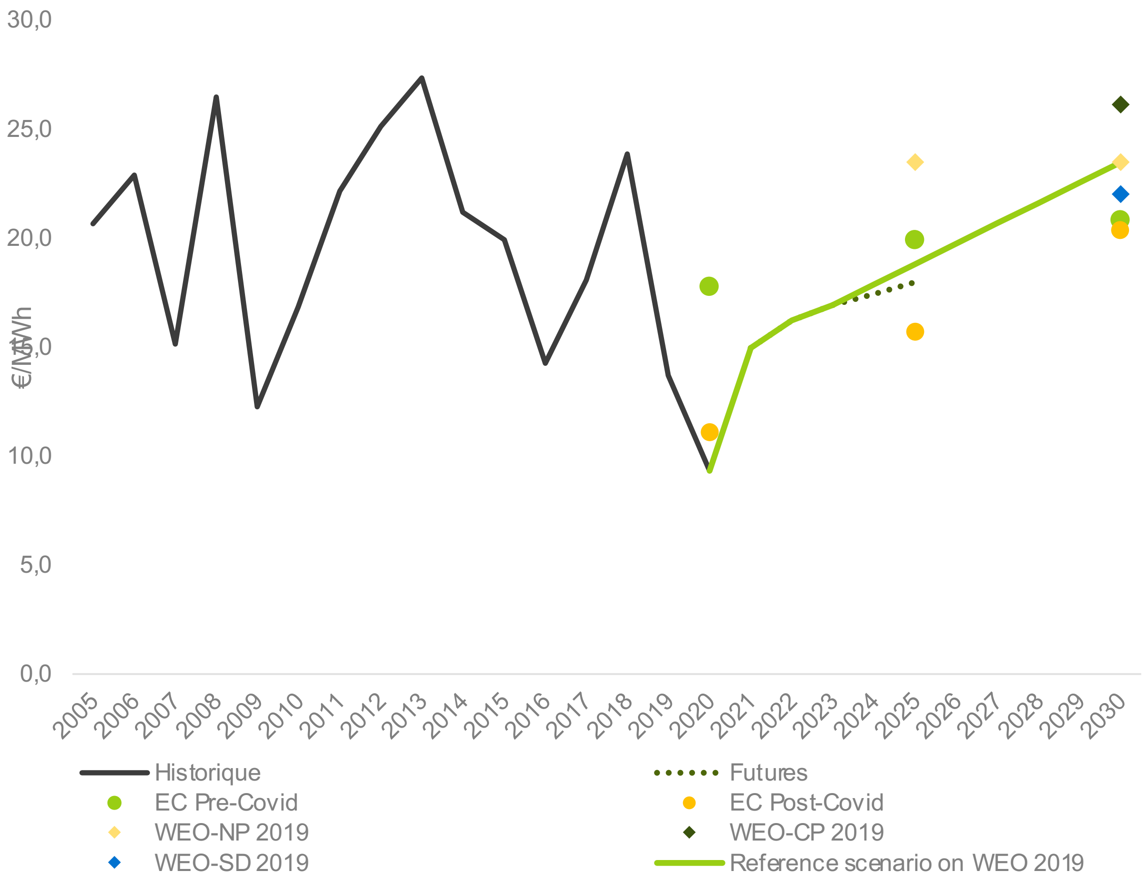
- **Between 2008 and 2016, CO2 prices fell by around 65%.**
- A combination of **several political and economic factors has led to a significant excess of emission allowances**:
  - Significant imports of international allowances during phase II of the ETS market
  - The reduction of industrial sector demand for quotas following the economic crisis in 2008
  - The implementation of European or national policies superimposed on the ETS market and led to a reduction of CO2 emissions covered by the ETS market
- The **recent negotiations and agreements for the ETS market reform** (in particular the establishment of the stability reserve, which reduces some of the excess quota from 2019) have led to an increase in CO2 in recent months: between 2017 and today, CO2 prices quadrupled.
- **The recent drop is prices is driven by the slowdown of emissions related to economic activity during the Covid-19 crisis. However the recent announcement of future reforms has reset the price on pre-crisis level.**

Going forward, CO_2 price outlook is uncertain as there are a number of upward and downward drivers :
While there are a general trend of reduction of CO_2 emission, overlapping policies (increased 2030 RES target), extension of the MSR intake rate post 2022, administrative closure of coal plants, Brexit, …

Source: Energy market prices

Outlook for gas prices

Gas price outlook (real 2020)



