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Study for the American Chamber of Commerce in Bulgaria

Decarbonisation options for the Bulgarian power sector

Final report

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AMERICAN CHAMBER OF COMMERCE IN BULGARIA

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1. Executive summary

In the context of the European Green Deal and Fit for 55 Package, Bulgaria will need to update its roadmap to 2050 to accelerate its energy transition

Objectives of the EU Green Deal:

- Reach **carbon neutrality by 2050** (current target is 80-95% emissions reduction by 2050).
- Increase the EU 2030 carbon emission reduction target from 40% to **55%** (relative to 1990 level)

- The European Commission published on July 14 2021 its **Fit for 55 Package - a package of 13 legislative proposals - to achieve the new climate goals of 55% reduction in carbon emissions in 2030 and net zero emissions by 2050.** This package notably includes revisions to the EU ETS, the Effort Sharing Regulation, the Renewables Directive (new target of 40% RES in 2030 vs current target of 32%), the Energy Efficiency Directive (new target of 36% vs current 32.5% in 2030).

➢ **Bulgaria like other Member States will have to contribute to the increased climate ambitions** and update its current National Energy and Climate Plan (NECP) and decarbonization roadmap to 2050.

➢ **In the case of Bulgaria, reaching carbon neutrality and ensuring a sustainable energy transition raises significant challenges** given the structure of its power sector, relying on fossil fuels for power production and security of supply.

In this context, Compass Lexecon has been mandated by AmCham to develop fact based evidence by modelling different decarbonisation options for the Bulgarian power sector and to derive some policy recommendations on the development of an investment framework.

The study models different possible pathways for the Bulgarian power sector transition and derives policy recommendations

A two stage approach was followed to: (i) identify and model possible low carbon transition pathways for the Bulgarian power sector; and (ii) derive policy recommendations on the investment framework to support the necessary investments.

Phase 1: Power sector modelling

- **Scope**: power sector
- **Modelling tool**: in-house power sector dispatch model based on Plexos
- **Objective**: decarbonisation scenarios for the Bulgarian power sector while ensuring security of supply, using a multi-criteria analysis
- **Methodology**:
  - Design **three scenarios and a range of sensitivities** combining demand, commodity, technology costs, capacity mix.
    - The **first scenario** will be based on **2020 NECP commitment** to be used as a counterfactual scenario
    - The **second scenario** will be based on **increased decarbonisation ambitions, based on the Fit for 55 package and full decarbonisation by 2050.**
    - The **third scenario** will explore an **Alternative transition pathway,** minimising the costs to achieve 55% reduction in Bulgaria by 2030 and reaching full decarbonisation in 2050.
  - KPIs: Capacity, generation, flexibility, emissions, investment, cost

Phase 2: Policy recommendations on investment framework

- **Scope**: power sector
- **Objective**: Identify the relevant investment and transition framework to support the decarbonisation objective
- **Methodology**:
  - Assess the support required for clean technologies to be competitive in the market based on the scenarios defined in phase 1
  - Review key support mechanisms that could allow Bulgaria to meet its power sector decarbonisation targets
  - Define the key directions for market reform to meet Bulgaria's decarbonisation targets, including the definition of an investment and transition framework

The study focuses on 3 scenarios and a range of sensitivities, to identify pathways for the Bulgarian power sector transition

The study focuses on 3 scenarios to identify pathways for the Bulgarian power sector transition

The "***2020 commitment scenario***" ('*2020 CS*') is based on 2020 NECP and the Bulgarian Energy Strategy and act as a counterfactual scenario to compare decarbonisation scenarios.

- This scenario uses commodity prices projections including EU ETS price and technology cost assumptions of the EU 2020 Reference scenario completed with Bulgarian specific inputs from AmCham Energy and Mineral Resources Committee. This scenario reflects the generation mix evolution to meet the energy sector 40% CO_2 emissions reduction target by 2030, implied by the economy wide 49% CO_2 emissions reduction target relative to 1990.

A second scenario "***EU Increased Ambition scenario***" ('*EU IAS*') explores the set of options available to fully decarbonise by 2050 while being compliant with the European "Fit for 55 package" in 2030.

- This scenario uses commodity prices projections and technology cost assumptions of the EU 2020 Reference scenario completed with Bulgarian specific inputs from AmCham Energy and Mineral Resources Committee. It also uses EU ETS price projections of the EU Ff55 MIX scenario, combining a cost-efficient development of generation capacities under a set of Bulgarian technical and environmental constraints defined by AmCham Energy and Mineral Resources Committee and European CO_2 emission reduction constraint.

A third scenario "***Alternative transition pathway***" ('*ATP*') tests the options that would minimise the costs to achieve the transitory 2030 overall 55% CO_2 emissions reduction for Bulgaria (and therefore would not overachieve the emission reduction target contrary to the "*EU Increased Ambition scenario*" but still going beyond the "*2020 Commitment scenario*"), and full decarbonisation by 2050.

- The scenario is based on the "*2020 Commitment scenario*" using commodity, EU ETS and technology price projections of the EU 2020 Reference scenario, as well as projected capacity of the 2020 Energy Strategy but allowing for additional renewables to be built. Contrary to the *2020 Commitment scenario,* the model optimises dispatch and implicit carbon price to achieve an overall 55% CO_2 emission reduction in Bulgaria by 2030 at least cost.
- The approach followed is such that it allows an optimal dispatch while identifying the implicit carbon price on top of the EU Reference scenario price that would allow a smooth transition – that is a carbon price that would be sufficient to induce the necessary CO_2 emission reduction to reach overall 55% CO_2 emission reduction by 2030 in Bulgaria.

Note: Final 2020 NECP has been published by end of 2020, EU 2020 Reference and EU Ff55 MIX scenarios have been published in July 2021. AmCham Energy and Mineral Resources Committee link.

The modelling provides a detailed assessment of the power sector demand, capacity, emissions and costs in the 3 scenarios

Capacity and generation outlook

- **Across both *ATP* and *EU IAS,* variable renewable and low carbon capacity is projected to play a larger role towards decarbonisation** both in 2030 and 2050 with a minimum of 7.5GW wind and solar capacity being developed by 2030 in *ATP*.
- This translates into an **increasing share of variable RES generation** in both scenario from 7% in 2020 to 23% (resp. 36%) in 2030 in *ATP* (resp. *EU IAS*) and 40% (resp. 51%) in 2050 in *ATP* (resp. *EU IAS*).
- Along the transition, ***EU IAS* is projected to rely more on new gas investments and accelerate lignite closure from 2025 onwards compared with *ATP***. Combined with higher EU ETS price in *EU IAS*, this leads to an accelerated reduction of lignite generation from 2025 onwards replaced temporarily by equivalent gas generation compared with *ATP*.
- **This interdependence between lignite and future flexible requirement capacities points to the critical role of an orderly transition** keeping a sizeable base of thermal plants available to ensure security of supply in the transition, through orderly lignite plants closure and new gas or flexible capacities low carbon investments.
- In addition to further decarbonise the Bulgarian power system by 2050, the **development of additional low carbon flexible generation in the form of new nuclear capacities or storage would help achieve full decarbonisation while ensuring security of supply.**

Carbon emission reduction and power system cost outlook

- While ***ATP* is designed to achieve an overall 55% CO2 emission reduction in Bulgaria by 2030** at least cost and reach full decarbonisation by 2050, *EU IAS* **overachieves Bulgaria's potential new intermediary emission reduction target for 2030**, reaching 88% CO_2 emission reduction in the energy sector by 2030, equivalent to an economy wide c70% CO_2 emissions reduction compared to 1990.
- This increased emission reduction in *EU IAS* leads **to a significant increase in power system costs**, **particularly over the next decade compared with *ATP,*** bringing forward investments in low carbon technologies and reducing the use of existing capacities as a hedge against rising carbon prices.
- However, *EU IAS* **shows how Bulgaria can put in place an ambitious decarbonisation strategy with rapid and deep emission reductions in the power sector** thanks to new technologies.

Note: AmCham Energy and Mineral Resources Committee link.

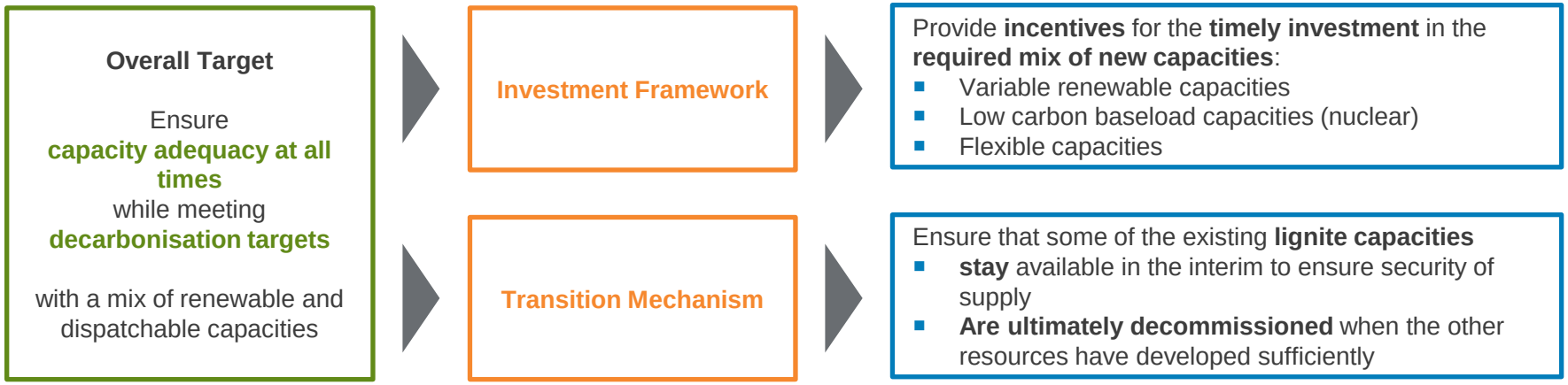
Key findings and policy recommendations: the need for a transition mechanism and investment framework to support decarbonisation

In all scenarios, the decarbonisation of Bulgaria's power sector will require significant investments in generation and energy infrastructure

- Some/most of the investments required to decarbonise Bulgaria's power sector while ensuring security of supply are not profitable based on energy market revenue alone
- The current immature Bulgarian Electricity market exposes market participants to risks and hinders investments
- The EU target model will not provide sufficient coordination and investment incentives to make sure decarbonisation targets are met while ensuring security of supply

Two key market design requirements were identified for a successful transition:

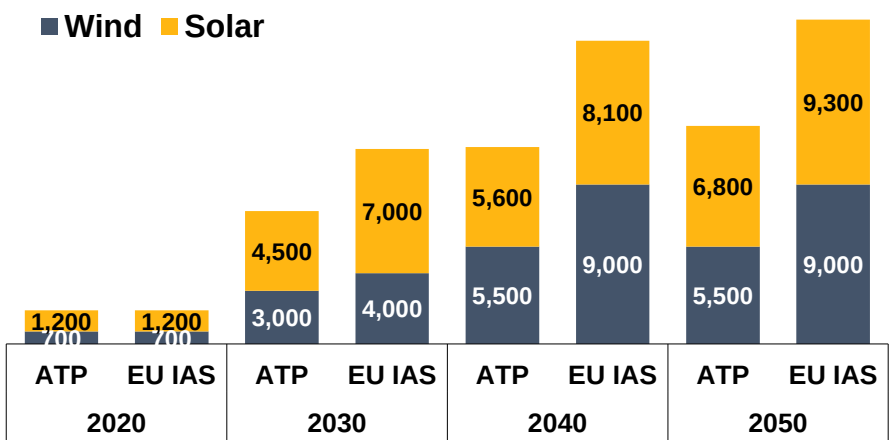
- (1) an **investment framework** for new capacities (financing & de-risking) including specific investment frameworks for Renewable generation capacities, Nuclear generation capacities, Flexible capacities and Energy grids
- (2) a **transition mechanism** securing lignite operation in the interim as well as a progressive phase-out.



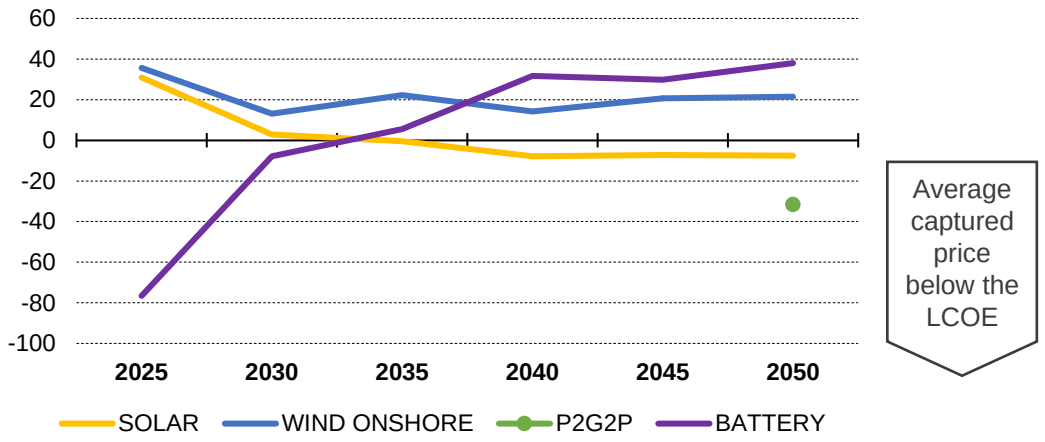
Source: Compass Lexecon Analysis

Reaching **renewables** ambitious targets will require a de-risking investment framework as their profitability declines with their increasing market penetration

RES capacity evolvement – EU IAS & ATP scenarios [MW]



Missing money for RES capacities [EUR_{2020}/kW/a] *EU IAS* (WACC=5%)



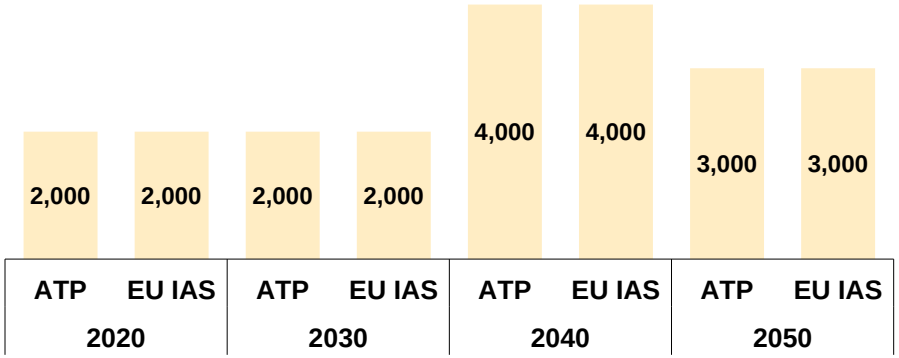
- **In both scenarios** (ATP and EU IAS) **significant wind and solar capacity expansions are required.**
- However, **profitability of investments in renewables declines** as their share grows and as revenues captured decrease.
- **For some RES and storage technologies** (e.g. solar PV and Power-to-gas-to-power for seasonal energy storage) merchant revenues will not provide sufficient **investment incentives even** at a low WACC – thereby already assuming some de-risking mechanisms are in place

Type of support	Description of mechanisms available for an investment framework – subject to EU staid aid clearance
Feed-in premiums (FIP) / Contracts for Premium	▪ FIPs enable power producers to benefit from a complementary remuneration, in addition to the remuneration they get by participating to the energy market. ▪ FIPs, however, do not eliminate market price risks
Contract for difference (CfD)	▪ CfDs enable to ensure a stable revenue to the operator with little exposure to wholesale market prices ▪ CfDs can be provided either automatically or through tendering procedures
Investment support	▪ Support via grants can support the build-up of capacities otherwise not profitable ▪ Preferential loans reduce financing costs

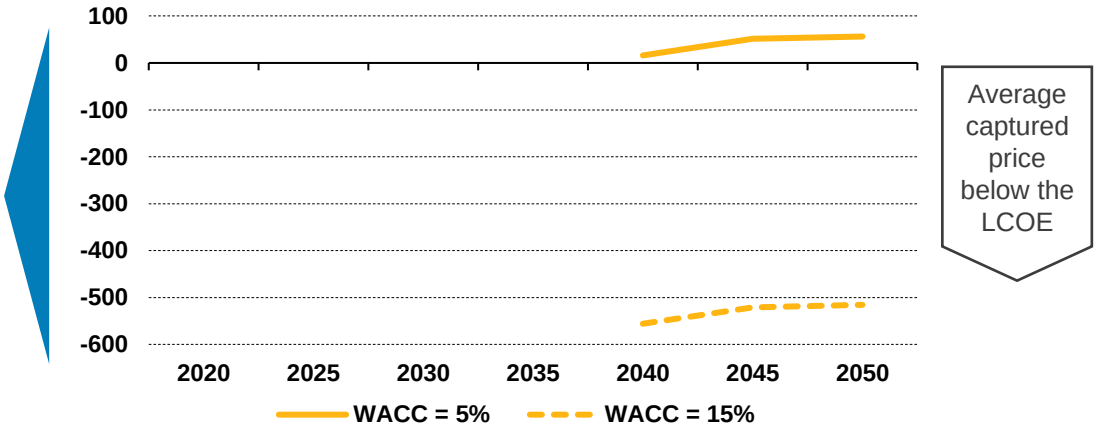
Source: Compass Lexecon Analysis
Abbreviations: ATP … Alternative Transition Pathway, EU IAS… EU Increased Ambition Scenario, LCOE … levelized cost of electricity, RES … Renewable Energy Source, P2G2P … power-to-gas-to-power, PV … Photovoltaics, WACC … weighted average cost of capital

The profitability of **new nuclear** is highly dependent on the cost of financing and a de-risking framework will be needed to support investment

Nuclear capacity evolvement – EU IAS & ATP scenarios [MW]



Missing money for Nuclear capacities [EUR$_{2020}$/kW/a] *EU IAS* (WACC=5%)



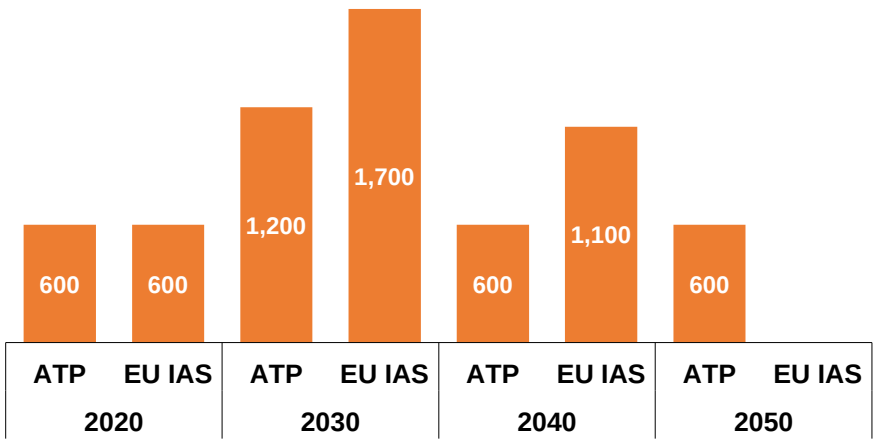
- **In both scenarios** (ATP and EU IAS) **two additional new nuclear reactors** replace aging plants and provide decarbonised baseload generation.
- The **business case for the highly capital intensive nuclear capacities** depends significantly on the required return (i.e. the WACC) which itself **depends** inter alia **on the energy market risks** to be borne by the investor.
- New nuclear capacities would require a **scheme for comprehensive de-risking** to be economically viable.

