Nuclear power operation in European scenarios of decarbonization with high shares of RES

Based on a study commissioned by Foratom

Electricity (re)volution: what role for baseload and dispatchable technologies?

NEA / OECD Workshop

Paris - 4 September 2019

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Content of the presentation

Study objectives and modelling approach

Study objective: Assess the contribution of nuclear generation towards a low-carbon European economy against key policy objectives

Policy objectives

Decarbonisation and sustainability

Security of supply

Affordability /competitiveness

Key research questions

What is the role that nuclear can play in a EU decarbonisation scenario with **growing power demand driven by strong electrification** of the economy?

How to manage nuclear plant closures, life extensions and new build in different countries to **avoid locking in inefficient fossil fuel technologies and emissions** in transition to a decarbonised power sector?

Can a EU scenario with a fully decarbonized electricity mix be **robust, secure and cost efficient** without a significant share of nuclear?

- The Vision 2050 study aims at **delivering fact-based evidence in response to these key questions** by analysing the contribution of the European nuclear sector across **three different scenarios** to achieving European energy policy objectives of security of supply, decarbonisation and sustainability, and affordability / competitiveness.

We assess three nuclear scenarios using a multi criteria analysis based on quantitative modelling and a literature review

Three nuclear scenarios 2020-2050

Low scenario | Medium scenario | High scenario

Impact assessment based on multi criteria analysis

European Power Market Dispatch Model	Literature review
Capacity requirements and security of supply	Job impact
Generation outlook	Transmission and Distribution cost
Storage requirements and curtailed energy	Balancing cost
Nuclear capacity factor	Land use
Fossil fuel consumption	SO2 emission
CO2 emissions	NOx emission
Power prices	Particular Matter emission
Customer cost	
Investment cost	

Key findings and policy recommendations

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ENERGY

FTI-CL Energy model relies on recognised third party sources for key assumptions

Modelling approach

- The study assumes across all scenarios:
  - **90% decarbonisation** of the energy mix in 2050, compared to 1990;
  - **further electrification** of the European economy: 2050 demand forecast is projected to reach c4100TWh

- The study also assumes technology improvements based on the European Commission reference assumptions on electricity technology costs and performances*

- The study leverages FTI-CL Energy's European power market model to dynamically simulate the impact and costs of the three different scenarios, based on a two-step optimisation process:
  - **Dynamic optimisation of the generation mix** based on the economics of RES, thermal plants and storage, to ensure security of supply and meet EC objectives at the least cost; and
  - **Short term optimisation of dispatch** of the different units on an hourly basis.

* Technology pathways in decarbonisation scenarios, Advanced System Studies for Energy Transition (ASSET), July 2018.

Geographic scope of the model

Source: FTI-CL Energy, Eurelectric, PRIMES EUCO

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 EUCO scenarios and Eurelectric	■ 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
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 2017 New Policy by 2025	■ Fixed set as an input (see appendix)
Coal ARA CIF	■ Forwards until 2021, converge to IEA WEO 2017 New Policy by 2025	■ Fixed set as an input (see appendix)
CO2 EUA	■ Forwards until 2021, converge to EUCO33 by 2025, EUCO30 by 2030/35	■ Fixed set as an input (see appendix)
Interconnections		
Interconnection	■ ENTSO-E TYNDP 2018 outlook for new and existing interconnections	■ Fixed set as an input (see appendix)

Note: Further details are presented in the Appendixes

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

Additionally to modelling European power markets, indirect impacts are assessed based on a thorough literature review

- The **Assessment of the three scenarios** on **security, economic** and **sustainability criteria** derived from outputs of the European power market modelling will be complemented with qualitative assessment of indirect costs related to air & water pollution, Transmission & Distribution grid development, land use and employment.

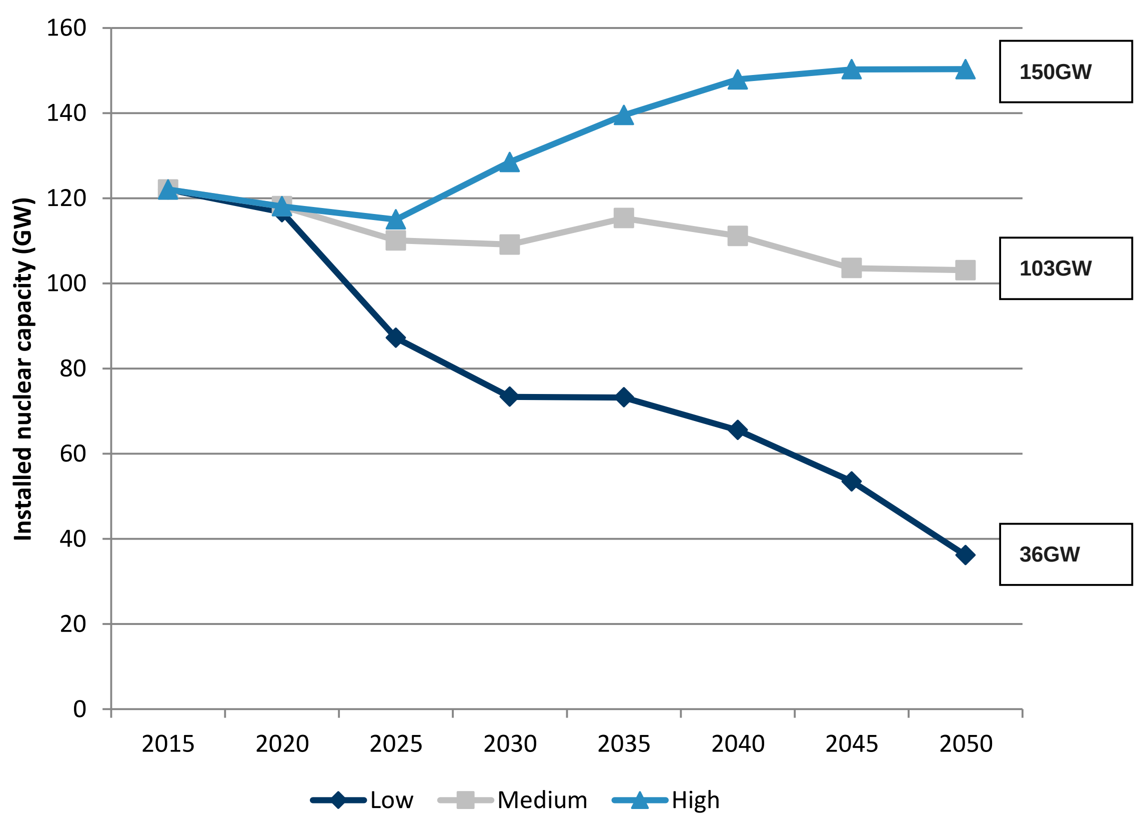
Key power price driver	Description	Sources
Security criteria		
Additional T&D infrastructure cost	How would the need for additional infrastructure (e.g. gas and power transmission) evolve on EU and national levels?	■ NEA, The Full Costs of Electricity Provision (2018), ■ AGORA (2015) ■ Delarue et al. (2016) ■ KEMA (2014)
Ancillary services and grid stability	What would be the need for Ancillary services in future power systems and how can nuclear contribute to ensuring network stability?	■ NEA, The Full Costs of Electricity Provision (2018) ■ Delarue et al. (2016) ■ AGORA (2015) ■ Hirth et al. (2013 & 2015) ■ Holttinen et al. (2011 & 2013)
Sustainable criteria		
Air and water pollution	How would Air and Water pollution change depending on nuclear contribution to decarbonisation?	■ European CASES Projects ■ Masanet et al., 2013
Land use	How would Land Use by the power sector change depending on nuclear contribution to decarbonisation?	■ Fthenakis and Kim (2009).
Economic criteria		
Employment	How would Employment in the power sector change depending on nuclear contribution to decarbonisation?	■ OECD/IAEA (2015)