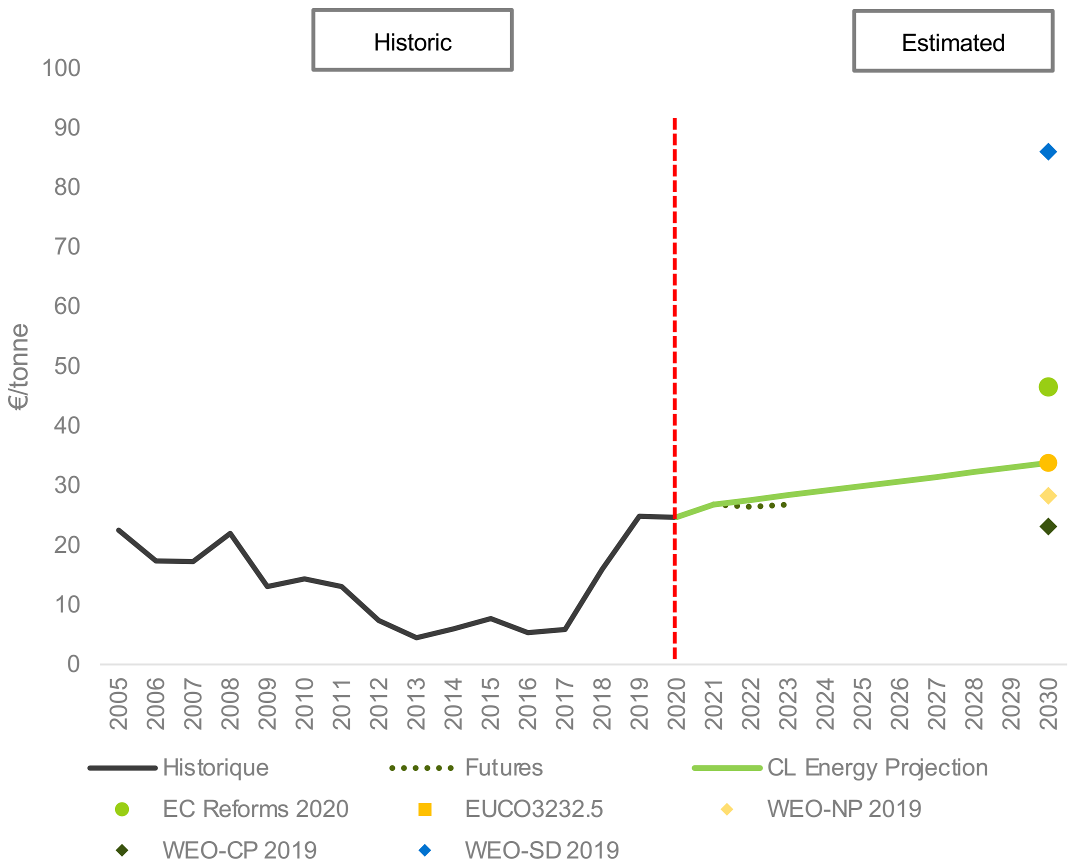
- The high volatility of European gas prices over the last couple of years reflects the numerous uncertainties in the European and global gas markets.
- **Uncertainties are expected to continue** due to:
  - The levels of LNG flows choosing Europe over Asia
    - Higher demand in Asia will push prices up in Europe
  - The levels of power coal to gas switching in Europe
    - Higher use of gas (instead of coal) will increase demand and thus prices
  - The levels of Russian flows to Europe
    - If Russia decides to increase its exports to Europe, it will tend to reduce European prices
- These different drivers will impact European gas prices outlook translating into **different trajectories**. To illustrate this large diversity, we show on the graph the different gas prices projections presented by the IEA on the World Energy Outlook
- The same level of uncertainties is visible **on the coal prices driven by the Asian demand and the level of supply**.

Important uncertainties on Europe gas prices are driven by fundamental drivers such as LNG and Russian imports as well as global demand after the Covid-19 crisis.

Source: CL Energy based on Bloomberg and IEA World Energy Outlook

Outlook for CO_2 prices

CO_2 EU ETS outlook (real 2020)