Type of support	Description of mechanisms available for an investment framework – subject to EU staid aid clearance
Full regulation	Full regulation is based on the provision of an authorized revenue based on all the costs that are supported (e.g. regulated asset base remunerated at the level of a regulated WACC, depreciation and OPEX remunerated at cost)
Purchase price / **regulated tariff**	A tariff is set (typically by the regulator) based on the different cost components (operating costs, re-investment, cost of capital), and the regulated assets benefit from this purchasing tariff.
Contract for differences (CfDs)	Depending on their structure, CfDs may ensure a (more) stable revenue to the operator by reducing/eliminating the exposure to wholesale market prices.
Investment support	Investment support could be provided for instance by the EU ETS Modernization fund which does not exclude nuclear investment, although this is not a priority investment.[1]

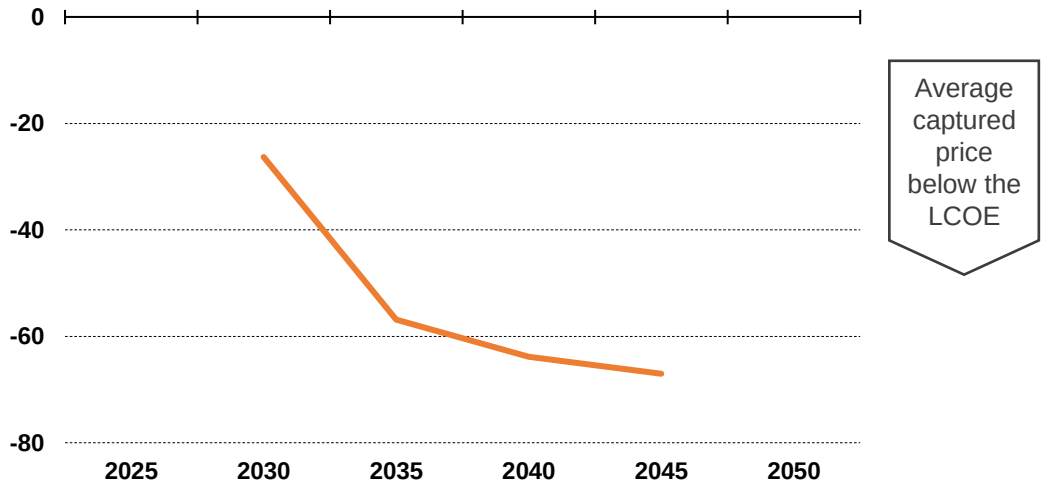
Source: Compass Lexecon Analysis
Abbreviations: ATP … Alternative Transition Pathway, EU IAS… EU Increased Ambition Scenario, LCOE … levelized cost of electricity, WACC … weighted average cost of capital

New **gas-fired** capacities could provide flexibility in the transition, but would require a support framework to be profitable

Gas-fired (CCGT) capacity evolvement EU IAS & ATP scenarios [MW]



Missing money for CCGT capacities [EUR_{2020}/kW/a] *EU IAS* (WACC=5%)



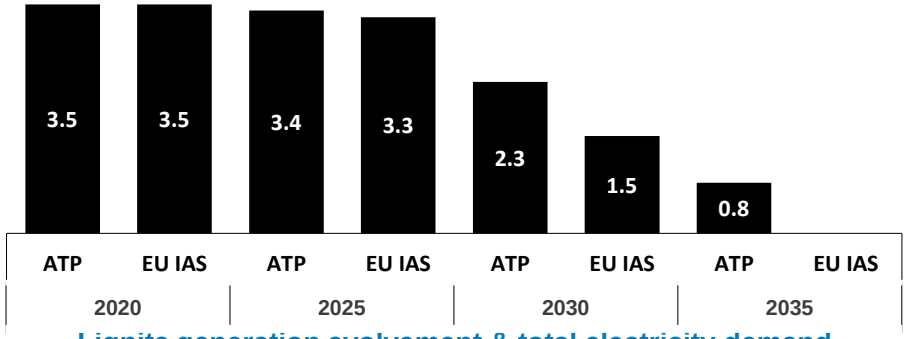
- **In both scenarios** (ATP and EU IAS) **new gas capacity** (CCGTs) **is developed** to support variable RES generation.
- However, the **profitability of investment is not ensured**, and **declines over time** as their load factors decline.
- De-risking (and the associated low WACC) is not sufficient to establish a business case – **CCGTs need** support to attract investment.

Type of support	Description of mechanisms available for an investment framework – subject to EU staid aid clearance
Capacity remuneration mechanisms (CRM)	CRMs can provide additional remuneration to flexible capacities to compensate for the missing money they would face in the energy market.
Investment support	Investment support can be available for flexible capacities investment in the form of grants or loans, through in particular the Recovery and resilience facility, the EU ETS Modernisation fund, and the InvestEU fund (although the later lacks an implementing partner in Bulgaria) – subject to certain emission limits.
Free ETS allocations	New flexible capacities projects (incl. CCGT) replacing lignite could benefit from free ETS allowances (if Bulgaria executes its respective right under Art. 10c of the EU ETS directive)

Abbreviations: C/OCGT … Combined/open cycle gas turbine, ETS … Emission Trading System, LCOE … levelized cost of electricity, RES … Renewable Energy Source, WACC … weighted average cost of capital

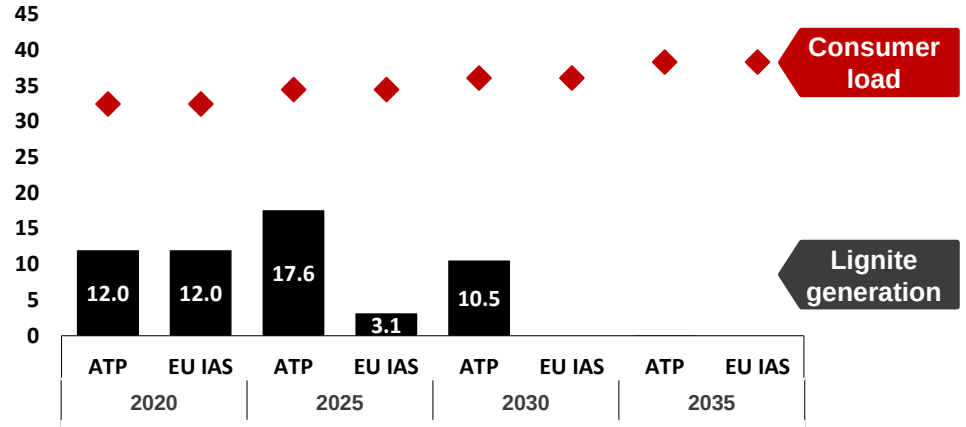
Lignite plants can act as bridging technology to ensure security of supply but will require a **transition mechanism** in the interim

Installed lignite capacity evolvement in scenarios achieving full power sector decarbonisation by 2050 (GW)



- **In both scenarios** (ATP and EU IAS) **reaching** the 2030 55% emission reduction target and **full decarbonisation by 2050, lignite capacity (and mine) availability are required** until 2030/2035 **to ensure security of supply and system stability**

Lignite generation evolvement & total electricity demand in scenarios achieving full power sector decarbonisation by 2050 (TWh)

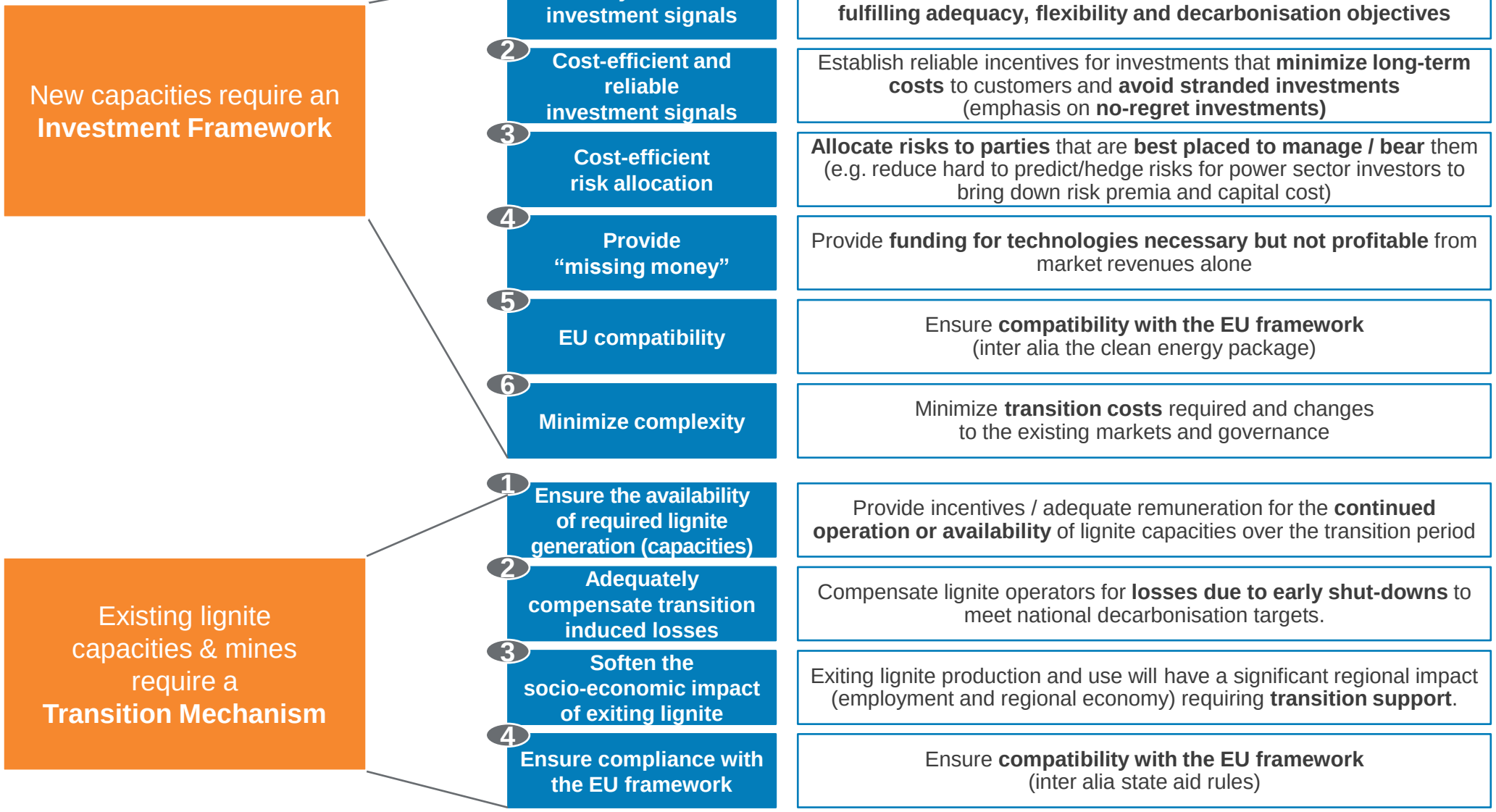


- **In both scenarios** (ATP and EU IAS) **reaching** the 2030 Fit-for-55 emission reduction targets and **full decarbonisation by 2050, lignite generation is required** up until 2025/30 **while other capacities are being expanded** to ensure sufficient electricity supply.
- Although **lignite capacity is required until 2030/2035** for security of supply reasons (see above), they **generate electricity only until 2030** at the latest. This is **not commercially viable without support**.

- **Ensuring the availability of lignite capacities to maintain security of supply** while little electricity is actually generated **requires support.**
- Also, the subsequent **retirement of lignite capacities and the closure and decommissioning of mines** ahead of their technical end-of-lifetime **requires support to mitigate the commercial and socio-economic impact** of this early decommissioning.
- A transition mechanism needs to be compliant with EU state aid regulations – there are several examples of EC approved national schemes.

Source: Compass Lexecon Analysis
Abbreviations: ATP … Alternative Transition Pathway, EC … European Commission, EU IAS… EU Increased Ambition Scenario

Both the Investment Framework and the Transition mechanism need to balance a broad set of requirements



Source: Compass Lexecon Analysis

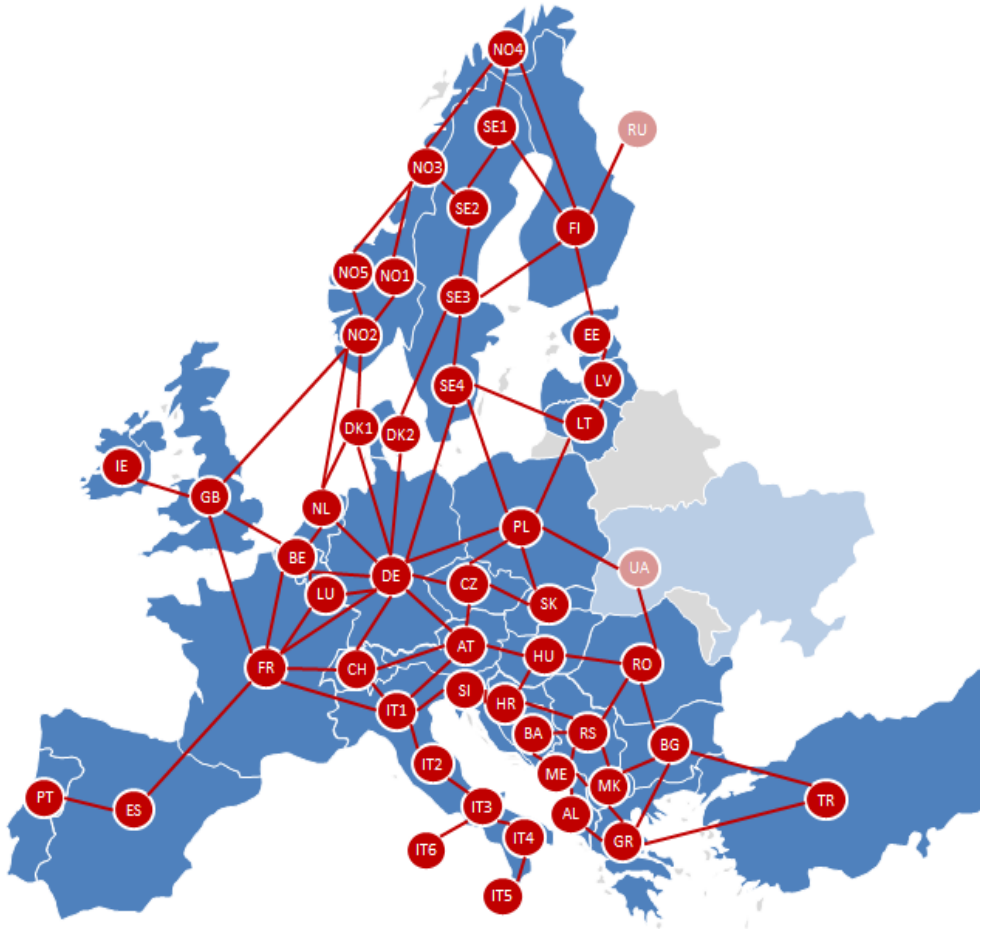
2. Modelling of decarbonisation options for the Bulgarian power sector

2.1 - Market modelling approach and key assumptions

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

- Compass Lexecon's power market model covers the **EU-27 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 Compass Lexecon for demand, supply, commodity price and interconnection.
- Compass Lexecon's power market model constructs **supply in each price zone based on aggregated 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.
- Compass Lexecon's power market model uses **ENTSOE Pan-European Climate Database (PECD)** for hourly time series for wind and solar production, hydro inflows and demand pattern.

Geographic scope of the model



Source: Compass Lexecon

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

Long term capacity scenarios

- **Long term capacity scenarios can be derived from two distinct approaches:**
  - **Dynamic long term optimisation** : Based on cost reduction assumptions, the capacity mix is optimized to minimise the cost of the system while meeting a number of constraints such as security of supply or CO_2 emission reduction target.
  - **Long term capacity scenarios based on energy policies and regulation**: Capacity projections are based on national and European energy policies and regulation which would structure the evolution of the capacity mix (cola closure policies, nuclear policies, renewable policies, …)
- Our modelling approach combines both long-term capacity scenarios based on energy policies and regulation and dynamic long-term optimisation through :

➢ **Power demand modelling:**

- **Future demand projection with embedded flexibility**
- National **power system security of supply** through ensured minimum margin

➢ **Capacity outlook modelling**

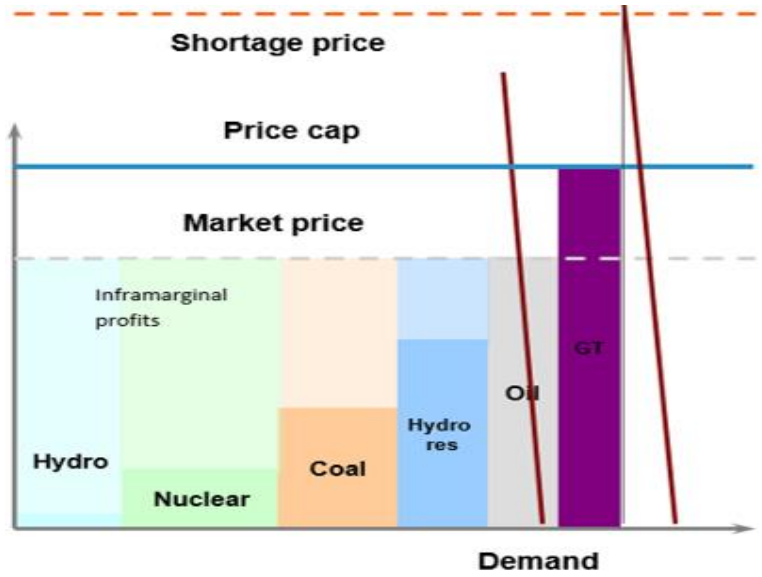
- **NECP renewable development** until 2030
- **Coal phase-down and nuclear plans** through 2050
- **European emission reduction** to net zero by 2050
- **CAPEX cost reduction** through 2050

Short term dispatch optimisation

- **Model constructs supply hourly in each price zone based on aggregated plants unit commitment constraints:**
  - European power plants database containing technical parameters of all thermal European plants
  - Model takes into account cross-border transmission and interconnectors

➢ **Zonal prices are found as the marginal value of energy based on Short Run marginal Cost (SRMC) bidding strategies**

➢ **Hourly generation results from the SRMC dispatch**



Source: Compass Lexecon

CL European power market model is set up with a range of inputs derived from latest announcements from TSOs, Regulators and Market Players

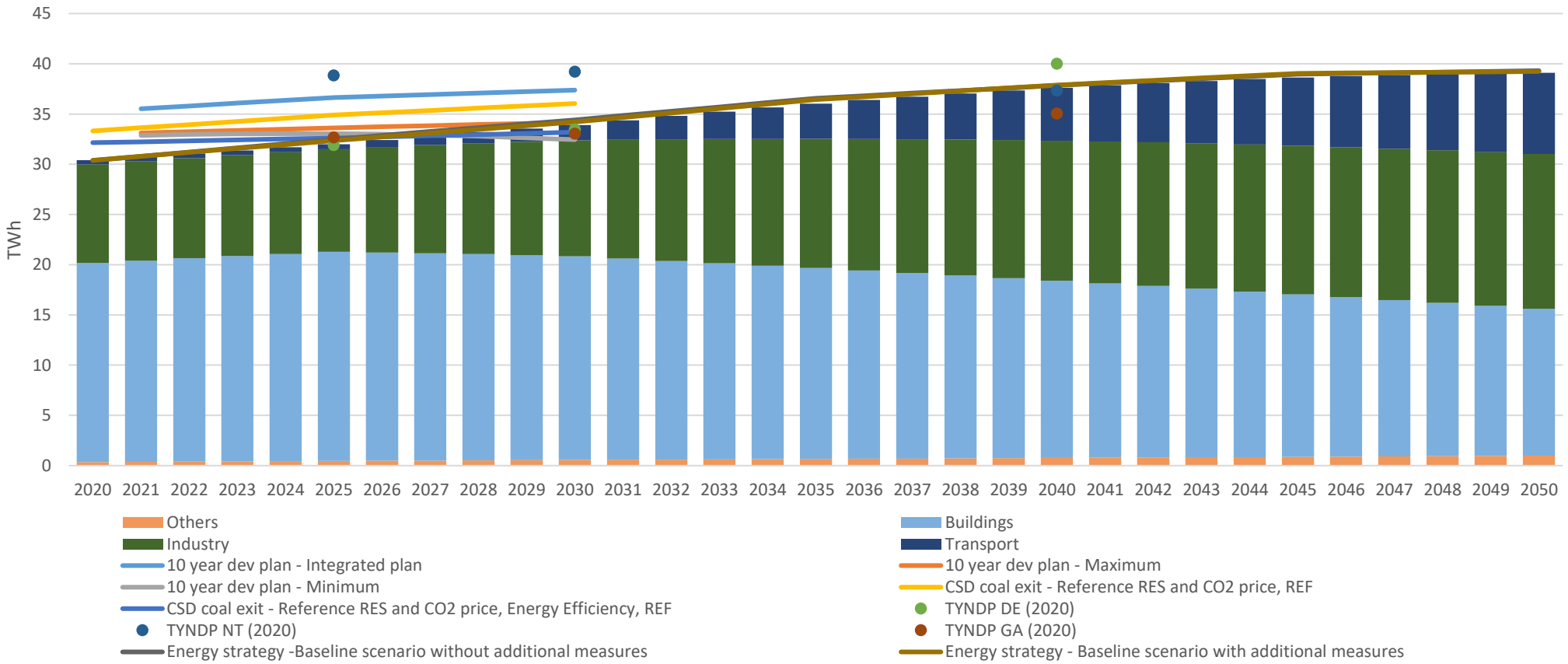
Key power price driver	Sources	Optimisation
Demand		
Power demand	■ Long term electrification based on BG Energy Strategy and EU decarbonisation scenario	■ Set as demand to be met
Supply		
RES capacity	■ Minimum set at NECPs and potential to reach EU-wide 60-65% RES-E penetration share by 2030 in line with Fit for 55. ■ Potential to 2050 based on national TSOs, ENTSOE ■ CAPEX and OPEX outlook based on latest data from EC Reference 2020 (July 2021)	■ EU and BG capacity dynamically optimised thereafter based on 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 optimised by hourly dispatch model. Capacity optimised in Bulgaria
Thermal capacity	■ Latest announcements from operators and National plans on phase-out or conversion to biomass ■ In Bulgaria, modelling of options for refurbishment, CCS retrofit or conversion ■ CAPEX and OPEX outlook based on latest data from EC Reference 2020 (July 2021)	■ EU and BG capacity dynamically optimised in the longer term based on NPV of anticipated costs and revenues ■ Dispatch optimised by hourly dispatch model
Storage technologies	■ CAPEX and OPEX outlook based on latest data from EC Reference 2020 (July 2021) and BNEF 2020 for batteries	
Commodity prices		
Gas	■ Forwards until 2023, convergence to EU Reference 2020 by 2025	■ Set as an input (see annex)
Coal ARA CIF	■ Forwards until 2023, convergence to EU Reference 2020 by 2025	■ Set as an input (see annex)
CO_2 EUA	■ Forwards until 2023, convergence to EU Reference 2020 or EU MIX scenario by 2025	■ Set as an input (see annex)
Interconnections		
Interconnection	■ ENTSO-E TYNDP 2020 / MAF 2020 outlook for new and existing interconnections	■ Set as an input (see annex)

Note: Further details are presented in the Appendixes
(1) MAF: Medium term adequacy forecast; (2) TYNDP: Ten Years Network Development Plan;

Power demand outlook to 2050 is derived from the Bulgarian Energy Strategy, projecting increased electrification and energy efficiency of the economy

- Power demand is projected to increase by c30% between 2020 and 2050, with the electrification of Transport (c85% by 2050), Industry (c60% by 2050) and Buildings (c65% by 2050), partially offset by increased energy efficiency measures (reaching 2.5% renovation rate by 2050).
- While remaining conservative compared to other benchmarks in the short term, the power demand outlook remains aligned with the Energy Strategy power demand outlook to 2050.