The nuclear scenarios cover a range of installed capacities reflecting different assumptions for retirements, life extensions and new build

Scenarios design

- The three scenarios are based on current nuclear plants and projects under construction as well as planed nuclear phase-down policies, and then assume different life extension decisions as well as different commissioning date for future new nuclear plants:
  - In the **short term**, in all scenarios, nuclear capacity **drops by 5 to 20GW by 2025.**
  - In the l**onger-term**, variation of extension and new built decisions lead to the following scenarios:
    - ➢ In the **low scenario**, most of the existing plants close without further extensions and new plants projects fail to conclude.
    - ➢ In the **medium scenario**, a number of long term operation (LTO) extensions are awarded and new plants are built, in line with current advanced projects.
    - ➢ In the **high scenario**, a number of additional new plants are commissioned replacing thermal baseload and contributing to decarbonisation of the power sector and wider European economy.

EU-28 nuclear installed capacity outlooks (GW)



Source: FTI-CL Energy analysis based on FORATOM inputs

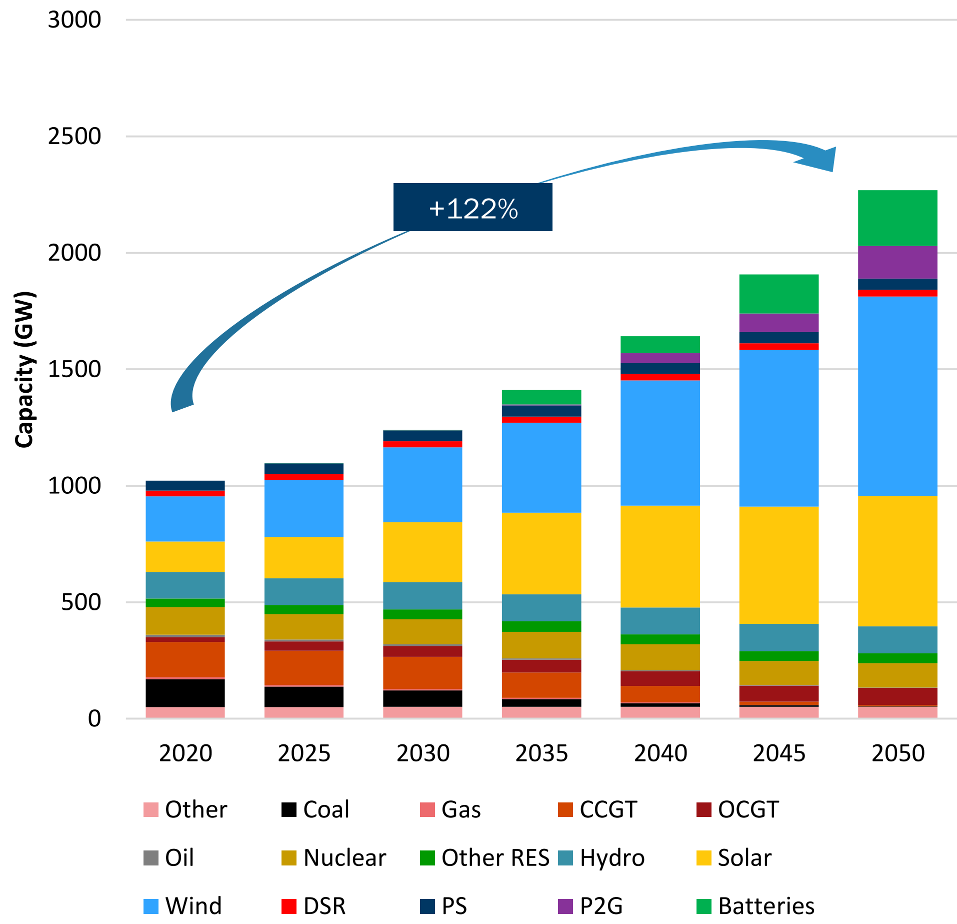
Key study findings

In the medium nuclear scenario, RES capacity reaches 1570 GW (+231%) by 2050, and flexible capacity hits 500 GW (+695%)

Installed capacity outlook:

- **Thermal plant closure**:
  - Between 2020 and 2050, 300GW of the existing 310GW of thermal capacity (97%), would close due to anticipated closure or reaching their end of life.
- **This would be replaced by**:
  - 1100GW of **new RES** over 2020-2050 reaching a total of 1570GW in 2050
    - Wind: 860GW; and
    - Solar: 560GW
  - 445 GW additional **new flexible capacity**:
    - 240GW battery;
    - 5GW DSR*;
    - 55GW thermal peakers; and
    - 145GW Power to X**

Medium scenario capacity outlook



Source: FTI-CL Energy modelling

Note: Other includes small distributed thermal non-renewable generation; Wind includes onshore and offshore; PS stands for "Pumped Storage"; P2G stands for "Power to Gas"

* The study considers that 25GW of DSR would already be operational by 2020

** "Power to Gas" refers to Power-X-Power storage technology

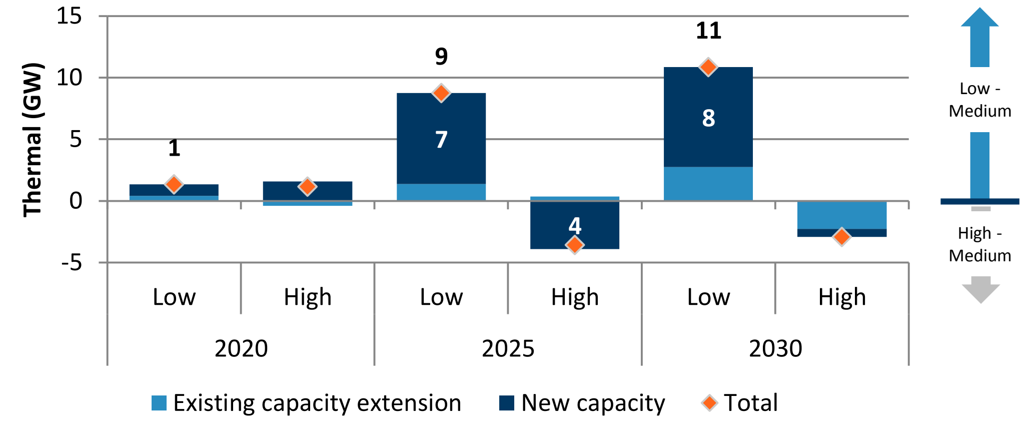
A low nuclear share increases investment in thermal and storage technologies by 128GW to ensure security of supply