Source: CL Energy based on Bloomberg, IEA World Energy Outlook

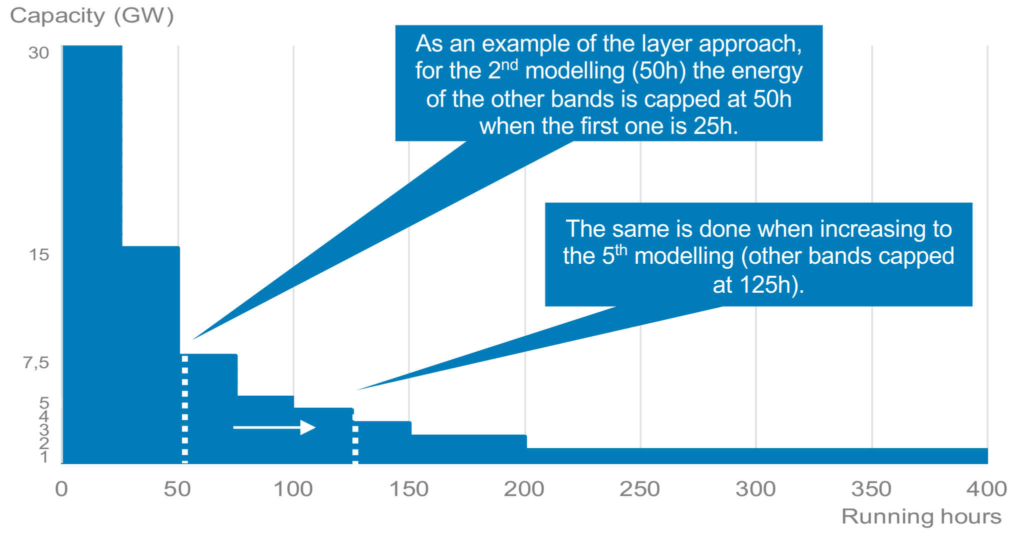
- In February 2018, the approval of the EU ETS reform pushed prices to higher levels. Market is currently trading at ~20€/t. This reforms aim at reducing the current surplus of emission allowances in the EU ETS market.
- Despite this new reform, **important uncertainties remain** regarding the level of carbon prices, driven by:
  - Overlapping policies with the EU ETS market : energy efficiency, renewable generation, coal phase-out …
  - Economic development
  - Decarbonisation objectives
  - EU ETS rules in the long term
- These uncertainties are illustrated by the different scenarios provided by the IEA and the EC.
- In the CL Energy projection, we assume that the future ETS reform will lead to an increase of CO2 prices to 34€/t in 2030.

Despite a recent rebound due to the 2018 EU ETS reforms, the carbon price outlooks remain difficult to determinate due to uncertainties about the installed capacity, demand and long term objectives as well as the post Covid-19 crisis.

A pyramidal approach allows a progressive modelling to represent the different types of DR

- **The approach consists of modelling DR capacity in several layers.**
  - The highest layer is running for only a couple of hours. The capacity is higher than other bands.
  - The lowest layer has low capacity and can run for longer
  - The purpose of this layer approach is to represent a realistic DR type portfolio.
- **We chose to retain a scanning approach with a large panel of bands for the main scenarios.**
  - The analysis successively increase the running hours of bands.
  - Max capacity remains constant (30GW)
  - Step-by-step addition of activation hours for lower than max capacity
- **The DR baseload is established at 1GW 400h when the peak band is at 15GW 25h. If all bands are combined on peak hours, the total capacity during the 25 highest hours is of 30 GW.**

Decomposition of capacity for DR - EU 2030 / Central Scenario



Running hours (h)	Capacity (GW)	Number of considered bands	Name
25	15	1	Portfolio (1/8)
50	7.5	2	Portfolio (2/8)
75	2.5	3	Portfolio (3/8)
100	1	4	Portfolio (4/8)
125	1	5	Portfolio (5/8)
150	1	6	Portfolio (6/8)
200	1	7	Portfolio (7/8)
400	1	8	Complete Portfolio

Annex 4
Other studies on DR

The results broaden conclusions from previous studies

Study		Main findings
European Commission, 2016, *Impact assessment study on downstream flexibility, price flexibility, demand response & smart metering*	 IMPACT ASSESSMENT STUDY ON DOWNSTREAM FLEXIBILITY, PRICE FLEXIBILITY, DEMAND RESPONSE & SMART METERING — ECOFYS, THEMA, vito, COWI	- 4 scenarios for the development of DR in the EU28. - network benefit represents more than 25% of generation benefits - estimation of variable costs (loss production), annual fixed cost and investment costs
RAP, 2016, *Benefiting Customers While Compensating Suppliers: Getting Supplier Compensation Right*	 RAP — Benefiting Customers While Compensating Suppliers: Getting Supplier Compensation Right	- 1GW 400h DR : ratio going from 10 to 33 depending on the year and country of study - 4GW 400h DR: ratio going from 4 to 10 depending on the year and the country of study
PJM, 2020, *2019 Demand Response Operations Markets Activity Report: April 2020*	 2020 Demand Response Operations Markets Activity Report: December 2020 — pjm	- Revenues mainly on capacity market - Reduced cost of energy sourcing of 5 to 8% for 100 hours

COMPASS LEXECON

EXPERTS WITH **IMPACT**™

Fabien Roques (France)
Energy Practice
Executive Vice President
+33 (0) 1 53 06 35 29
FRoques@compasslexecon.com

Yves Le Thieis (France)
Energy Practice
Senior Economist
+33 1 53 05 36 26
YLeThieis@compasslexecon.com