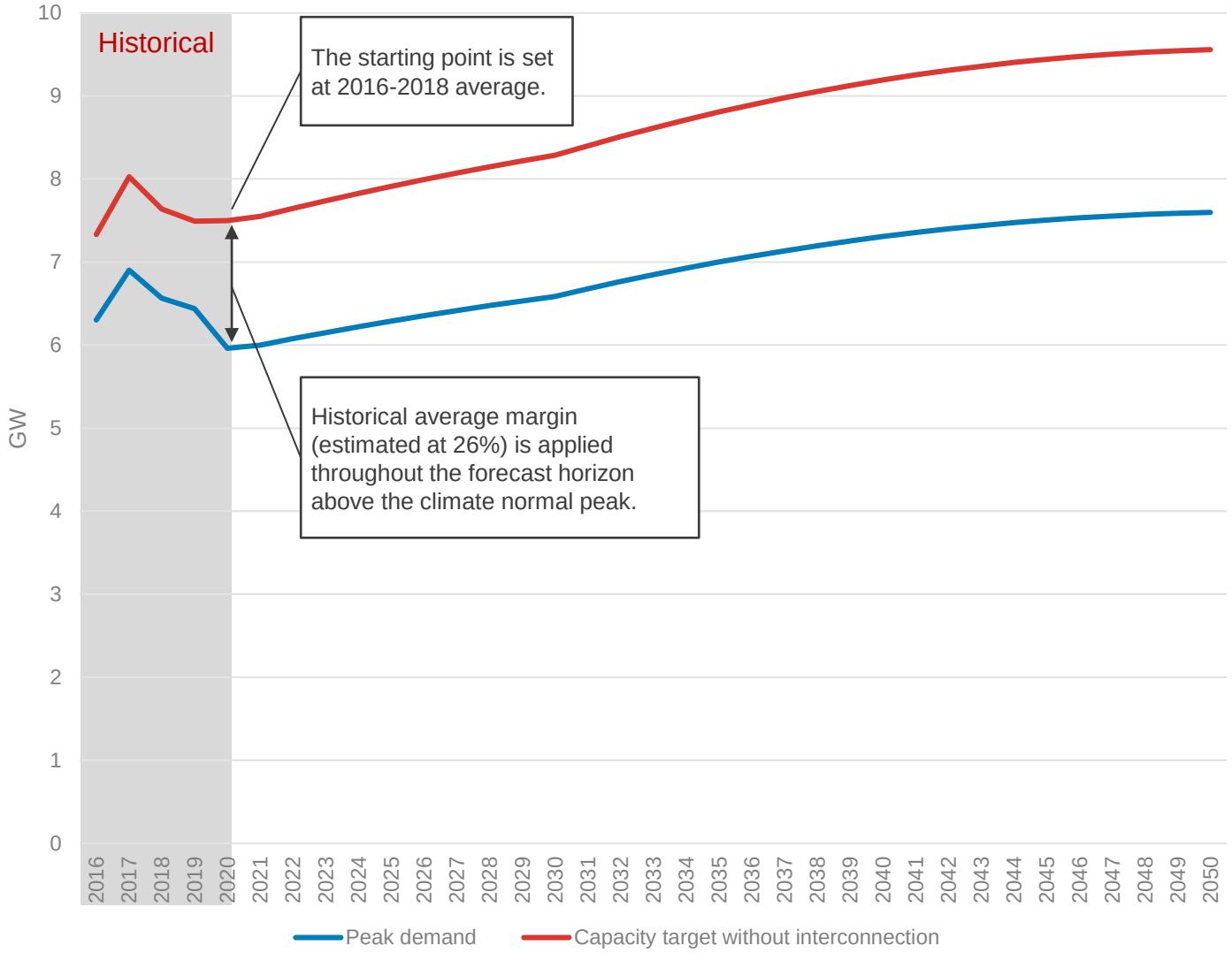
Benchmark of final electricity consumption (net) forecast in Bulgaria



Source: Total demand aligned with the Bulgarian Energy Strategy and sectorial demand from Compass Lexecon Analysis and AmCham Energy and Mineral Resources Committee inputs

To ensure security of supply, the modelling considers a minimum capacity margin to be maintained throughout the horizon, set at historic average level

Net capacity target (MW)

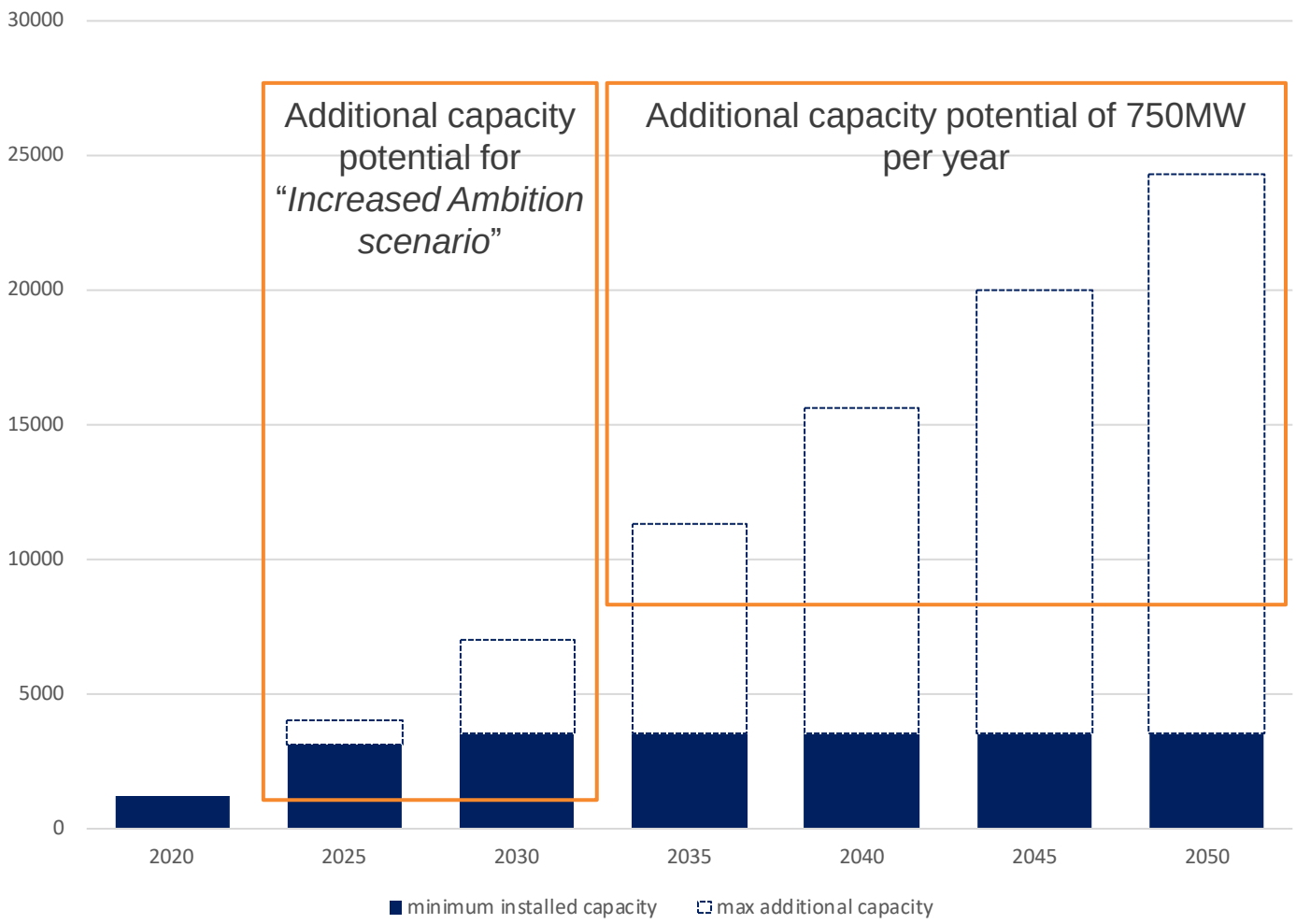


- To ensure security of supply, the modelling considers a minimum capacity margin to be maintained throughout the horizon set at historic average level.
- The capacity margin is assessed to equate 26% on top of climate normal peak demand. This corresponds to maintaining system services requirements and a buffer for demand outturns to cover extreme peak demand on top of observed peak demand.
- This margin also reflects the coincidence of peaks across the regional power markets in a 'deficit capacity' region, thus implying that Bulgaria can only rely to a limited extent on imports at time of scarcity.

Source: AmCham Energy and Mineral Resources Committee inputs and Compass Lexecon analysis

Solar PV: Beyond NECP targets, the modelling assumes a maximum potential of 7GW in 2030 and max buildout of 750MW per year thereafter

Solar PV – minimum capacity built and potential (MW)

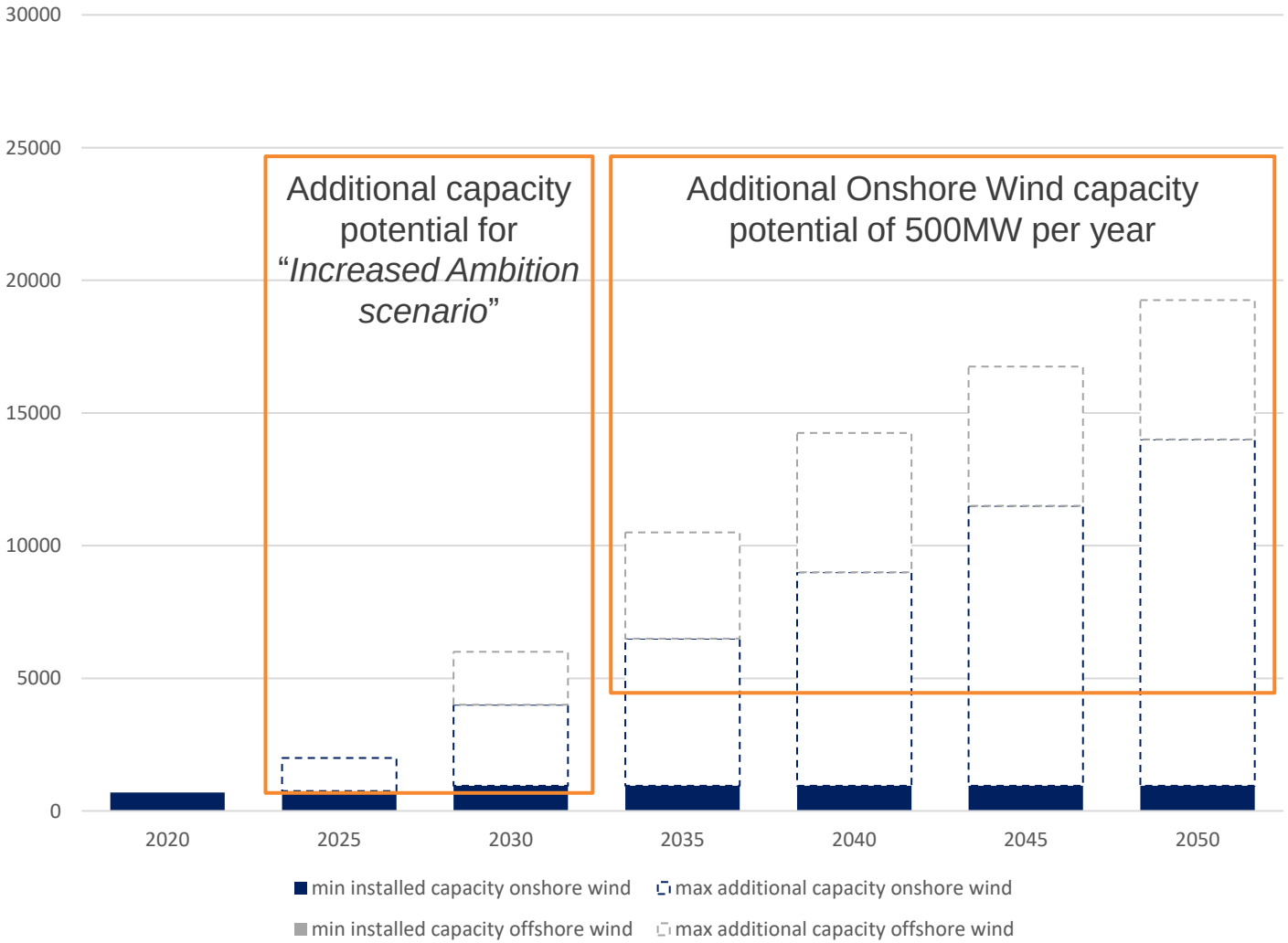


- Solar PV installed capacity is optimised from 2025 onwards, **given a minimum installed capacity reaching the NECP target by 2030**, and minimum rooftop PV increase to 2050.
- While in the "*2020 Commitment scenario*", no additional capacity potential is assumed before 2030, in the "*EU Increased Ambition scenario*", **additional capacity potential is assumed to be at 3500MW in 2030**, reflecting the additional supply chain capability to deliver new capacities beyond NECP targets.
- Beyond 2030, solar capacity potential is modelled assuming **a maximum additional capacity of 750MW per year** after 2030 for a total potential of below 25GW by 2050. This captures the potential future supply chain capability to deliver steady new capacities.

Source: AmCham Energy and Mineral Resources Committee inputs and Compass Lexecon analysis

Wind: Beyond NECP targets, the modelling assumes an onshore potential of 4GW in 2030 and c15GW by 2050 and an Offshore potential of c5GW by 2050

Wind – minimum capacity built and potential (MW)

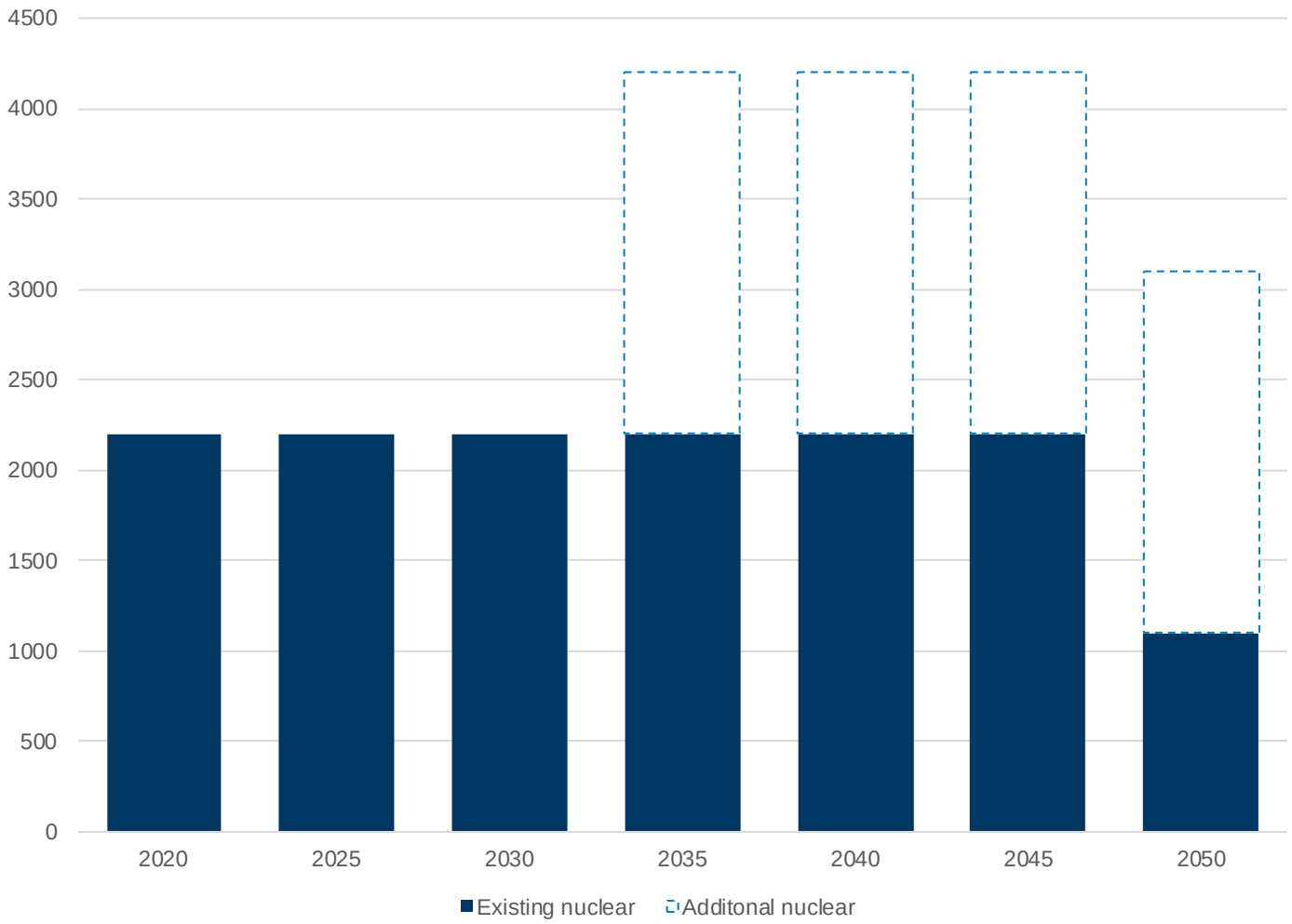


- Wind installed capacity is optimised from 2025 onwards, **given a minimum installed capacity reaching the NECP target by 2030**.
- While in the "*2020 Commitment scenario*", no additional capacity potential is assumed before 2030, in the "*EU Increased Ambition scenario*", **additional capacity potential is assumed to be at 3050MW in 2030**, reflecting the additional supply chain capability to deliver new capacities beyond NECP targets.
- Beyond 2030, onshore wind capacity potential is modelled assuming **a maximum additional capacity of 500MW per year** after 2030 for a total potential of below 15GW by 2050. This captures the potential future supply chain capability to deliver steady new capacities.
- Offshore wind capacity can reach a total installed capacity of up to 5GW.

Source: AmCham Energy and Mineral Resources Committee inputs and Compass Lexecon analysis

Nuclear: Beyond existing nuclear units, the modelling allows for the potential buildout of up to 2GW of new nuclear capacity

Nuclear capacity outlook (MW)

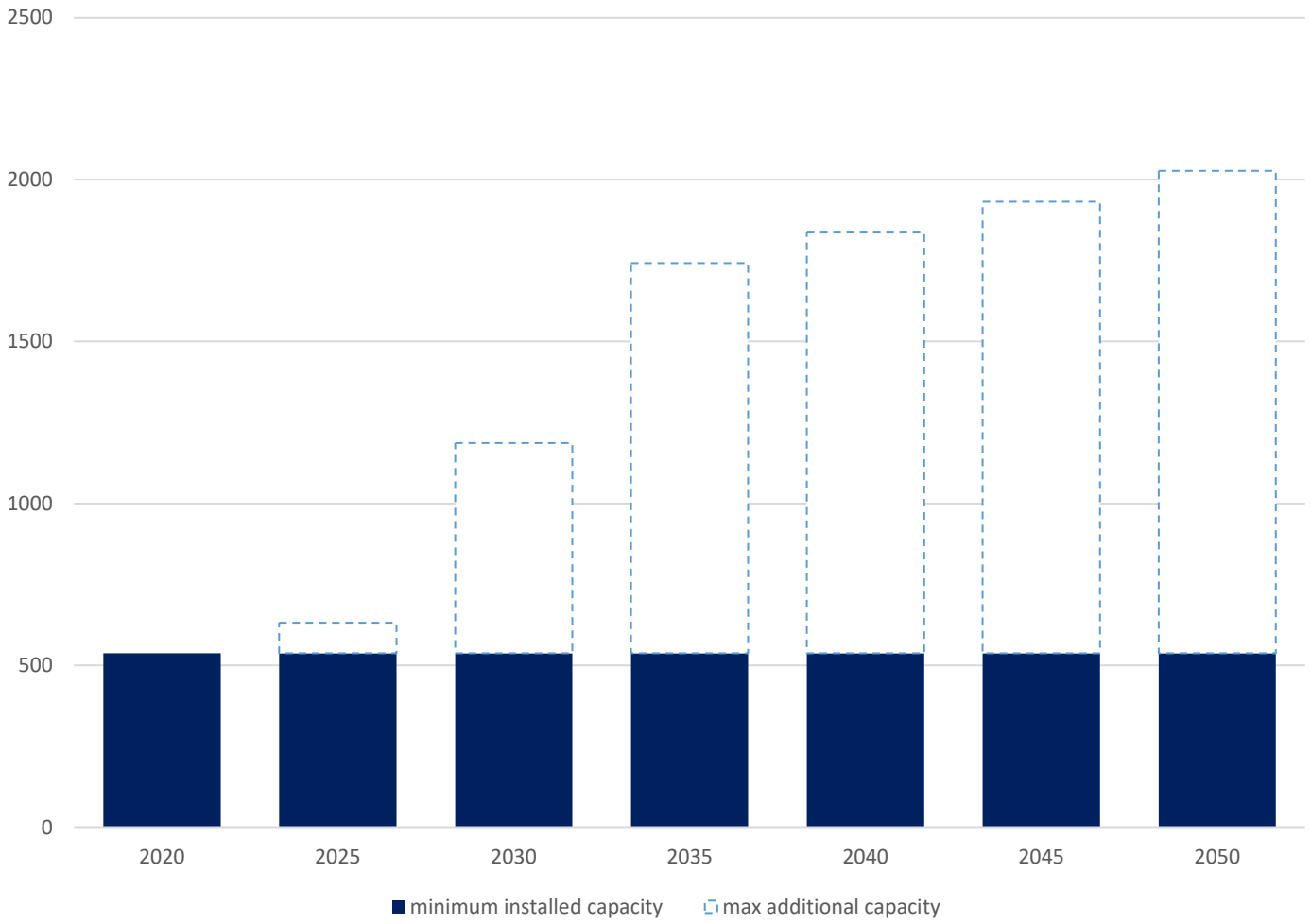


- **Existing nuclear units** assumed to be extended to 60 years:
  - Kozloduy 5 (1100MW) would be decommisionned in 2047
  - Kozloduy 6 (1100MW) would be decommisionned after 2050
- **New nuclear** is modelled endogenously after 2030 for up to 2GW assuming an investment cost projection based on Nuclear III generation including economies of scale of the EU reference 2020 Technology pathways.
  - We assume a 25% cost reduction from current investment cost estimates.