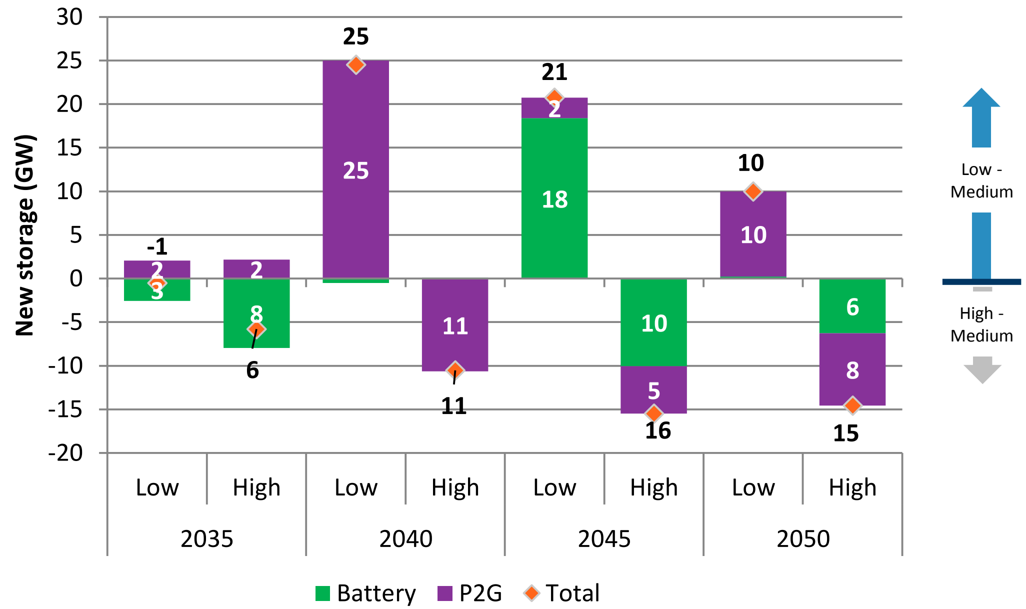
Impact of low nuclear scenario vs high nuclear scenario:

- In the short term (to 2030), anticipated closure of nuclear capacity would require about **27GW of additional thermal capacity**.
- In the longer term, anticipated nuclear closure and limited new nuclear investments would require about **93GW of additional new investments in flexible resources in 2050** (31GW Battery and 62GW Power to gas):

A low nuclear generation share would materially increase the reliance of the long term power system on storage technologies.

Additional new capacity compared to medium scenario



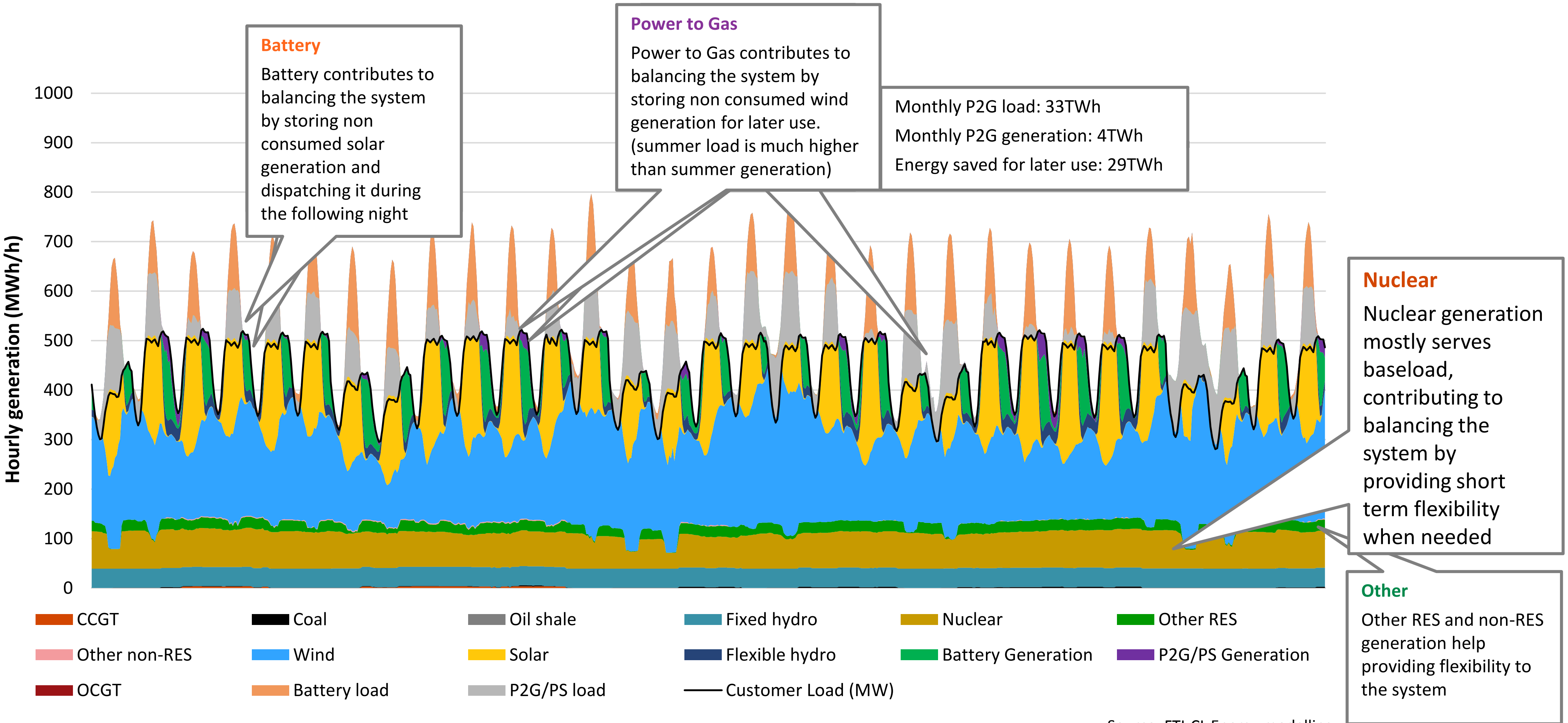


Note: comparison between low and high is derived from the sum of [Low – Medium] – [High – Medium].

-CL Energy modelling

In the summer in 2050, nuclear plant cycle during the day to provide flexibility to the power system to complement RES generation

Hourly generation mix during a summer month – July 2050

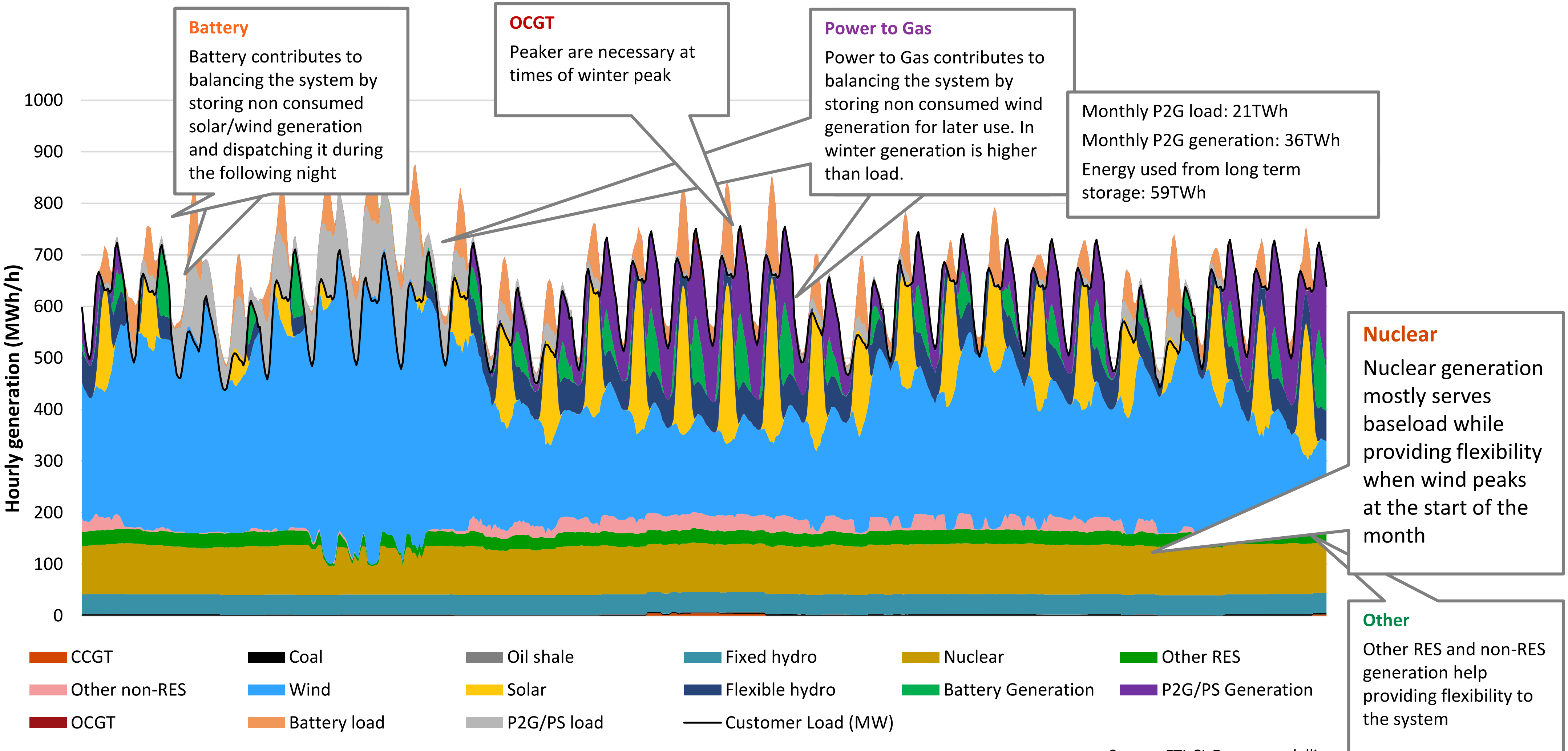


Source: FTI-CL Energy modelling

Note: PS stands for Pumped Storage

In the winter in 2050, nuclear continues to operate baseload most of the time as excess RES production is absorbed by storage and P2G

Hourly generation mix during a winter month – February 2050



Source: FTI-CL Energy modelling

Optimising the use of short term and long term storage will be critical to maintain an efficient and economic operation of nuclear plants

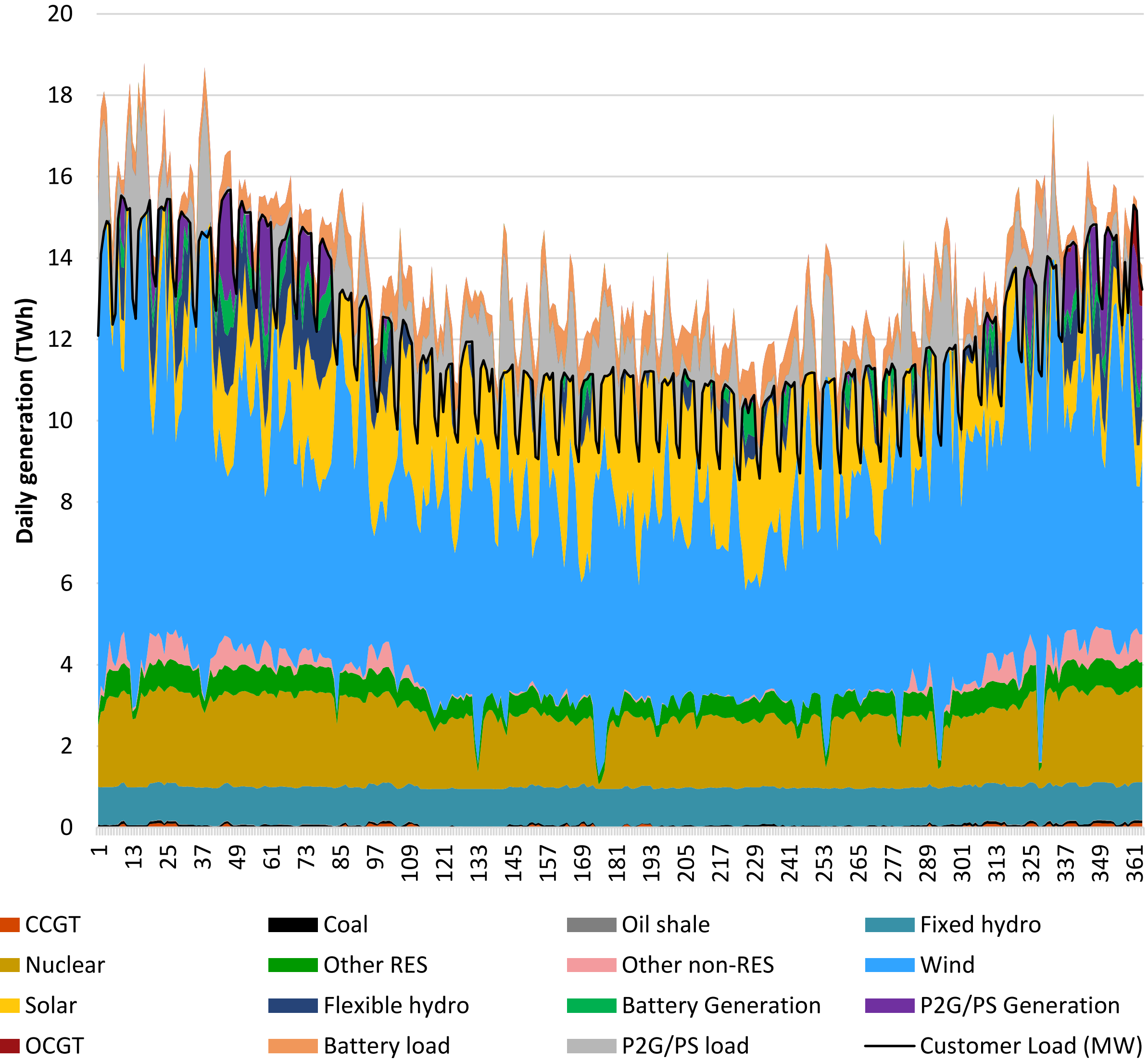
Nuclear contributes to providing flexibility and baseload power to the system by cycling at different times:

- **It can complement solar and wind variability** by providing flexible and dependable carbon free generation.