Source: AmCham Energy and Mineral Resources Committee inputs

Hydropower: In addition to existing run-of-river capacity, the model optimises new capacity of up to 1.5 GW by 2050 and Pumped Storage expansion

ROR capacity outlook (MW)

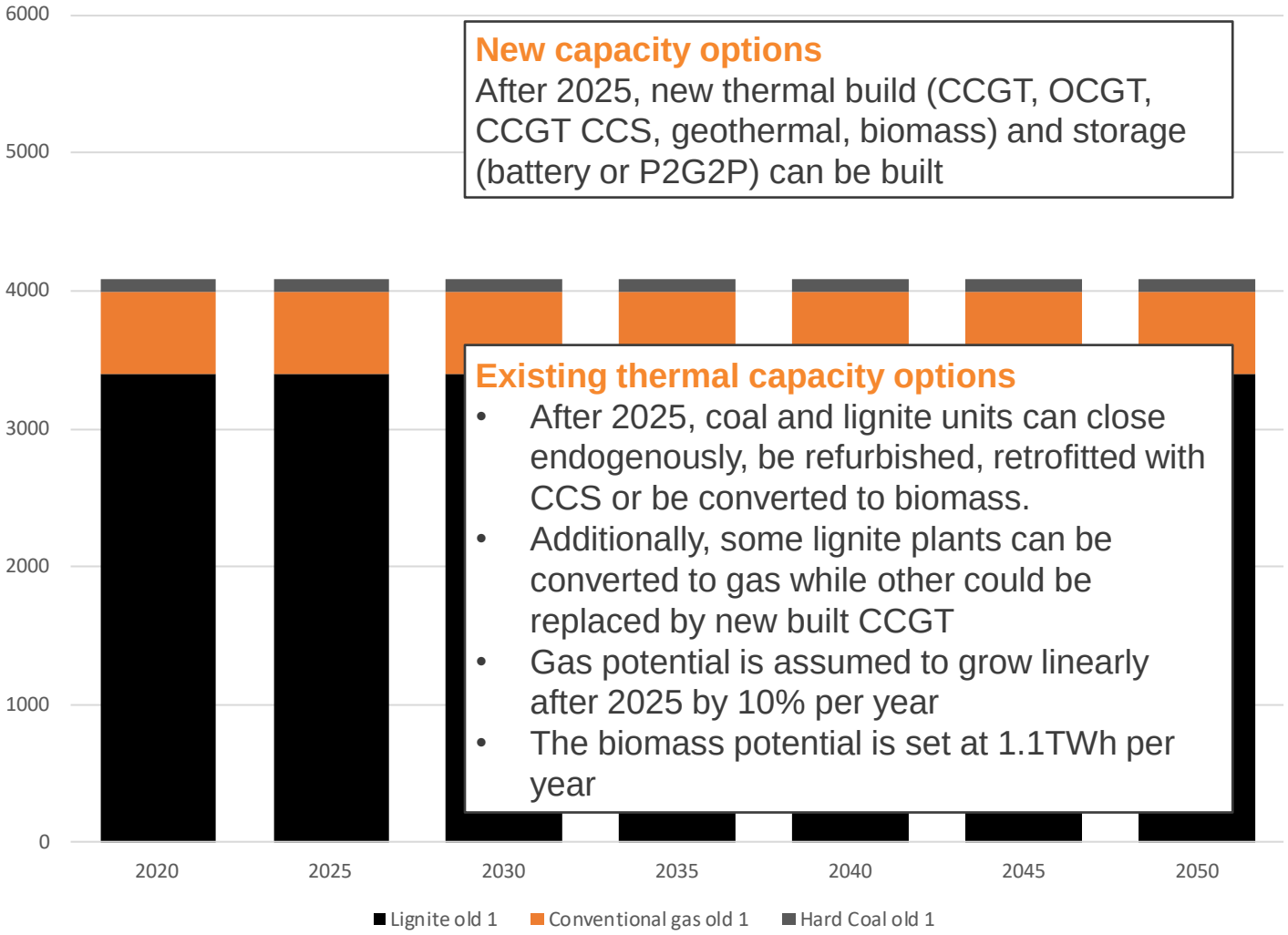


- **Existing run-of-river currently stands at c. 500MW**
- **New run-of-river capacity** is modelled endogenously after 2025 for up to 1.5GW additional run-of-river capacity by 2050.
- **Pumped storage energy storage capacity expansion** (from 8 to 24 hours) is also included in the modelling and **appears to be a low regret option** developed across the different scenarios and sensitivities from 2030 onwards.

Source: AmCham Energy and Mineral Resources Committee inputs

The existing thermal fleet evolution and new capacity buildout are optimised by the model after 2025 in order to ensure security of supply

Thermal capacity outlook (MW)



- **Existing thermal capacities** are initially set based on existing units but then are optimised by the model through:
  - Decommissioning existing plants
  - Refurbishing existing plants
  - Retrofitting CCS (apart from Bobov Dol units)
  - Converting existing plants
- **New thermal build and storage capacities** are endogenously determined by the model under the set of predefined constraints including the gas potential increase of 10% per year from a starting potential of c3-3.5GW and the biomass potential of 1.1TWh per year.
- **Commodity price assumptions** used are based on the EU Reference 2020 scenario and EU MIX scenario (see annex).

Source: AmCham Energy and Mineral Resources Committee inputs and Compass Lexecon analysis
Notes: P2G2P corresponds to the hydrogen used for power system balancing.

2.2 - 2020 Commitment scenario results

The "*2020 Commitment scenario*" is based on 2020 NECP and the Energy Strategy and acts as a counterfactual scenario for the study

The "***2020 Commitment scenario***" ('2020 CS') is based on 2020 NECP and the Bulgarian Energy Strategy .

- This scenario uses commodity prices projections including EU ETS price projections and technology cost assumptions of the EU 2020 Reference scenario completed with Bulgarian specific inputs from AmCham Energy and Mineral Resources Committee and reflects the generation mix evolution to meet the energy sector 40% CO_2 emissions reduction by 2030, implied by the overall 49% CO_2 emissions reduction compared to 1990.
- It is aimed to act as **a counterfactual scenario** to allow a comparison of the other scenarios involving potential further actions by Bulgaria towards the low carbon transition.

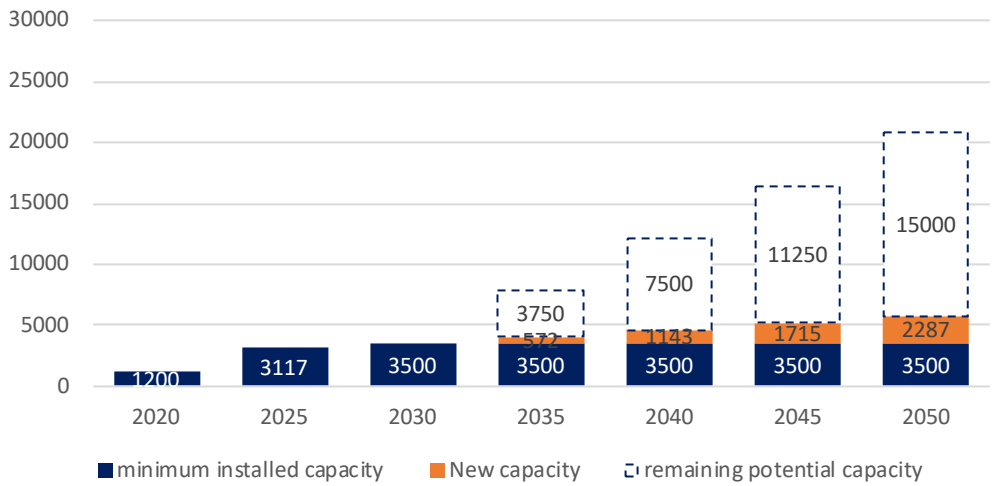
A 2020 Commitment scenario

- 2020 CS -

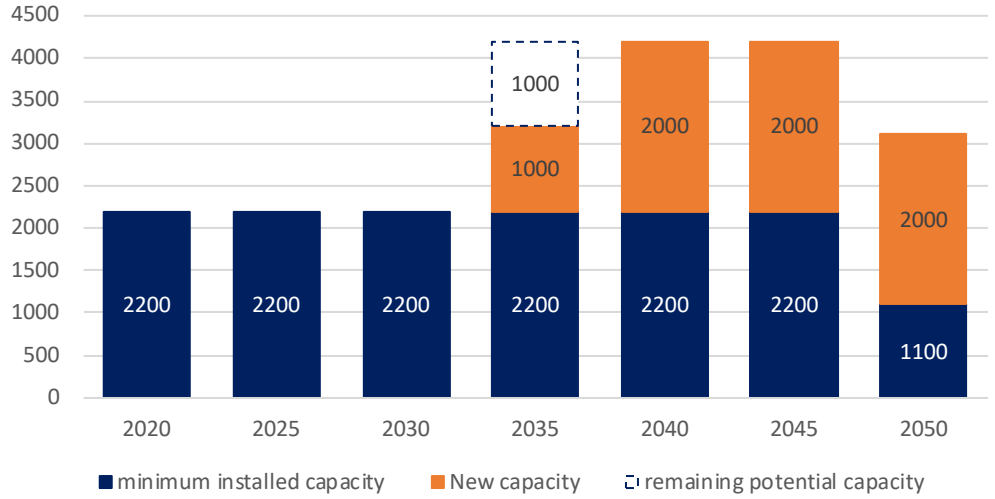
- **BG Energy Strategy** capacity and generation projections up until 2035, extended to 2050 with **cost-efficient development** of generation capacity with limited technical constraints
- **BG NECP target**: Reduction by 49% of emissions by 2030 compared to 1990 and 27% RES target in 2030
- **No further emission reduction target by 2050** apart from ETS allowances reduction (~300MtCO_2 from EU power sector in 2050)
- **Commodity and EU ETS price** outlook as per EU Reference 2020

In line with the 2020 Energy Strategy, lignite then nuclear power plants remain prominent in the mix, despite an increase in RES capacity to 2050

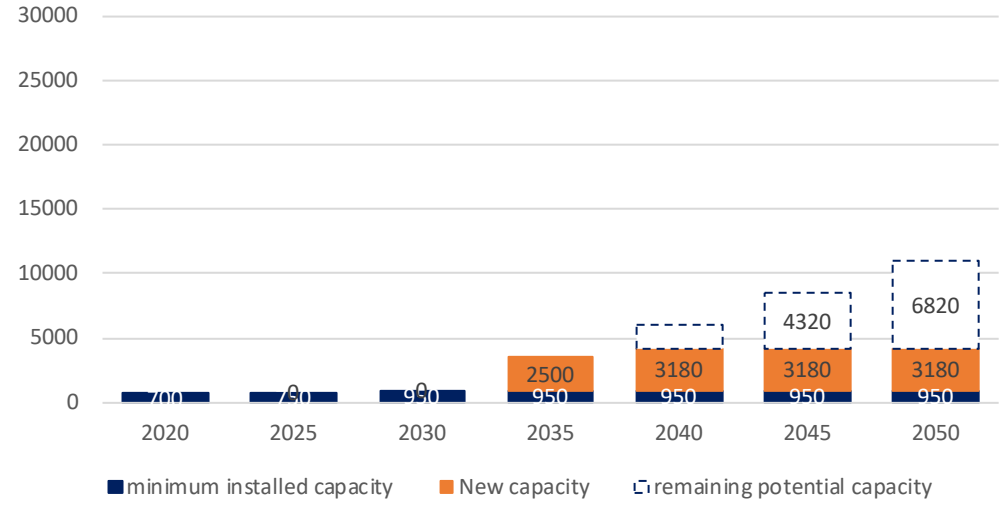
Solar PV – min cap. built, newbuild and remaining potential (MW)



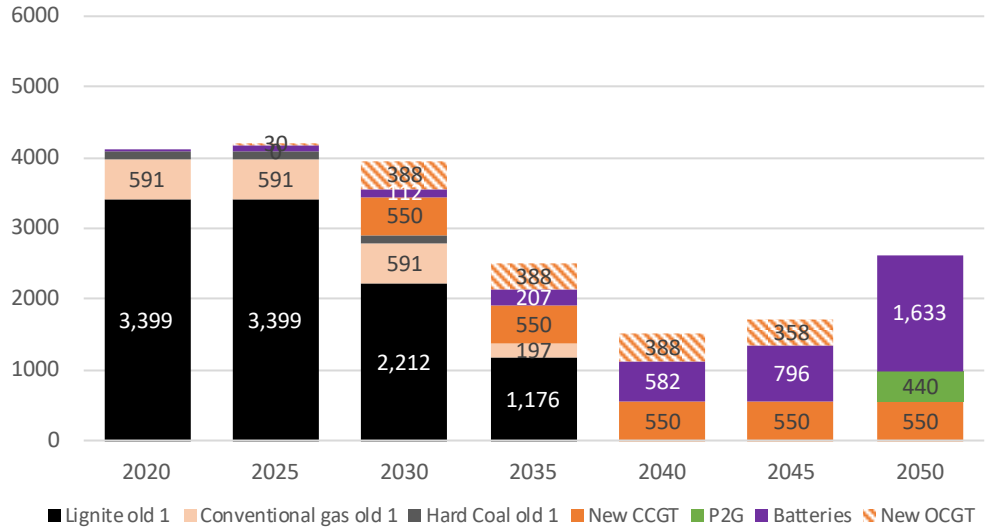
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



Thermal capacity outlook (MW)

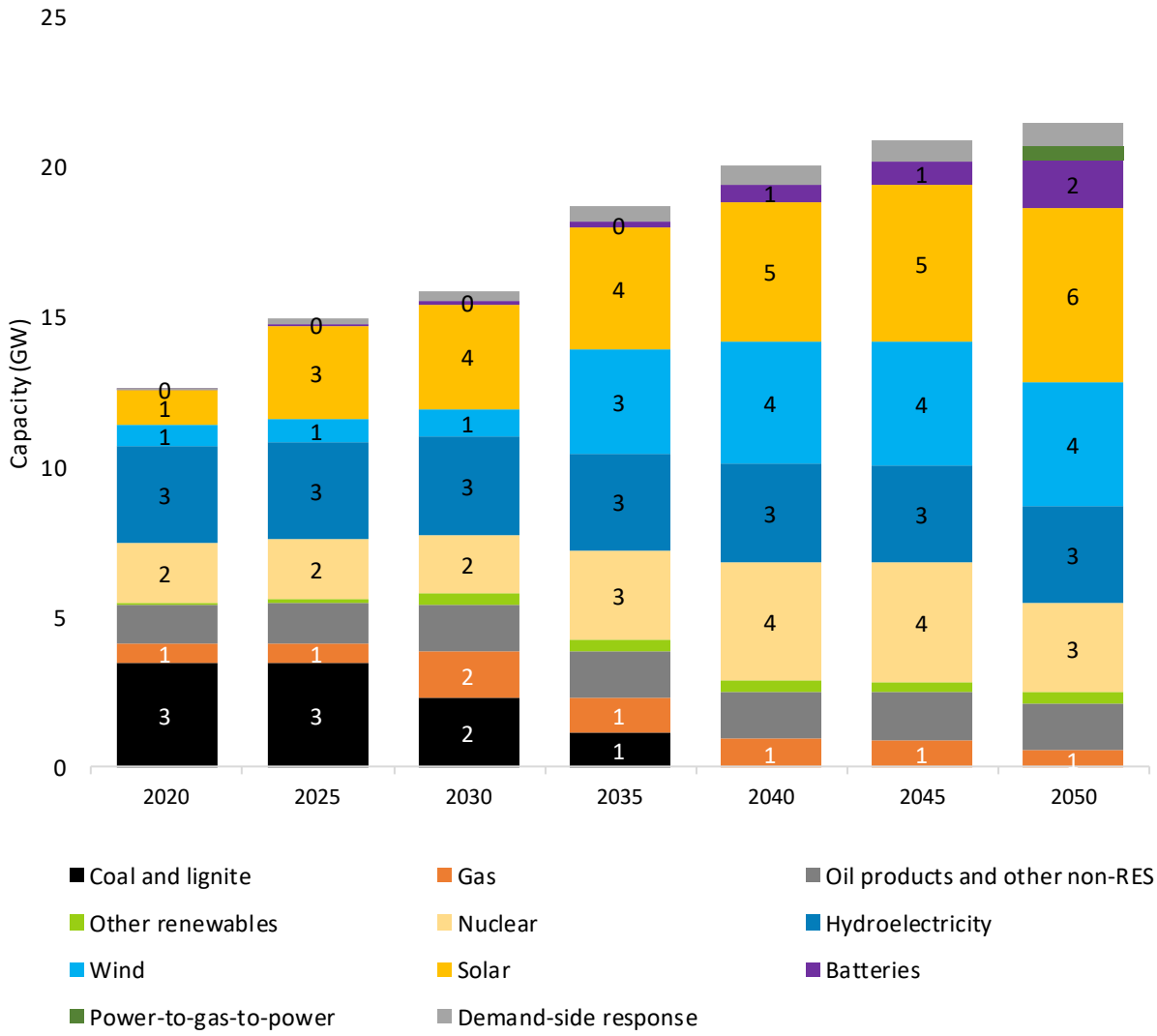


Source: Compass Lexecon

Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

Bulgaria transitions away from lignite in the mid 2030s, and increasingly relies on low carbon capacities throughout the forecast

Installed capacity (GW)

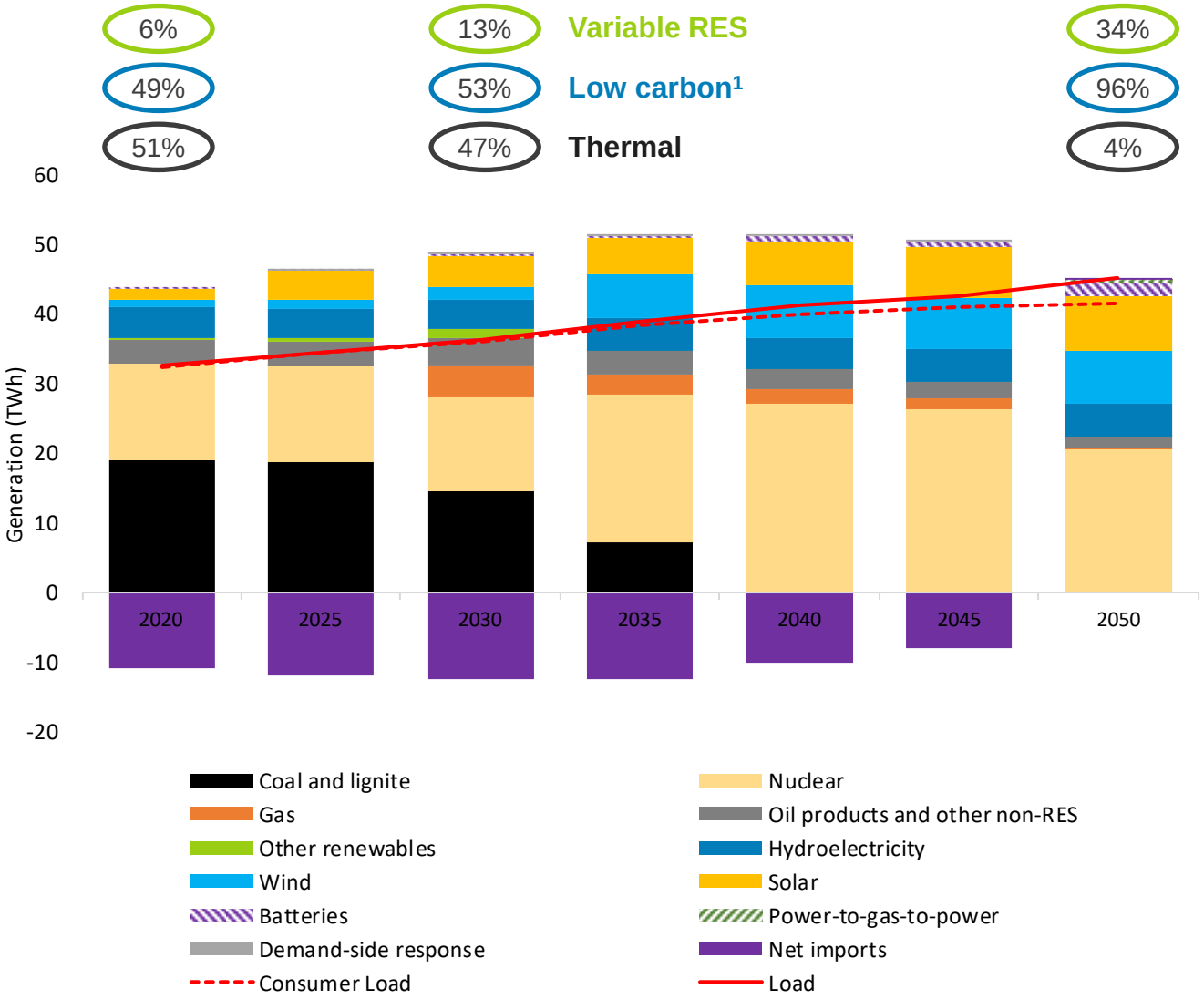


- Lignite plants are gradually replaced from 2030 onwards by new gas capacity which allows to ensure security of supply in the medium term.
- From 2035 onwards new nuclear reactors come online for a total capacity of 2 GW, providing both low carbon electricity and ensuring security of supply.
- Overall, installed capacity increases by 9 GW by 2050 relative to today. This increase is primarily driven by the growth of renewables, with onshore wind and solar capacity reaching 4.1 GW and 5.8 GW respectively.
- The growth of renewables is also accompanied with an increase in battery capacity, with c.1.6GW installed by 2050, as well as DSR and P2G2P.