Seasonal utilisation of storage and P2G:

- **Storage capacities** are essential to stabilise the power system by capturing excessive production and generating in scarcity situations.
- **In summer**, beyond batteries transferring solar power from day to night, P2G enables solar power to be transferred from one day to the next. It can represent up to 10% of the customer load.
- **In winter**, P2G enables to offset low wind days and weeks, transferring power on a seasonal timeframe. P2G can represent up to 20% of the customer load.

Daily generation mix - 2050



Source: FTI-CL Energy modelling

The nuclear average capacity factor remains above the 70% threshold in all three scenarios

In all three scenarios, the nuclear average capacity factor remains above the 70% threshold over 2020-2050.

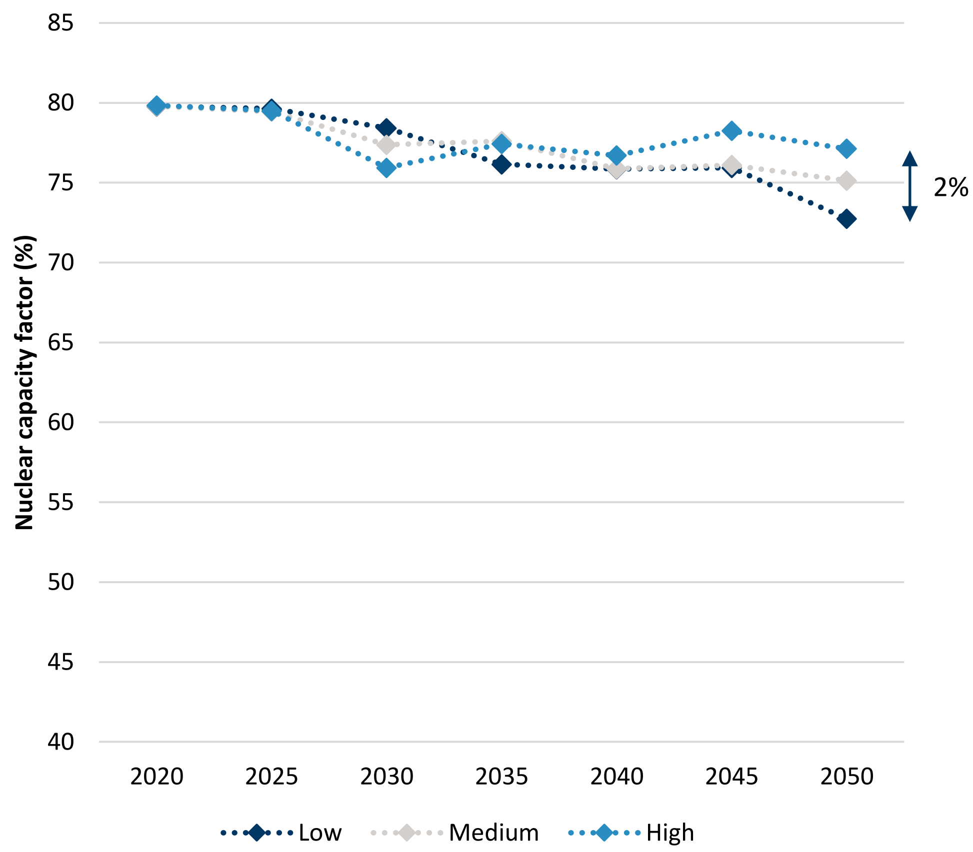
The average nuclear capacity factor decreases slightly in each scenario with the growth of RES - particularly after 2035:

- In the Low nuclear scenario, faster growth of RES would further decrease nuclear average capacity factor by 2% in 2050.
- In the high scenario, lower RES penetration would enable to maintain a higher capacity factor in the long term.

A faster deployment of short term and seasonal storage would support a high utilisation of nuclear plants

- With increasing renewable penetration, nuclear power would benefit from a timely deployment of storage to optimize its operation

Average nuclear capacity factor outlook



Source: FTI-CL Energy modelling

A low share of nuclear would increase fossil fuel consumption

Increased reliance on fossil fuels generation

- By closing nuclear capacity instead of investing in its long-term operation, **2790TWh of additional fossil fuel based thermal generation will be needed** in the short to medium term, representing a **+20% increase** or the equivalent of 4 years of the EU's total power generation

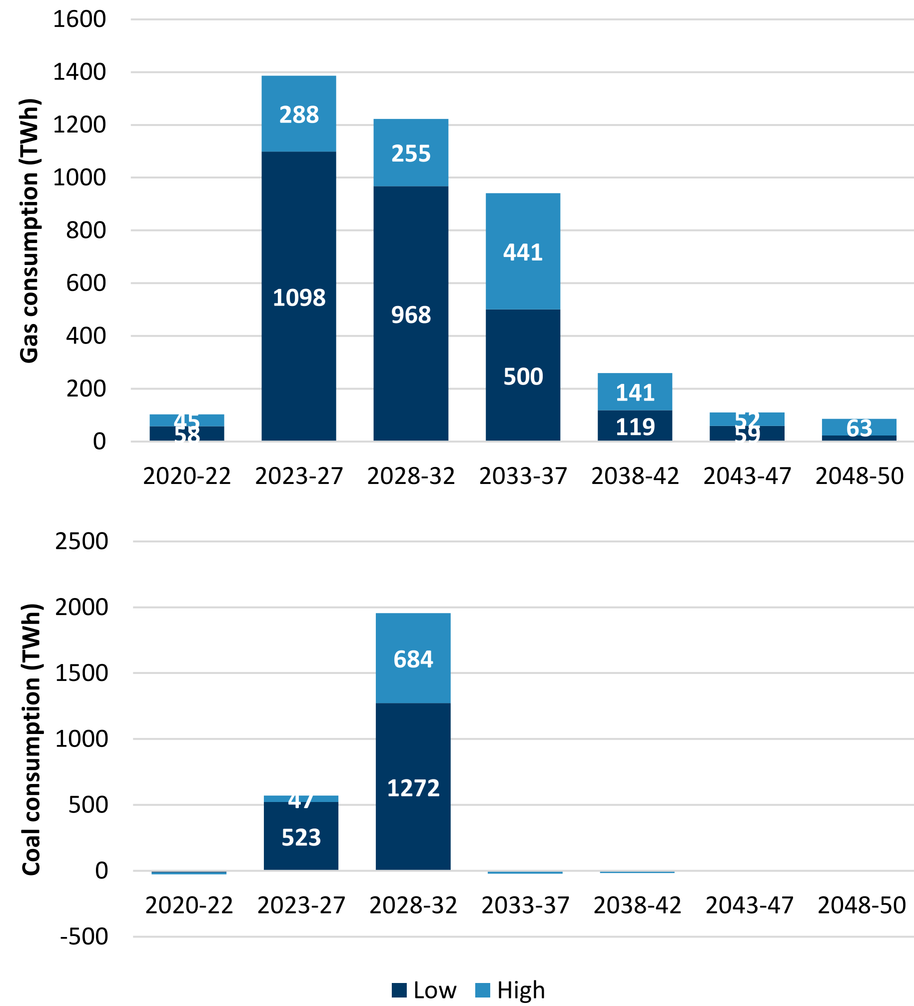
Increased dependency on imported fuel

- The low nuclear scenario would **increase fossil fuel consumption** (gas and coal) **by 6500TWh**, pushing up Europe's dependence on fossil fuels to an equivalent of +36% in gas consumption and +18% in coal consumption between 2020 and 2050.