Source: Compass Lexecon

Despite the slow change in the short-term, the *2020 CS* sees a strong growth of low carbon generation to 2050, with lignite gradually phasing out by 2035

Generation (TWh)

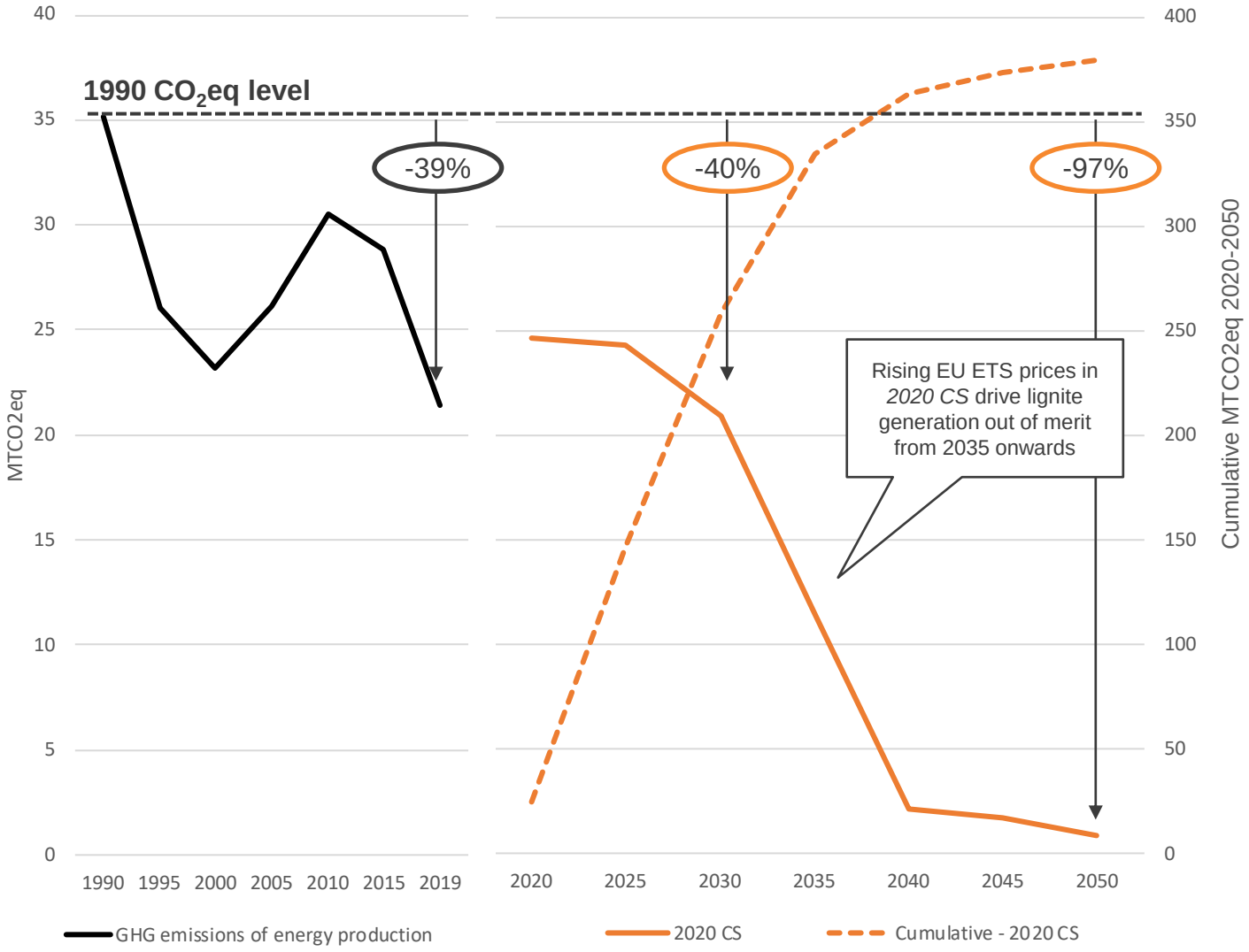


- Bulgaria still strongly relies on lignite generation in the 2020s, before switching to gas in the 2030s, and to nuclear and renewables in the 2040s.
- Overall, the Bulgarian export balance remains positive throughout most of the forecast horizon, before reaching equilibrium by 2050.
- Over the forecast horizon, solar generation quintuples and onshore wind generation sextuples bringing the Variable RES generation share from 6% in 2020 to 34% in 2050.
- Combined with nuclear generation, Low carbon generation share nearly doubles from 49% in 2020 to 96% in 2050

Source: Compass Lexecon
Note: 1. Includes nuclear, hydro, variable RES, storage and DSR

In line with the Energy Strategy, emissions drop by 40% in the energy sector by 2030, before further decreasing close to full decarbonisation by 2050

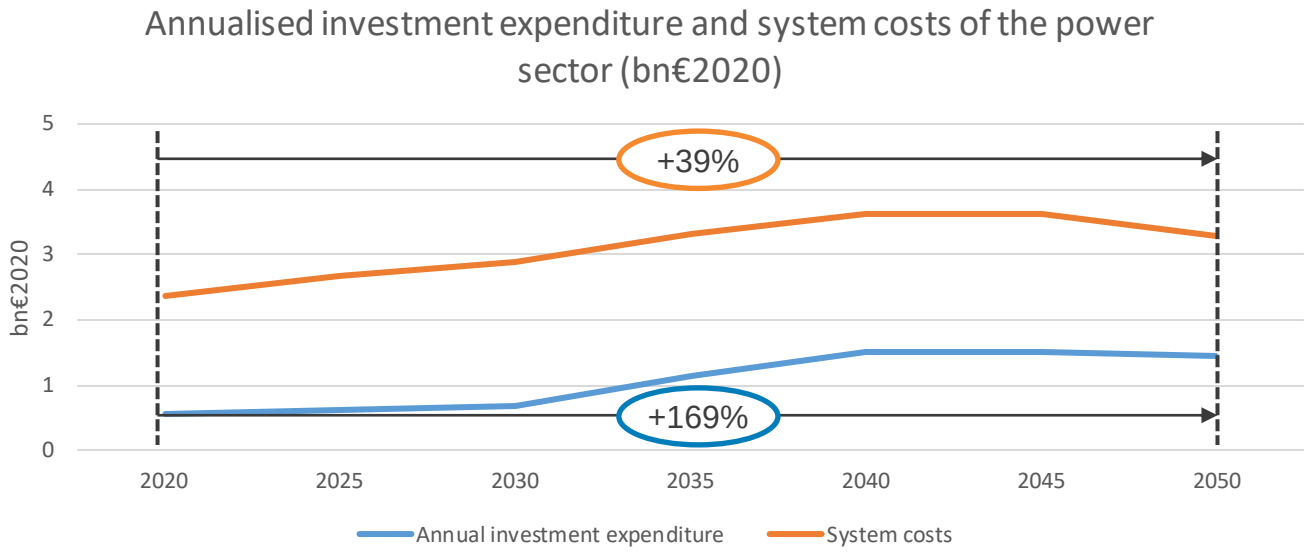
GHG emissions of the energy sector

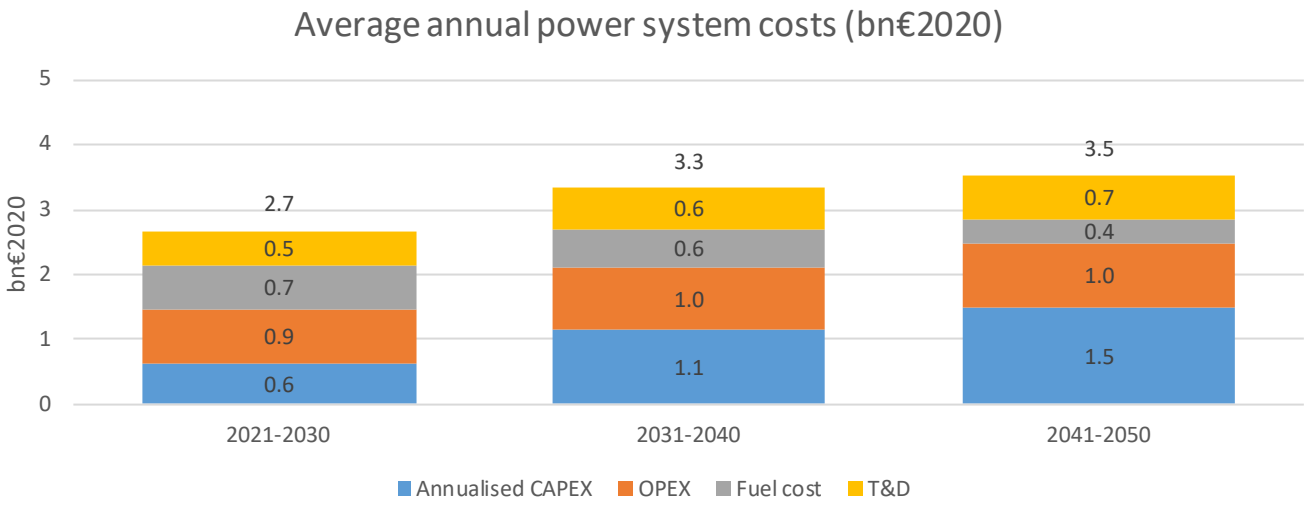


- The 49% NECP 2020 CO_2 emission reduction target translates into c.40% emission reduction for the energy sector relative to 1990, or the equivalent of c.21MtCO_2eq in 2030.
- Given that CO_2 emissions from the energy sector already dropped by 39% over the 1990-2019 period, additional efforts necessary to reach the NECP target are rather limited.
- Thus in *2020 CS*, the bulk of emission reduction occurs after 2030, when lignite production drops materially.
- With the increasing penetration of low carbon production into the Bulgarian power mix and the reduction of lignite generation, emissions drop significantly by 2050 reaching 97% reduction.

Source: Compass Lexecon
Note: Historical emissions from Bulgaria's national inventory report 2021.

The power sector becomes increasingly CAPEX intensive over time with the development of low carbon generation





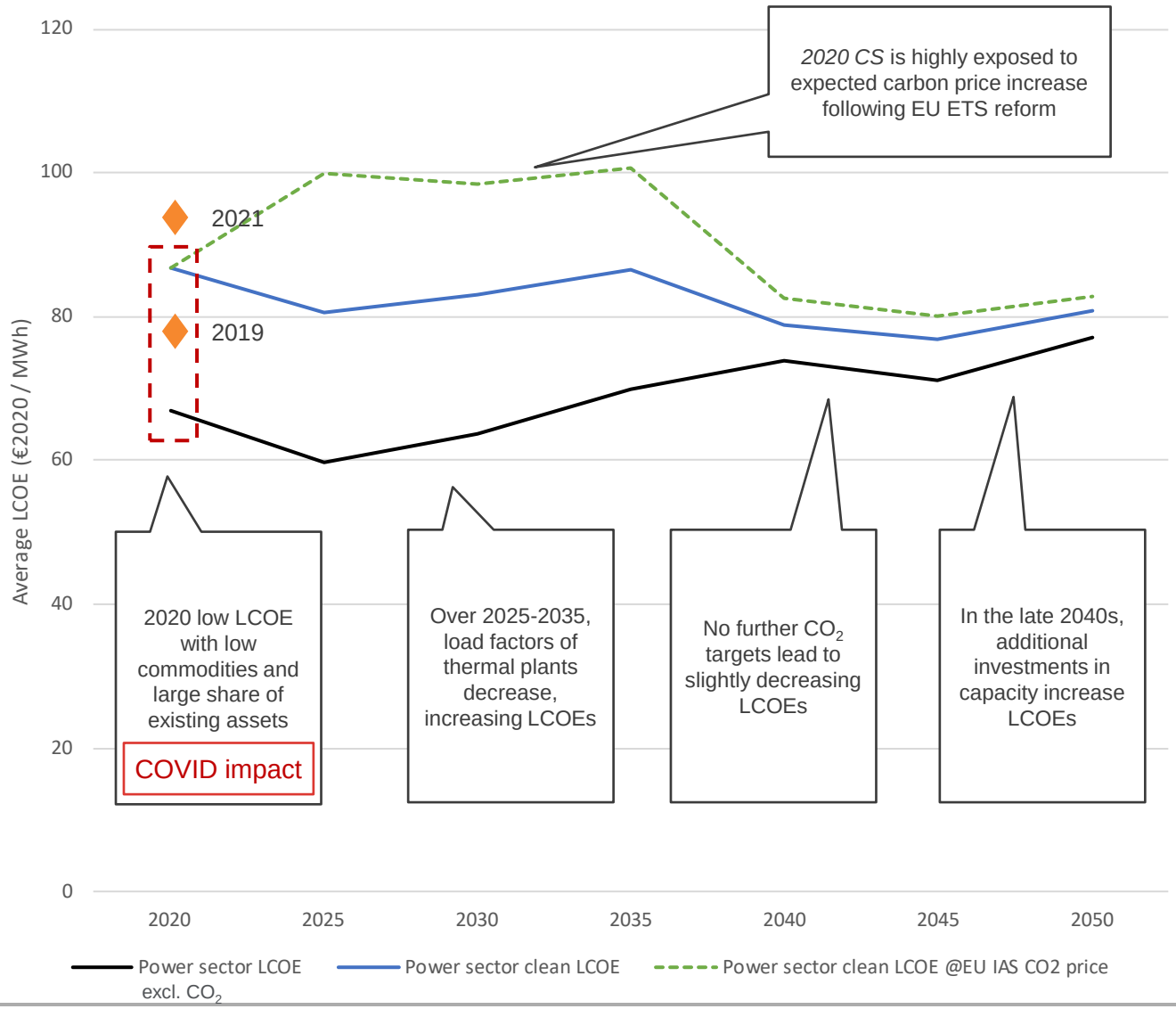
- The power sector becomes increasingly CAPEX intensive over time.
  - Investments in low carbon capacities are organically increasing compared to today's levels to decarbonise the Bulgarian power system.
- Power system costs increase by c.40% in *2020 CS* between 2020 and 2050. This is primarily driven by the capital cost of new installations, which increases by c.170% between 2020 and 2050, partially offset by the reduction of fuel costs.

- Note 1: Capital expenditures are accounted for in the system costs as annuity payments. A discount of 5% is applied to compute annualised CAPEX. Power system costs do not include emission costs.
- Note 2: Power system costs include existing T&D costs as well as additional T&D costs from RES penetration and peak demand increase based on EU benchmarks. Detailed Bulgarian specific assessment of T&D costs would require separate consideration and analysis.
- Note 3: Power system costs do not include the costs associated to operating or closing lignite mines or the cost associated to the gas network.

Source: Compass Lexecon

While LCOEs increase in line with the system cost growth, clean LCOEs remain stable throughout the forecast

Average power sector LCOE



- Power sector LCOEs increase through time, as thermal plants' load factors drop and new greenfield investments are being commissioned between 2025 and 2040 to further decarbonise.
- However when looking at the clean LCOEs which include emissions costs, the contrast is quite stark: Contrary to increasing LCOEs excl. emission costs, clean LCOEs **remain relatively stable overtime**, apart from the increase in 2035 led by a still material lignite generation.

Note: Power sector LCOE corresponds to annual power system cost (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

Source: Compass Lexecon

2.3 - EU Increased Ambition scenario results

The "*EU Increased Ambition scenario*" explores the set of options to meet full decarbonisation by 2050 while being compliant with the EU "Ff55 package"

A second scenario "***EU Increased Ambition scenario***" explores the set of options to 2050 to meet full decarbonisation in 2050 while being compliant with the European "Fit for 55 package" in 2030.

- This scenario uses commodity prices and technology cost assumptions of the EU 2020 Reference scenario completed with Bulgarian specific inputs from AmCham Energy and Mineral Resources Committee. It also uses EU ETS price projections of the EU Ff55 MIX scenario, and combines a cost-efficient development of generation capacities under a set of Bulgarian technical and environmental constraints defined by AmCham Energy and Mineral Resources Committee and European CO_2 emission reduction constraint.

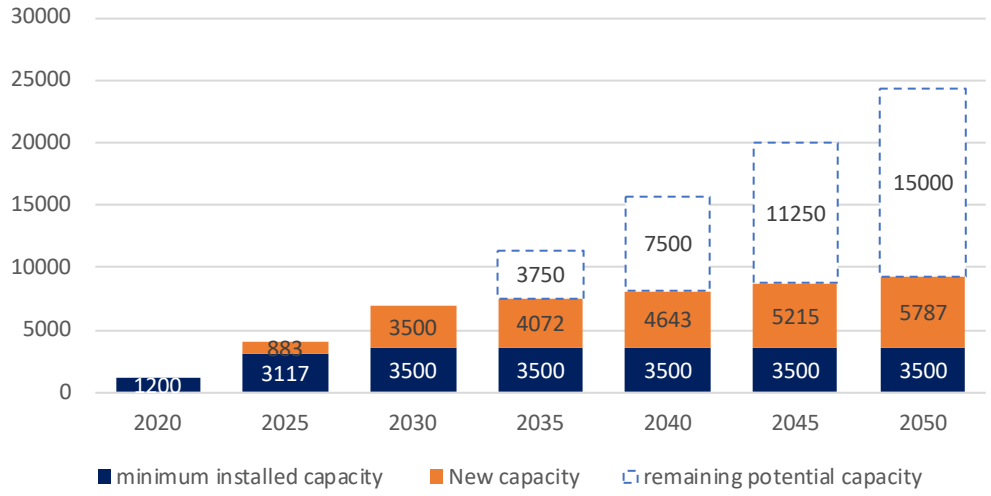
B EU Increased Ambition scenario

- EU IAS -

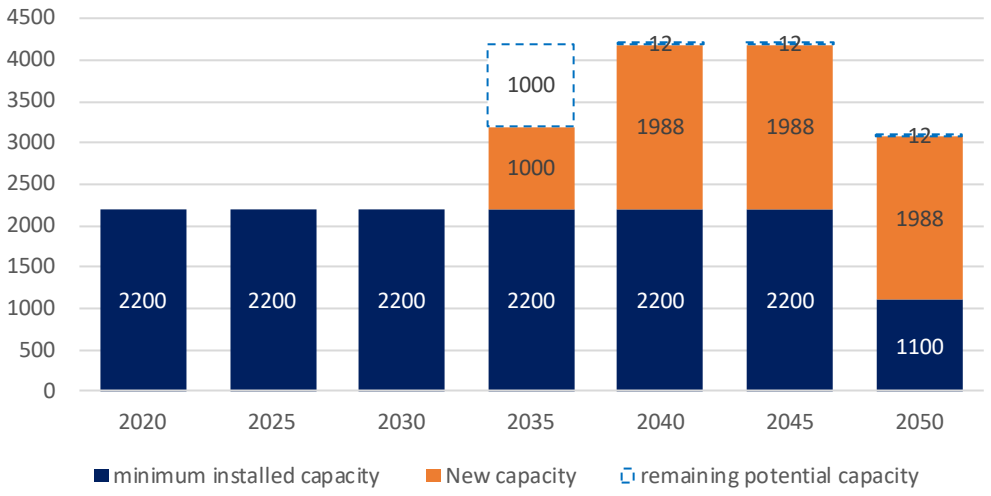
- **Cost-efficient development** of generation capacity with limited technical constraints, with additional renewable potential buildout relative to NECP target.
- **Upscaled EU target to reach 55%** of emission reduction by 2030 compared to 1990
- **Full decarbonisation for the power sector by 2050**
- **EU ETS price** in line with Ff55 impact assessment MIX scenario in 2030 and reaching 250€/tCO_2 by 2050 (lower band of EC 2050 Roadmap 2018)

EU IAS projects a transition from lignite to gas in the late 2020s to maintain security of supply, and a significant increase of low carbon capacities to 2050