Need for storage

- A low share of nuclear in the energy mix will significantly increase the power system's reliance on large scale yet immature storage technologies (reaching around 440 GW of batteries and seasonal storage such as Power2X in 2050 in the Low scenario)

Fossil fuel consumption difference from the power sector



Note: Low compares Low – Medium scenario; High compares Medium – High scenario.

Source: FTI-CL Energy modelling

The low nuclear scenario would materially increase CO_2 emissions over 2020-2050, local pollution, and the power sector footprint

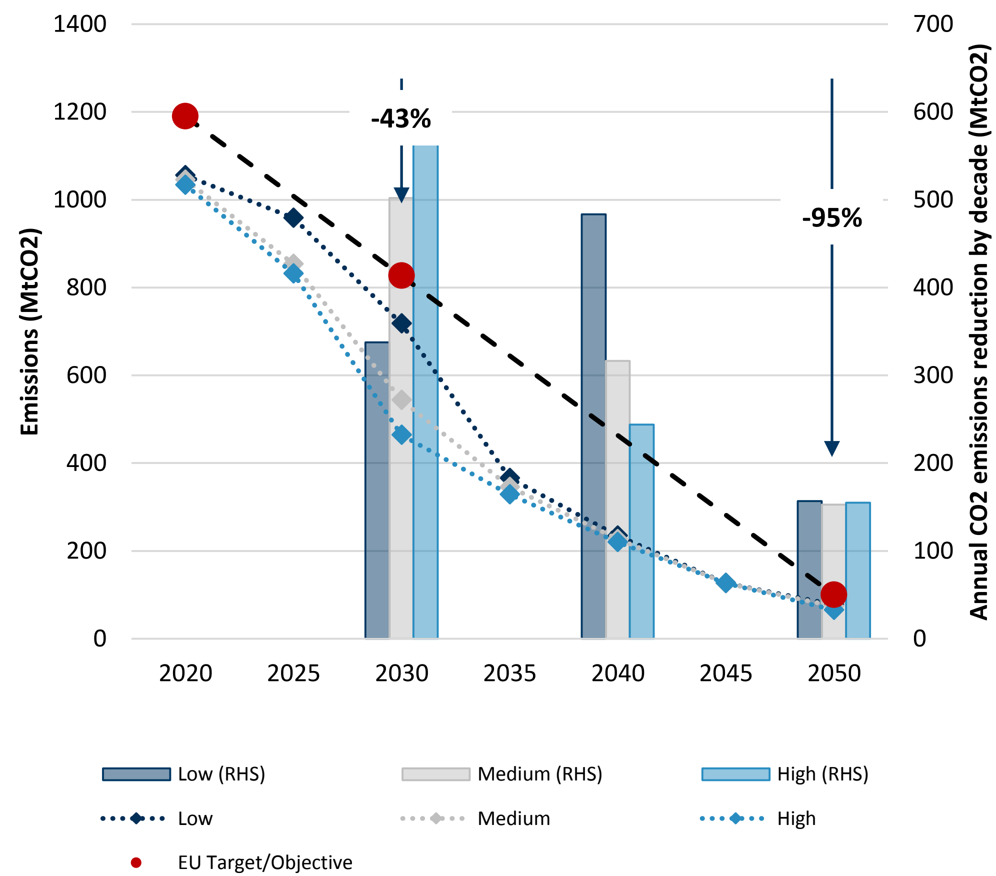
Anticipated nuclear closure and limited new nuclear investments in the low scenario would **increase total CO_2 emissions over 2020-2050 by about 2270Mt or 17% of total CO_2 emissions from the power sector**

While all considered scenarios meet the 2030 target and 2050 decarbonisation objective**, the probability to reach the objective is higher in the scenarios featuring at least a stable nuclear share**, as these show less cliff-edge effects in the long run and reduce emissions in the transition in the short and medium term

Local air pollutants would be reduced by c14%, including a 15% reduction in SO_2 emissions, 9% in NOx and 18% in PM

The amount of land needed for power generation would be about 15800km2 lower by 2050 – equivalent to half the size of Belgium – because nuclear generation requires less land than variable RES and fossil fuels to produce the same amount of energy

CO_2 emissions outlook from the power sector



Source: FTI-CL Energy analysis

In the low scenario, customer cost would increase significantly over 2020-2050 compared to the medium scenario

Anticipated nuclear closure in the low scenario compared to the high scenario would impact customer cost through:

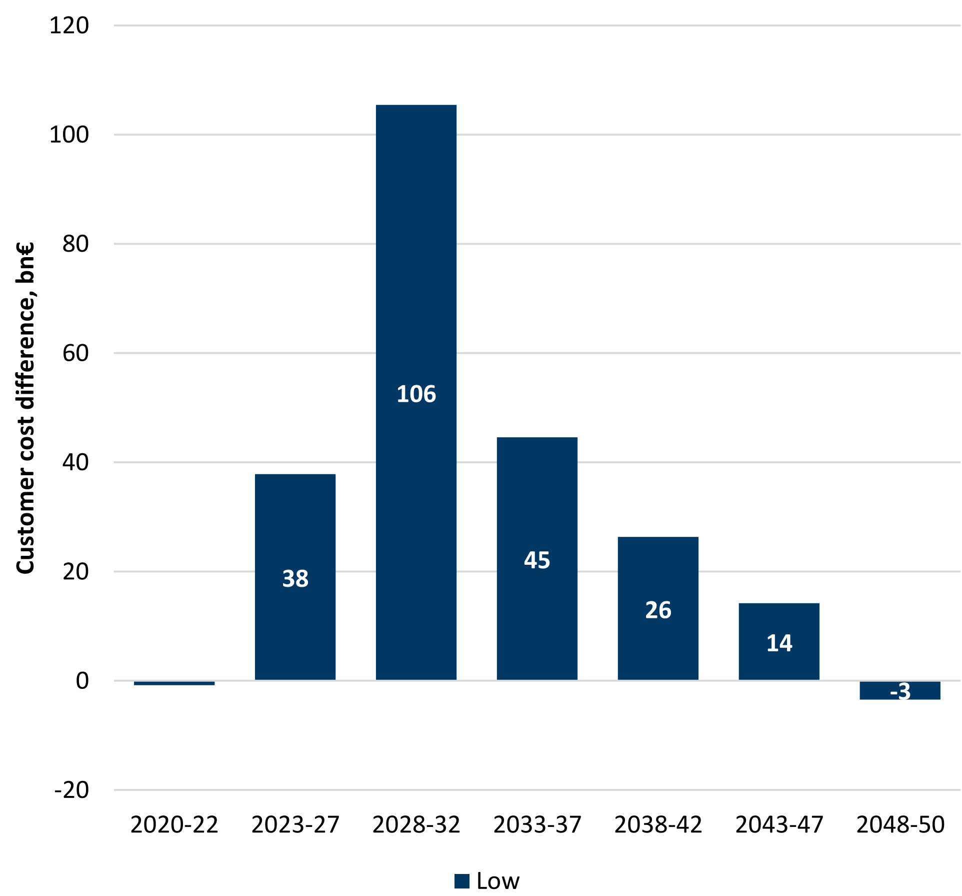
- **Energy cost increase** as cheap nuclear baseload is replaced by more expensive gas and coal generation in the short to medium term;
- **Partly offset by reduced generation capacity cost** from reduced investment in low carbon generation;
- **And lower low carbon subsidy cost** from reduced subsidies in low carbon generation in the short to medium term.

Overall, the anticipated nuclear closure would increase total undiscounted customer cost by about €350 billion over 2020-2050 when compared to the high nuclear scenario, c5% of total customer cost over 2020-2050.

90% of these savings on customer benefit would occur in the short to medium term before 2035.

Moreover, compared to the Low scenario, further nuclear development in the High scenario would reduce network and balancing costs by 160bn€ (real 2017) by 2050.

Customer cost difference between low and medium scenario (real 2017)



Note: Low compares Low – Medium scenario; High compares Medium – High scenario.

Source: FTI-CL Energy modelling

Conclusions and policy recommendations

Conclusions

Nuclear energy provides an important contribution to an efficient the transition towards a decarbonized European power system:

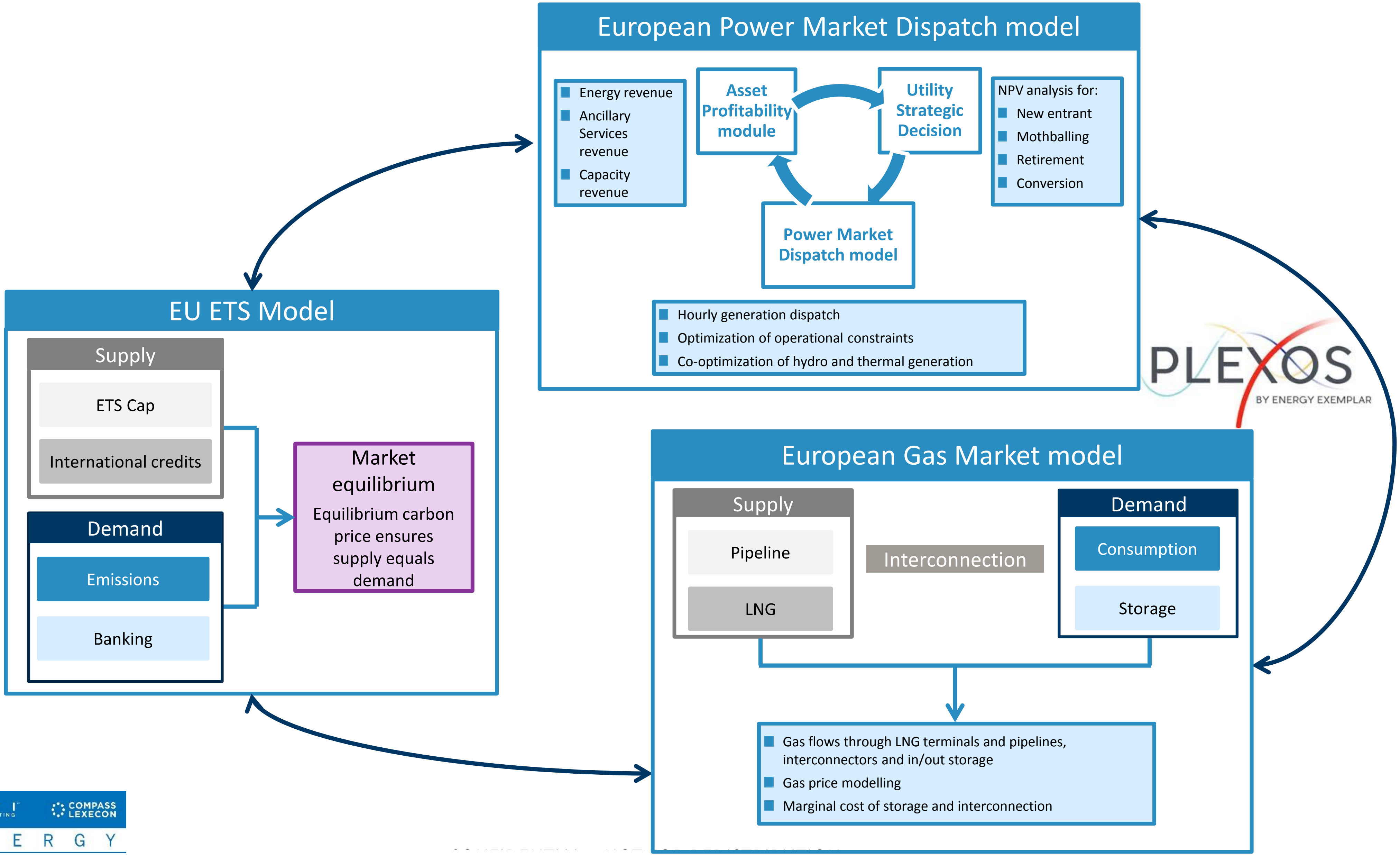
- **In the short to medium term**: Nuclear long term operation helps (i) ensure compliance with EU emission targets (ii) avoids temporary increase of emissions (iii) avoids locking in fossil fuel investments;
- **In the longer term**: nuclear supports variable renewables by (i) providing carbon free flexible electricity (ii) and reducing reliance on storage technologies / curtailment.