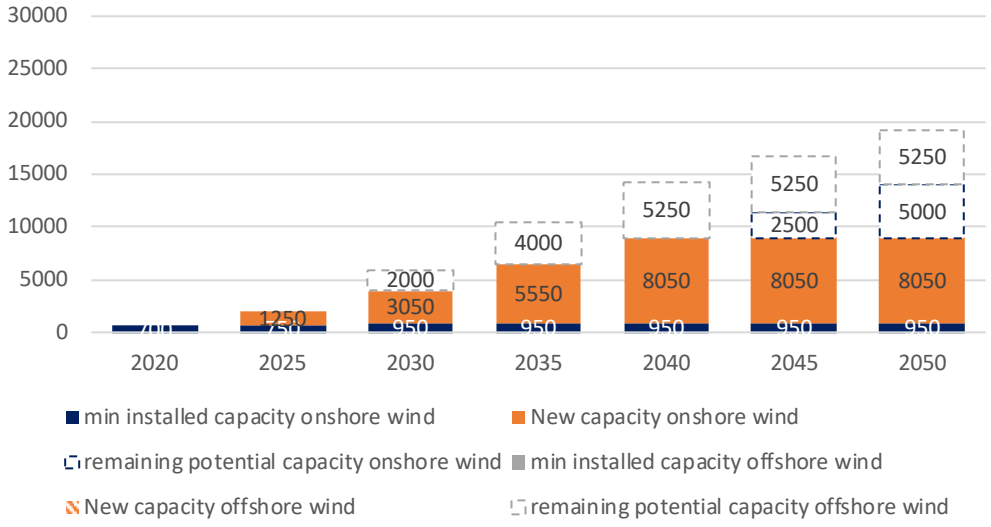
Solar PV – min cap. built, newbuild and remaining potential (MW)



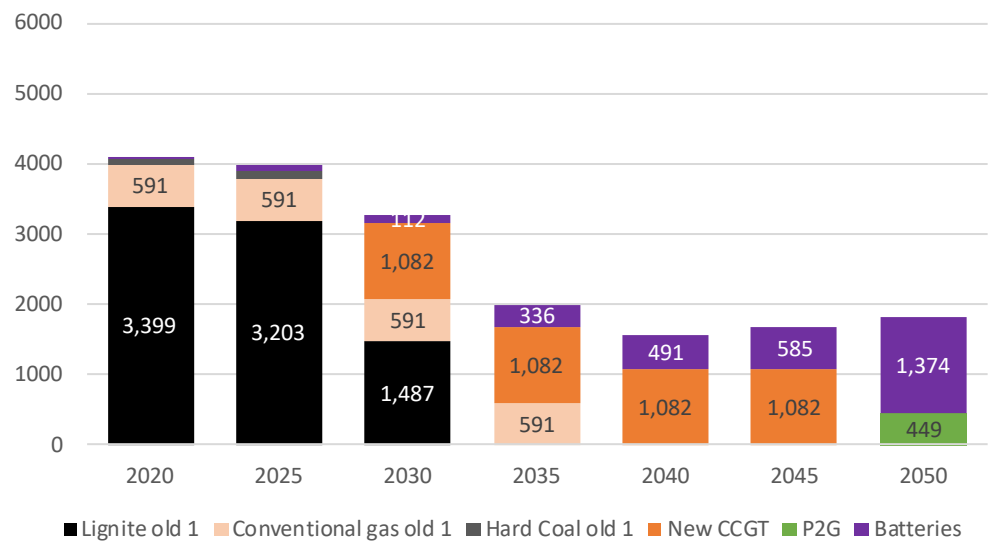
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



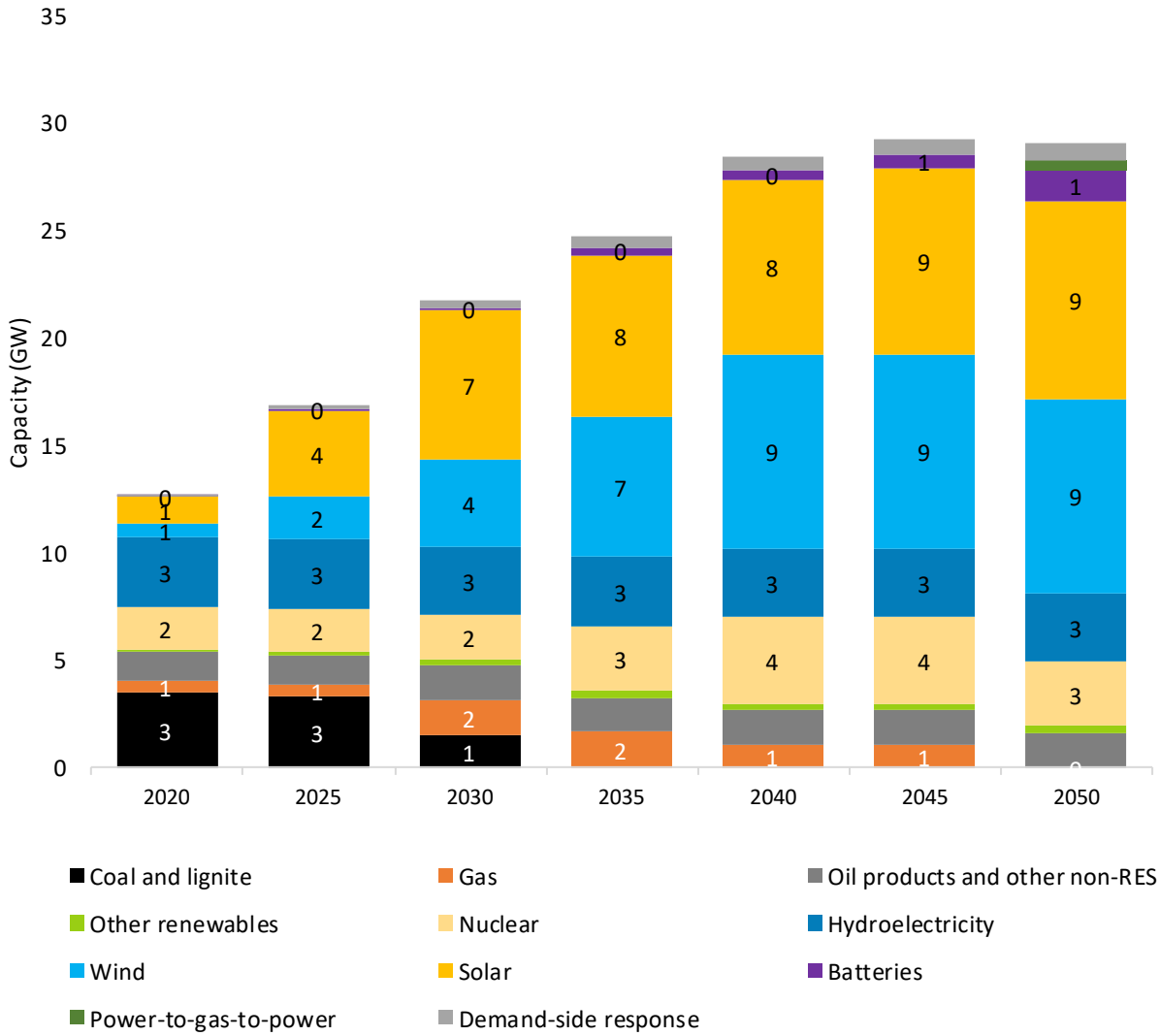
Thermal capacity outlook (MW)



Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

In *EU IAS*, Bulgaria transitions away from lignite at the beginning of the 2030s, coupled with a rapid growth of low carbon capacity from 2025 to 2050

Installed capacity (GW)

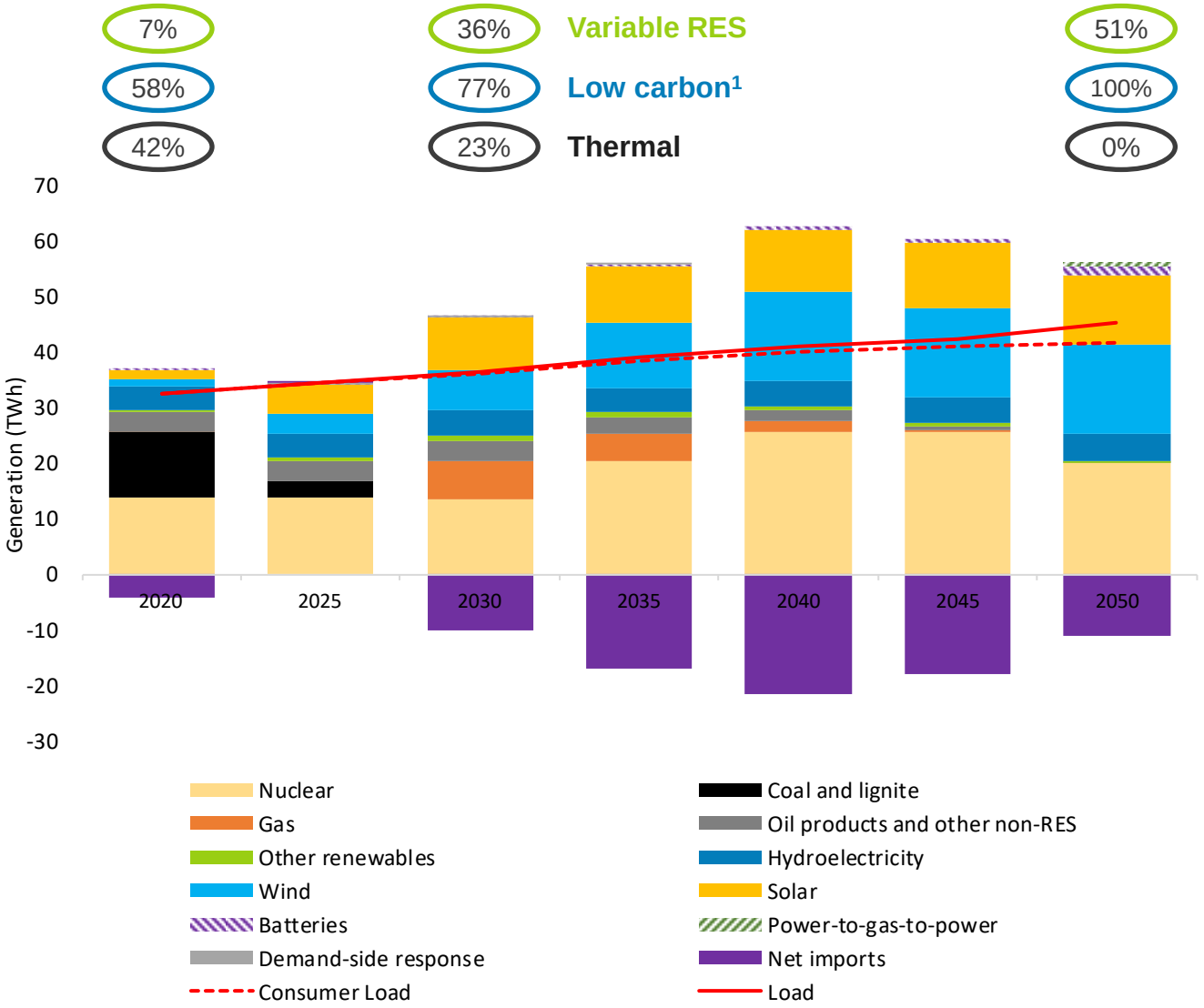


- Lignite plants are replaced from 2025 onwards by new gas capacity which allows to ensure security of supply in the medium term.
- From 2035 onwards new nuclear reactors come online for a total capacity of 2 GW, providing both low carbon electricity and ensuring security of supply.
- Overall, installed capacity increases by 16.4 GW by 2050 relative to today. This increase is primarily driven by the growth of renewables, with both onshore wind and solar reaching 9 GW of installed capacity by 2050.
- The growth of renewables is also accompanied with an increase in battery capacity, with c.1.4GW installed by 2050, as well as DSR and P2G2P.

Source: Compass Lexecon

In line with the capacity mix evolution, *EU IAS* sees a strong growth of low carbon generation, with lignite production gradually phasing out by 2030

Generation (TWh)

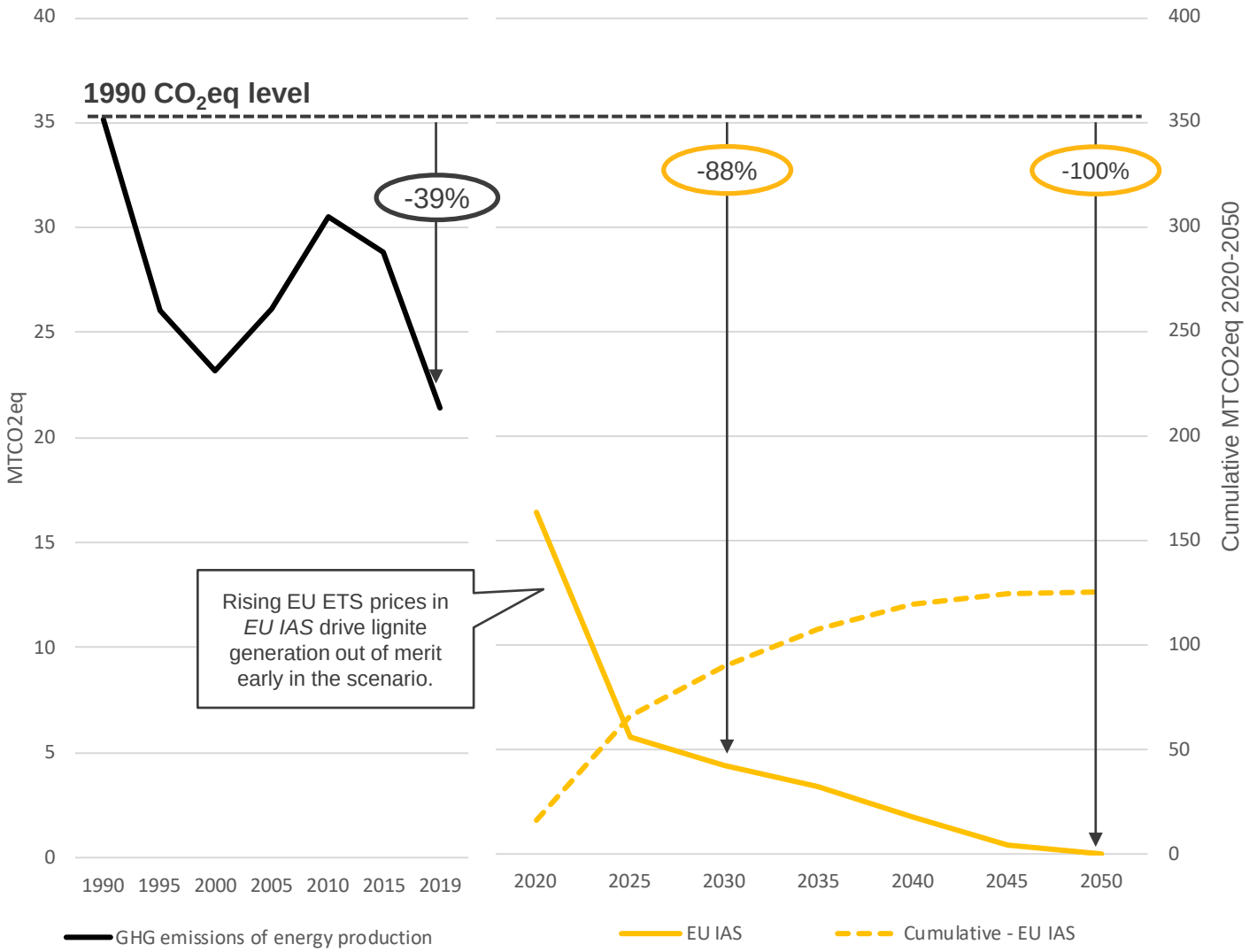


- Bulgaria still strongly relies on lignite generation up until 2025, before switching to gas in the medium term, and to nuclear and renewables in the 2040s.
- Overall, the Bulgarian export balance remains positive throughout most of the forecast horizon.
- Variable renewable generation grows substantially over the 2020-2050 period, reaching a share of 51% in the production mix by 2050.
- Combined with nuclear generation, Low carbon generation share nearly doubles from 58% in 2020 to 100% in 2050

Source: Compass Lexecon
Note: 1. Includes nuclear, hydro, variable RES, storage and DSR

With the decrease of thermal generation in the first decade, emissions drop by 88% by 2030 before further decreasing to full decarbonisation by 2050

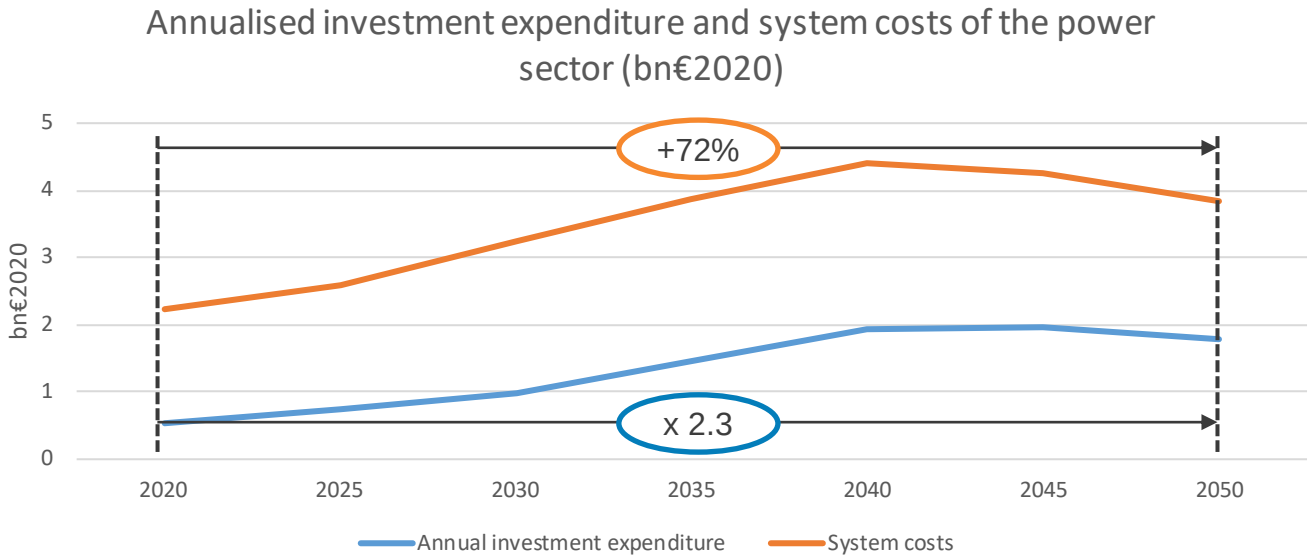
GHG emissions of the energy sector

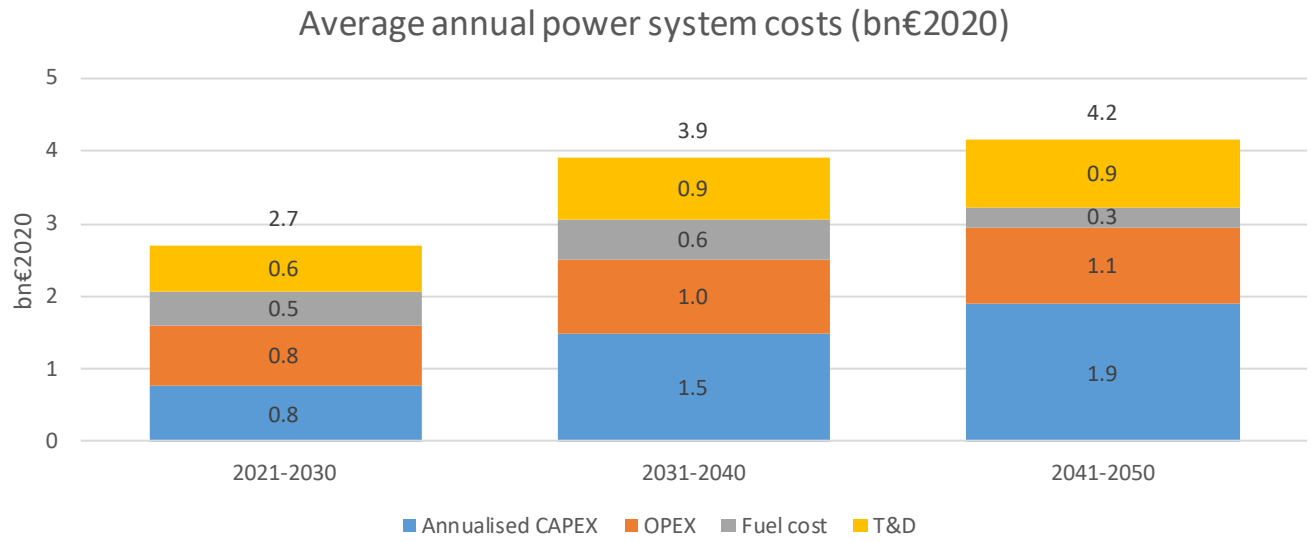


- In line with the decrease of thermal generation in the first decade, driven by the increase of carbon prices with the EU ETS Reform as part of the European "Fit for 55 package", energy sector emissions drop by 88% by 2030, which is equivalent to an overall c70% emission reduction for Bulgaria.
- Thus, in *EU IAS* the bulk of emission reduction occurs by 2025, when lignite production drops materially.
- With the increasing penetration of low carbon production into the Bulgarian power mix and the reduction of lignite generation, emissions drop significantly by 2050 reaching full decarbonisation.

Source: Compass Lexecon
Note: Historical emissions from Bulgaria's national inventory report 2021.

Power system costs increase by c75% over the forecast horizon in *EU IAS*, and annual investment expenditures are multiplied by 2.3





- The power sector becomes increasingly CAPEX intensive over time.
- Investments in low carbon capacities are organically increasing compared to today's levels to decarbonise the Bulgarian power system.

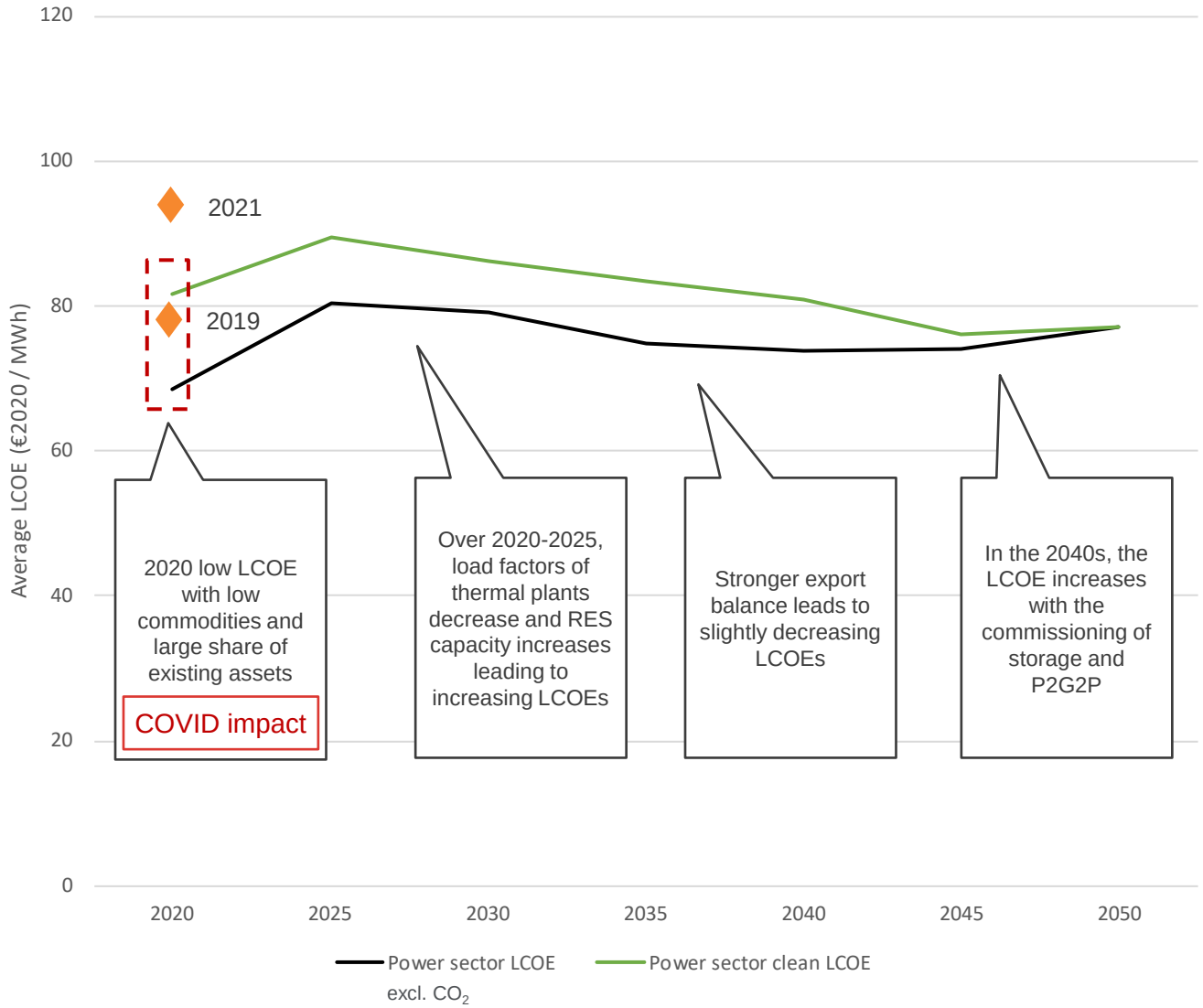
- Power system costs increase by c75% in *EU IAS* between 2020 and 2050, mainly due to the capital cost of new installations.
- Annual investments costs increase 2.3x between 2020 and 2050, partially offset by a reduction in fuel costs.

- Note 1: Capital expenditures are accounted for in the system costs as annuity payments. A discount of 5% is applied to compute annualised CAPEX. Power system costs do not include emission costs.
- Note 2: Power system costs include existing T&D costs as well as additional T&D costs from RES penetration and peak demand increase based on EU benchmarks. Detailed Bulgarian specific assessment of T&D costs would require separate consideration and analysis.
- Note 3: Power system costs do not include the costs associated to operating or closing lignite mines or the cost associated to the gas network.

Source: Compass Lexecon

While LCOEs strongly increase in the short term before stabilizing, clean LCOEs decrease overtime as decarbonisation efforts are frontloaded

Average power sector LCOE



- LCOEs increase by 2025, as thermal plants' load factors drop and new greenfield investments are necessary to decarbonise Bulgaria, before stabilizing with the increase of net export balance in the 2030s.
- However, when looking at clean LCOEs which include emissions costs, the contrast is quite stark: **Clean LCOEs continuously decrease from 2025** onwards to converge to LCOEs excl. emission cost, indicating that decarbonisation efforts are brought forward at the beginning of the horizon in *EU IAS*.
- Note: Power sector LCOE corresponds to annual power system cost (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

Source: Compass Lexecon

2.4 - Alternative Transition pathway results

The "*Alternative transition pathway*" tests the options that would minimise the costs to achieve the 2030 overall 55% emissions reduction for Bulgaria

A third scenario "***Alternative transition pathway***" tests the options that would minimise the costs to achieve the transitory 2030 overall 55% CO_2 emissions reduction for Bulgaria (and therefore would not overachieve the emission reduction target contrary to the "*EU Increased Ambition scenario*" but still going beyond the "*2020 Commitment scenario*")

- The scenario is based on the "*2020 Commitment scenario*" using commodity, EU ETS and technology price projections of the EU 2020 Reference scenario, as well as projected capacity of the 2020 Energy Strategy but allowing for additional renewables to be built. Contrary to the *2020 Commitment scenario,* the model **optimises dispatch and implicit carbon price to achieve an overall 55% CO_2 emission reduction in Bulgaria by 2030 at least cost**.
  - The approach followed is such that it allows an optimal dispatch while identifying the implicit carbon price that would allow a smooth transition – that is a carbon price that would be sufficient to induce the necessary CO_2 emission reduction to reach overall 55% CO_2 emission reduction by 2030 in Bulgaria.
- In addition, this scenario further decarbonises the power sector, reaching full decarbonisation by 2050.

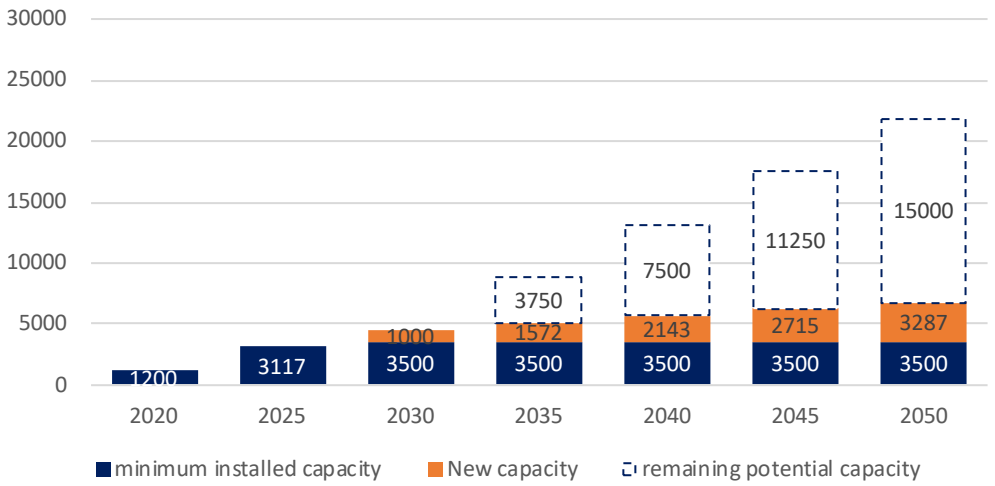
C Alternative Transition Pathway

- ATP -

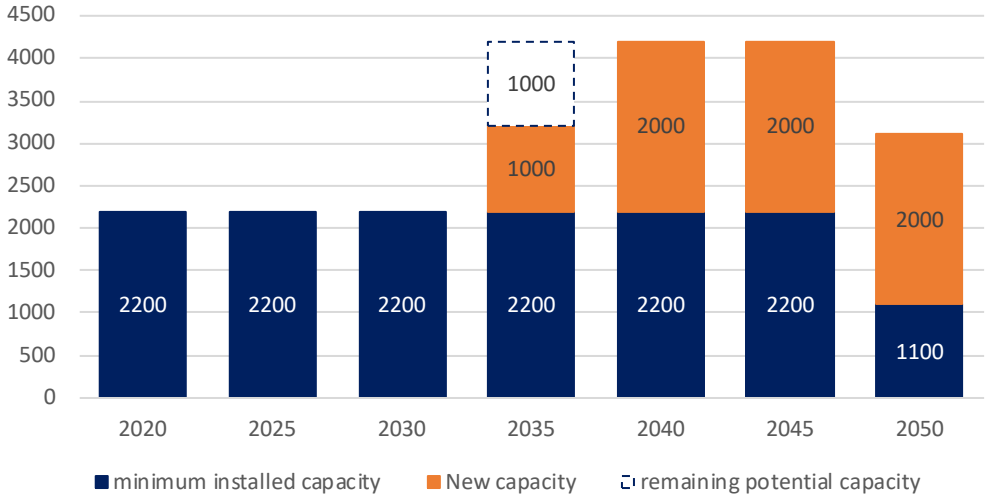
- **Based on BG Energy Strategy** capacity projections up until 2035 with additional potential RES buildout, extended to 2050 with **cost-efficient development** of generation capacity with limited technical constraints
- **Decarbonisation target**: Reduction by 55% of emissions by 2030 compared to 1990
- **Full decarbonisation by 2050 of the power sector**
- **Commodity and EU ETS price** outlook as per EU Reference 2020

ATP sees a shift from lignite to gas in the late 2020s, the buildout of 2GW of nuclear in the late 2030s, and additional RES capacity relative to *2020 CS*

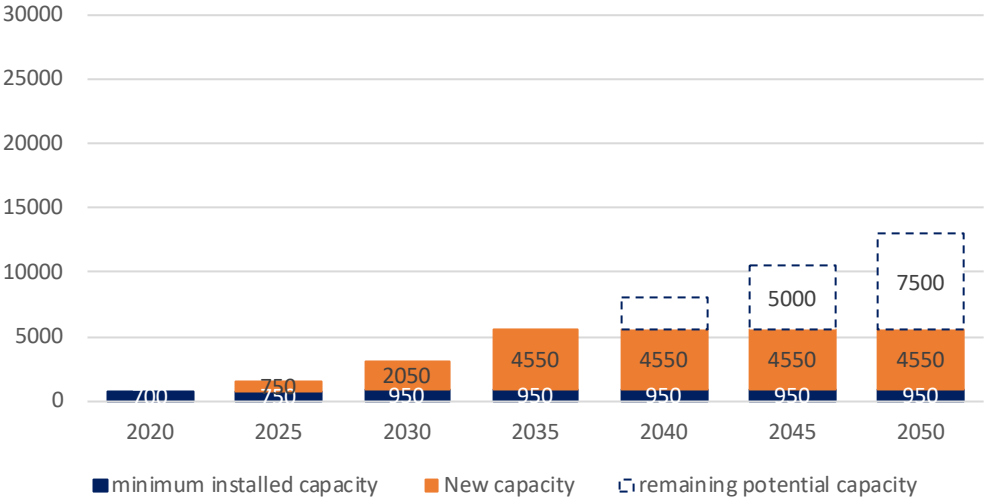
Solar PV – min cap. built, newbuild and remaining potential (MW)



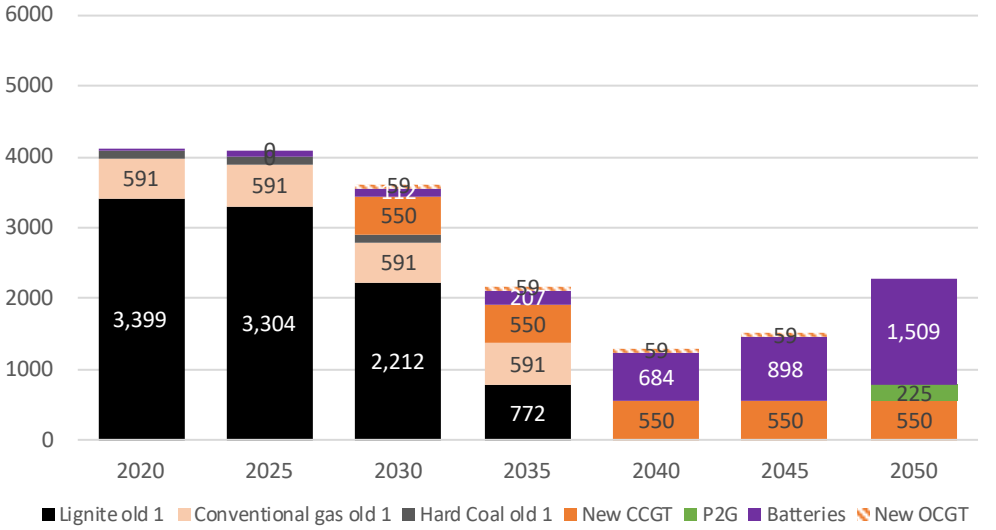
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



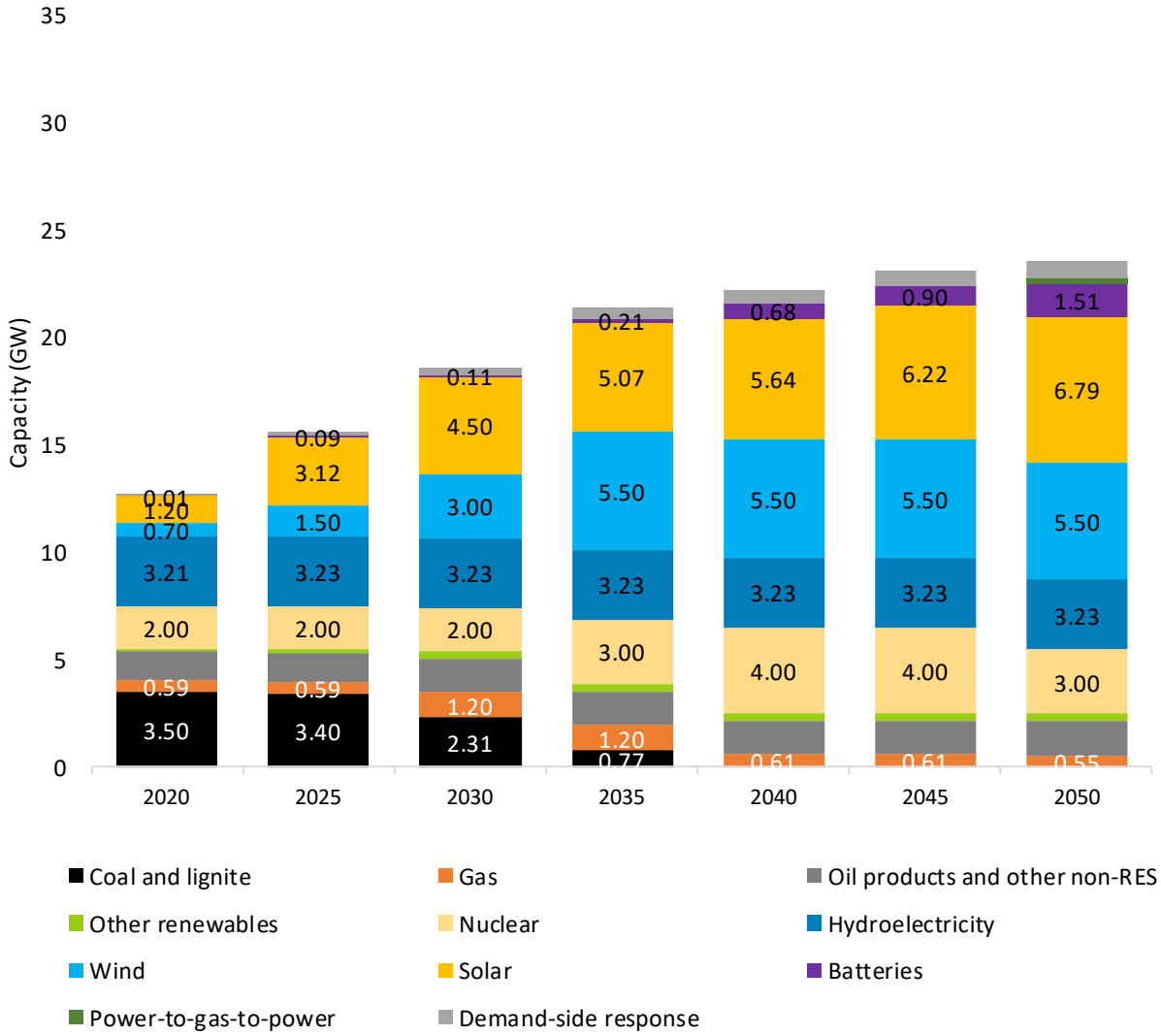
Thermal capacity outlook (MW)



Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

In *ATP*, Bulgaria transitions away from lignite in the mid 2030s, and increasingly relies on low carbon capacities throughout the forecast

Installed capacity (GW)

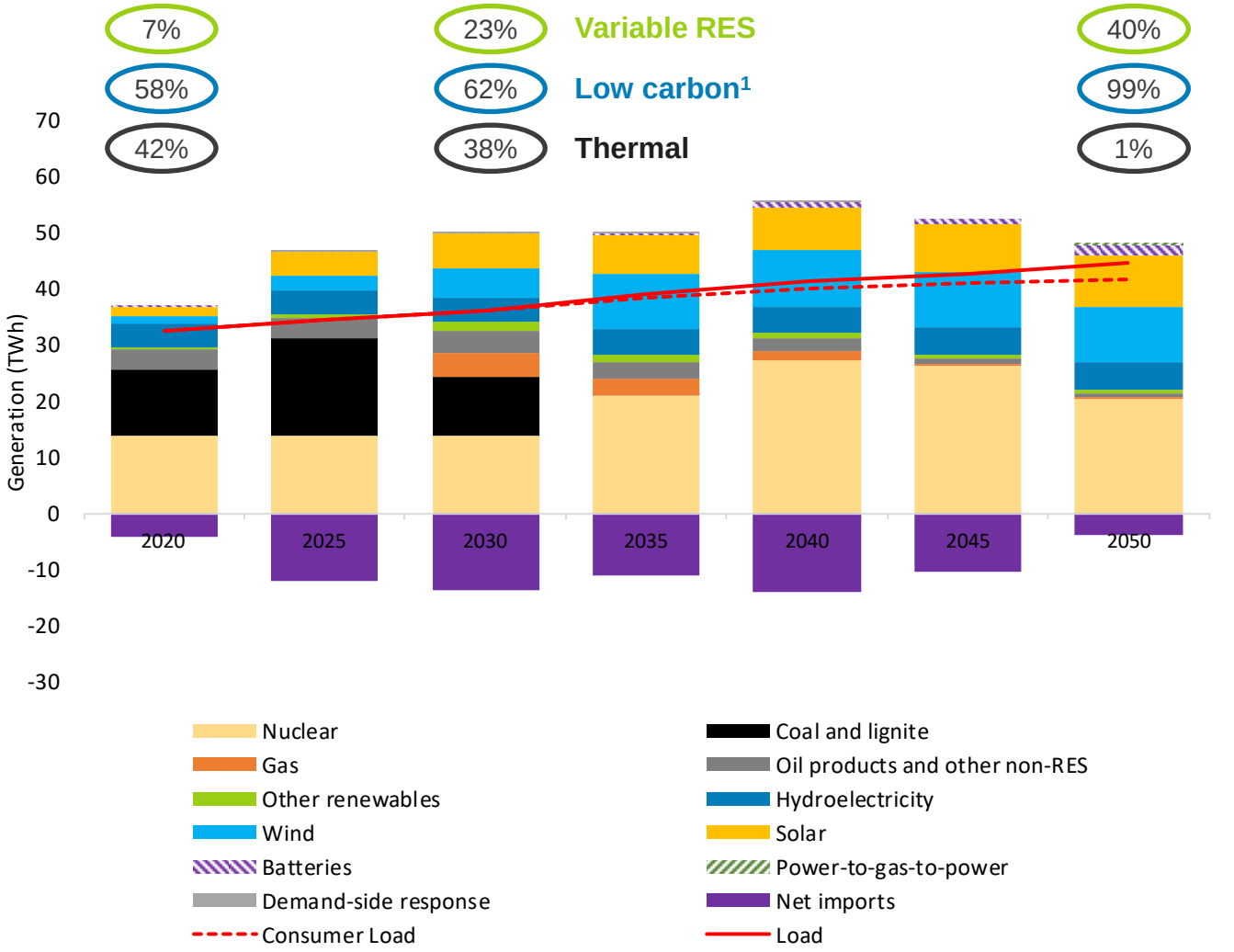


- Lignite plants are gradually replaced from 2030 onwards by new gas capacity which allows to ensure security of supply in the medium term.
- From 2035 onwards new nuclear reactors come online for a total capacity of 2 GW, providing both low carbon electricity and ensuring security of supply.
- Overall, installed capacity increases by 10.9 GW by 2050 relative to today. This increase is primarily driven by the growth of renewables, with onshore wind and solar capacity reaching 5.5 GW and 6.8 GW respectively.
- The growth of renewables is also accompanied with an increase in battery capacity, with c.1.5GW installed by 2050, as well as DSR and P2G2P.