Key enablers for the sustainable role of nuclear power in the European power system include:

- New nuclear power needs to **demonstrate significant cost reductions** to succeed in liberalised European power markets.
- **Timely development & cost reduction of storage technologies as well as flexible operation of nuclear are** critical to ensure nuclear - vRES complementarity.
- To address the high vRES environment challenges**, the market design should (i) reward dependable & flexible sources system value and (ii) provide stable long-term investment signals.**

Appendix: FTI-CL Energy model and key assumptions

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

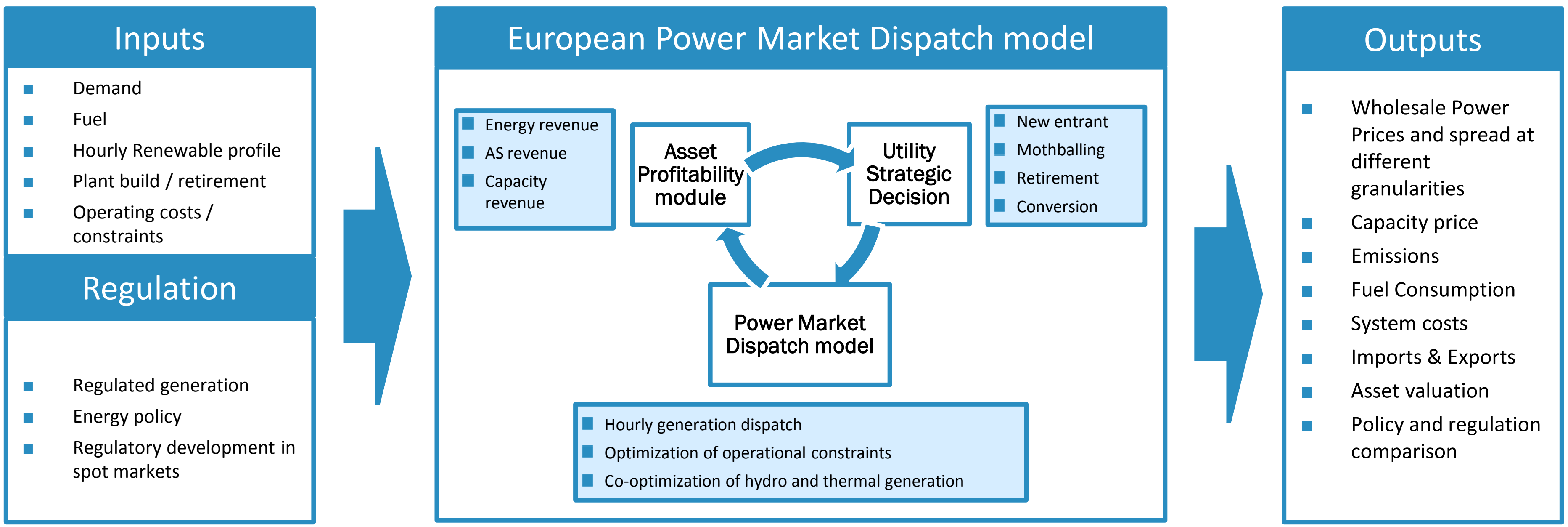


FTI-CL Energy’s power market model relies on a dispatch optimisation software with detailed representation of market fundamentals

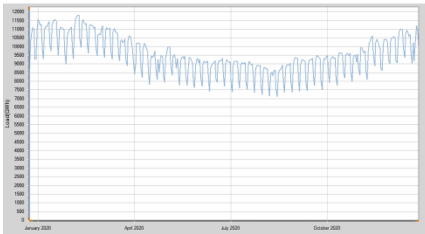
Dispatch optimisation based on detailed representation of power market fundamentals

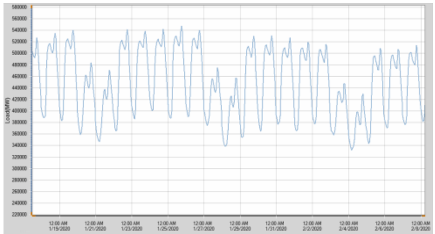
- At the heart of FTI-CL Energy’s market modelling capability lies a dispatch optimisation software, Plexos®, based on a detailed representation of market supply and demand fundamentals at an hourly granularity. Plexos® is globally used by regulators, TSOs, and power market participants.
- FTI-CL Energy’s 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 hydro thermal co-optimization algorithm embedded at the heart of Plexos®.

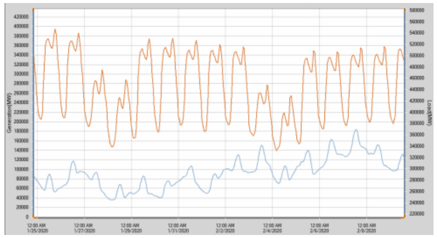
FTI-CL Energy’s modelling approach (input, modules and output)

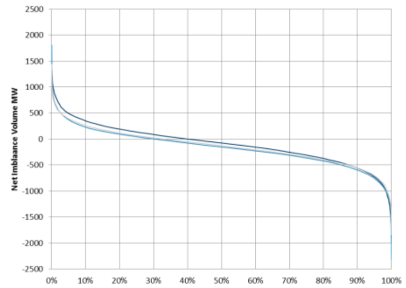


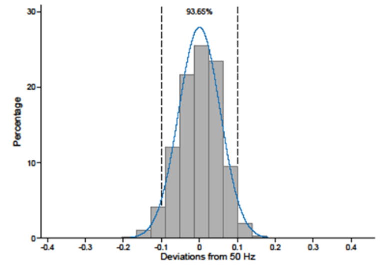
FTI-CL Energy’s power market suite allows to capture the flexibility and market arbitrage values on short time frames

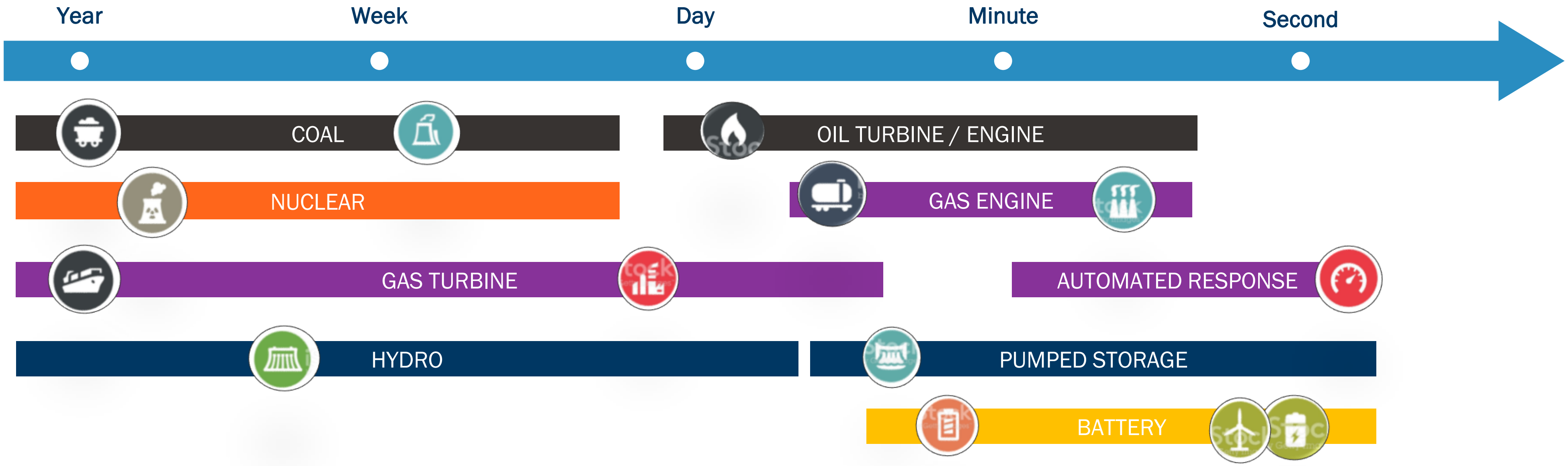












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