Source: Compass Lexecon

ATP projects a gradual transition from lignite to low carbon generation in the 2030s with a transitional role for gas before full decarbonisation by 2050

Generation (TWh)

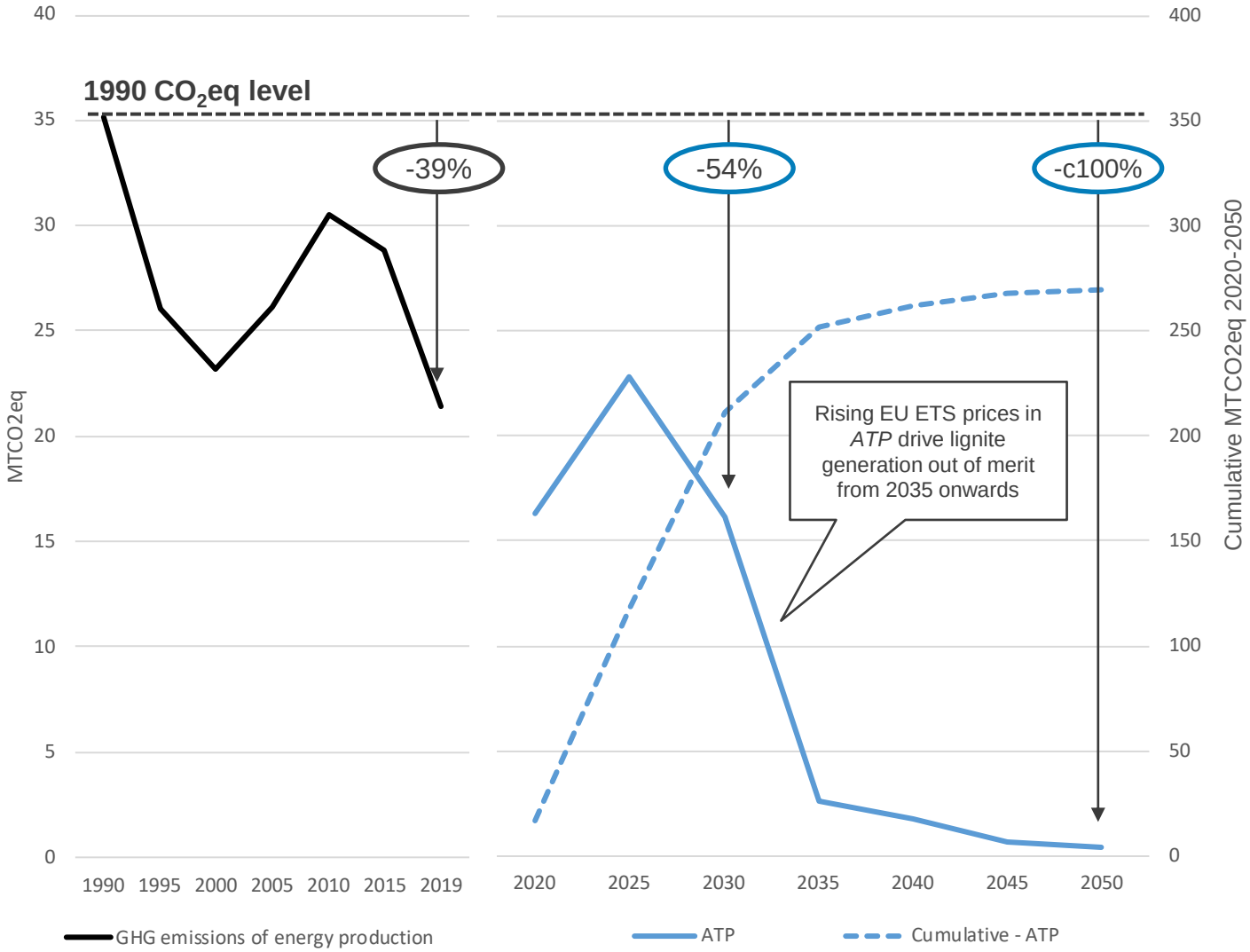


- Bulgaria relies strongly on lignite generation in the 2020s, before switching to gas in the 2030s, and to nuclear and renewables in the 2040s.
- Overall, the Bulgarian export balance remains positive throughout most of the forecast horizon, before reaching equilibrium by 2050.
- Over the forecast horizon, solar generation sextuples and onshore wind generation increases 8x bringing the variable RES generation share from 7% in 2020 to 40% in 2050.
- Combined with nuclear generation, Low carbon's generation share nearly doubles from 58% in 2020 to 98.5% in 2050.

Source: Compass Lexecon
Note: 1. Includes nuclear, hydro, variable RES, storage and DSR

In line with the overall 55% objective, *ATP* emissions drop by 54% in the energy sector by 2030, before fully decarbonising by 2050

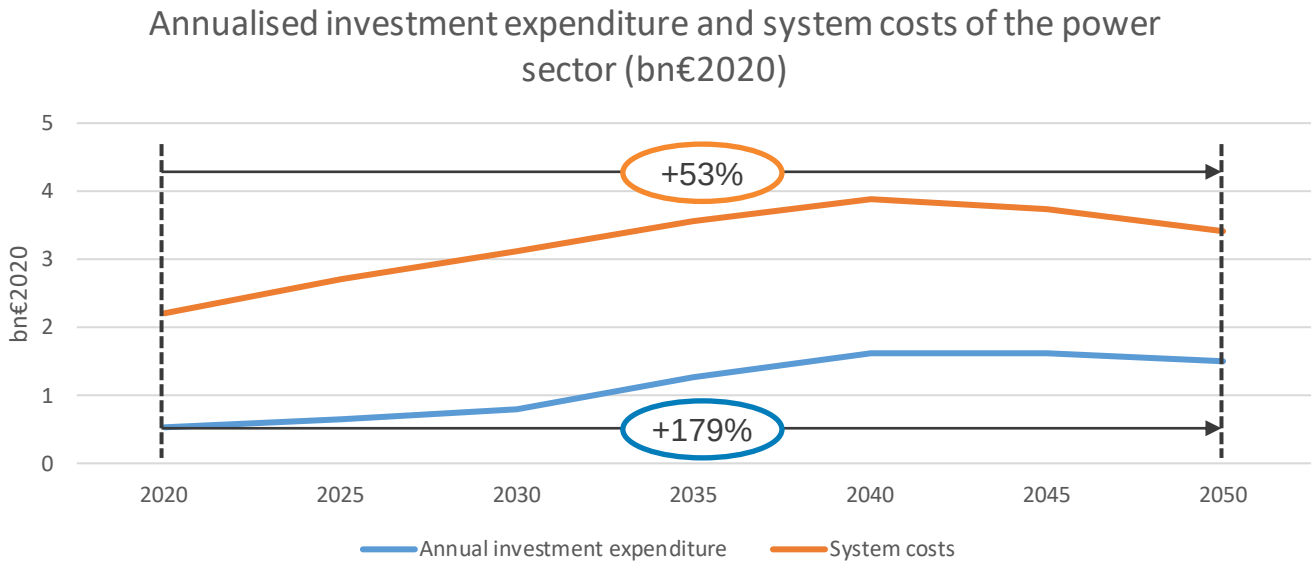
GHG emissions of the energy sector

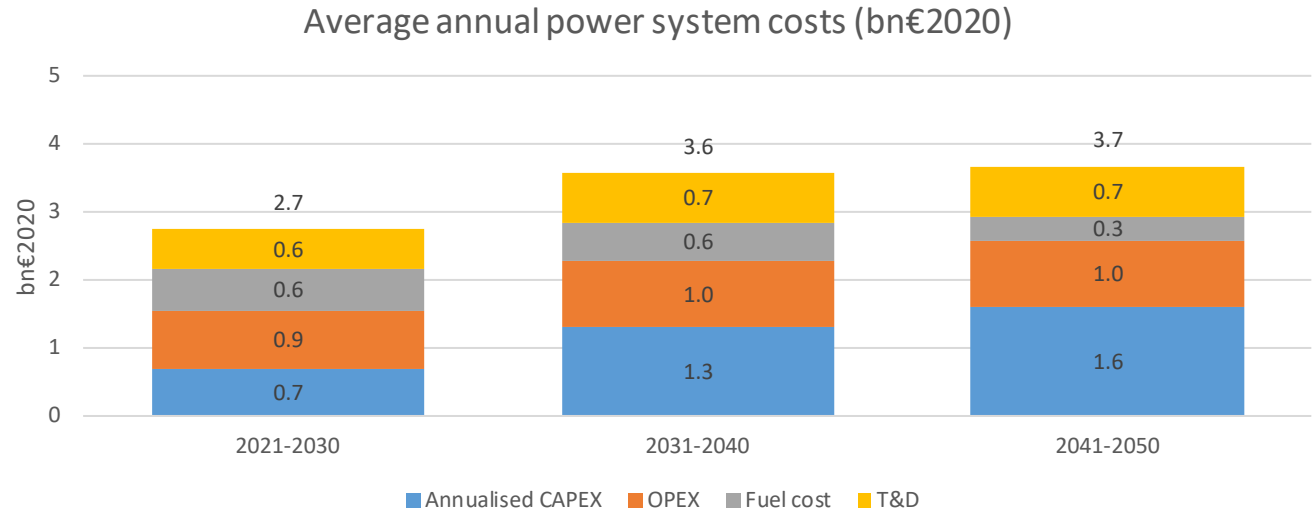


- In line with the decrease of thermal generation in the first decade, and the objective to reach overall 55% emission reduction by 2030 in Bulgaria, energy sector emissions drop by 54% by 2030.
- Thus in *ATP*, the bulk of emission reduction occurs after 2030, when lignite production drops materially.
- This is achievable at an implicit carbon price of about 30€/tCO_2
- With the increasing penetration of low carbon production into the Bulgarian power mix and the reduction of lignite generation, emissions drop significantly post 2030, reaching full decarbonisation by 2050.

Source: Compass Lexecon
Note: Historical emissions from Bulgaria's national inventory report 2021.

The power sector becomes increasingly CAPEX intensive over time with the development of low carbon generation





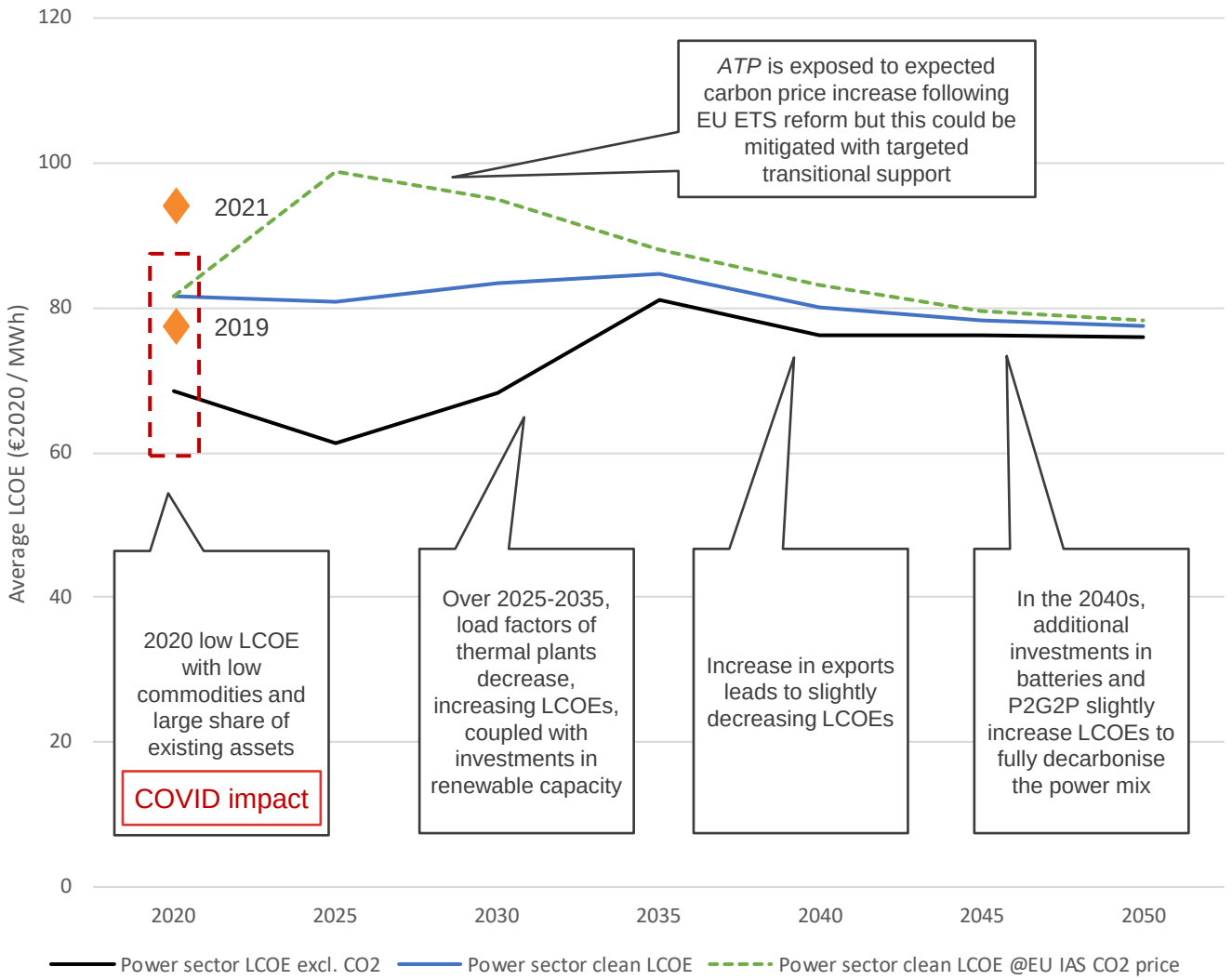
- The power sector becomes increasingly CAPEX intensive over time.
  - Investments in low carbon capacities are organically increasing compared to today's levels to decarbonise the Bulgarian power system.
- Power system costs increase by c.53% in *ATP* between 2020 and 2050. This is primarily driven by the capital cost of new installations, which increases by c.179% between 2020 and 2050, partially offset by the reduction of fuel costs.

- Note 1: Capital expenditures are accounted for in the system costs as annuity payments. A discount of 5% is applied to compute annualised CAPEX. Power system costs do not include emission costs.
- Note 2: Power system costs include existing T&D costs as well as additional T&D costs from RES penetration and peak demand increase based on EU benchmarks. Detailed Bulgarian specific assessment of T&D costs would require separate consideration and analysis.
- Note 3: Power system costs do not include the costs associated to operating or closing lignite mines or the cost associated to the gas network.

Source: Compass Lexecon

While LCOEs increase in line with power system cost increase, clean LCOEs remain relatively stable throughout the forecast

Average power sector LCOE



- Power sector LCOEs increase through time, as thermal plants' load factors drop and new greenfield investments are being commissioned between 2025 and 2040 to further decarbonise.
- However when looking at the clean LCOEs which include emissions costs, the contrast is quite stark. Contrary to increasing LCOEs excl. emission costs, clean LCOEs **remain relatively stable overtime.**

Note: Power sector LCOE corresponds to annual power system (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

Source: Compass Lexecon

2.5 Comparison of the three core scenarios

The comparison of *2020 CS, EU IAS* and *ATP* allows to assess CO_2 emission reduction gains relative to power system cost increase

This section compares the key outcomes of the *2020 Commitment scenario,* the *Increase Ambition scenario* and the *Alternative Transition pathway*

- The "***2020 Commitment scenario***" is based on 2020 NECP and the Bulgarian Energy Strategy.
- The "***EU Increased Ambition scenario***" explores the set of options to 2050 to meet full decarbonisation by 2050 while being compliant with the European "Fit for 55 package" in 2030.
- The "***Alternative transition pathway***" tests the options that would minimise the costs to achieve the transitory 2030 overall 55% CO_2 emissions reduction for Bulgaria, and full decarbonisation by 2050.

A 2020 Commitment scenario

- 2020 CS -

- **BG Energy Strategy** capacity and generation projections up until 2035, extended to 2050 with **cost-efficient development** of generation capacity with limited technical constraints
- **BG NECP target**: Reduction by 49% of emissions by 2030 compared to 1990 and 27% RES target in 2030
- **No further emission reduction target by 2050** apart from ETS allowances reduction (~300MtCO_2 from EU power sector in 2050)
- **Commodity and EU ETS price** outlook as per EU Reference 2020

B EU Increased Ambition scenario

- EU IAS -

- **Cost-efficient development** of generation capacity with limited technical constraints, with additional renewable potential buildout relative to NECP target.
- **Upscaled EU target to reach 55%** of emission reduction by 2030 compared to 1990
- **Full decarbonisation for the power sector by 2050**
- **EU ETS price** in line with Ff55 impact assessment MIX scenario in 2030 and reaching 250€/tCO_2 by 2050 (lower band of EC 2050 Roadmap 2018)

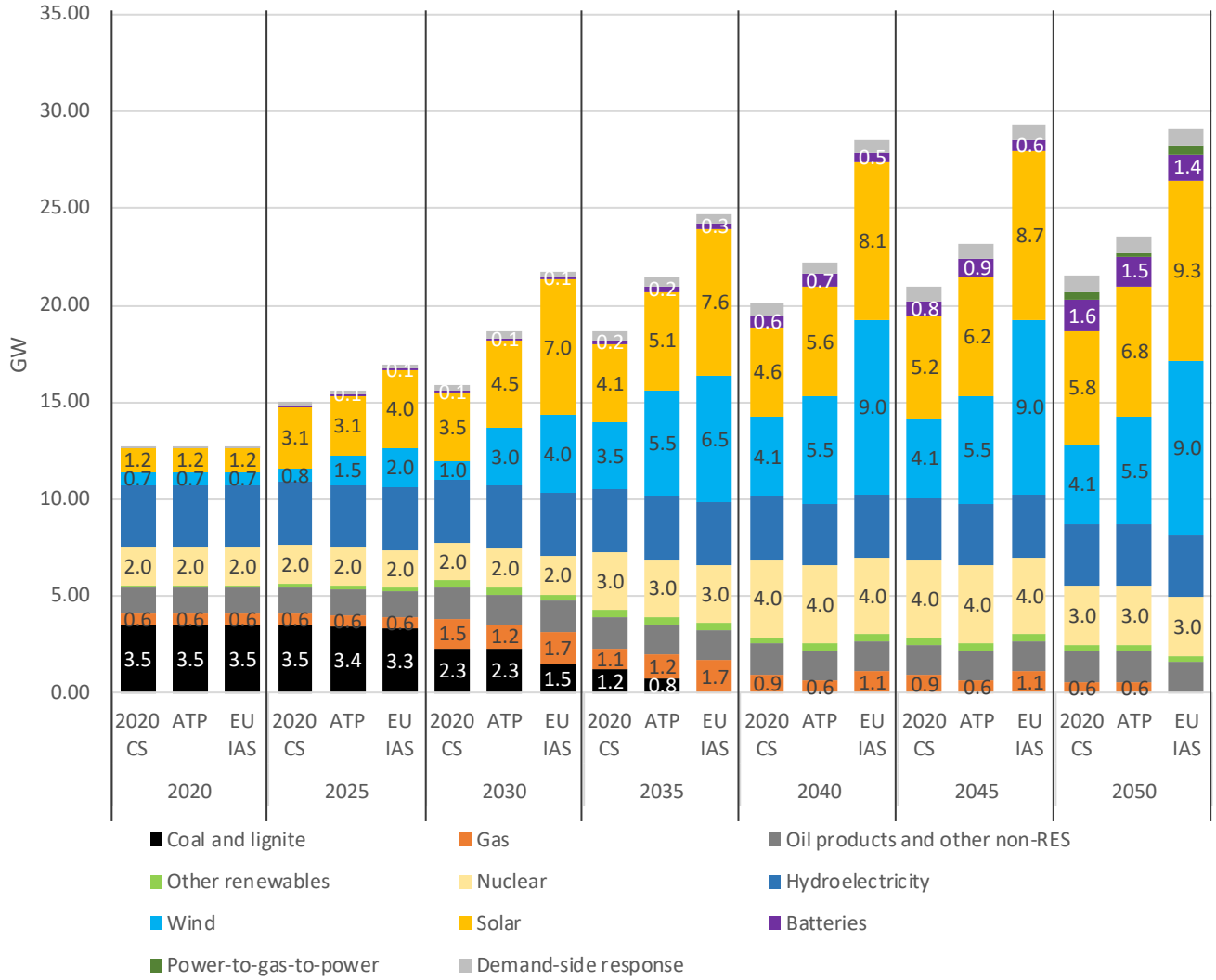
C ATP scenario

- ATP -

- **Decarbonisation target**: Reduction by 55% of emissions by 2030 compared to 1990 through implicit carbon pricing and additional RES buildout compared to *2020 CS*, full decarbonisation by 2050

Lignite and gas plants are relied upon for a longer period of time in *2020 CS* and *ATP* than in *EU IAS*

Capacity comparison between scenarios

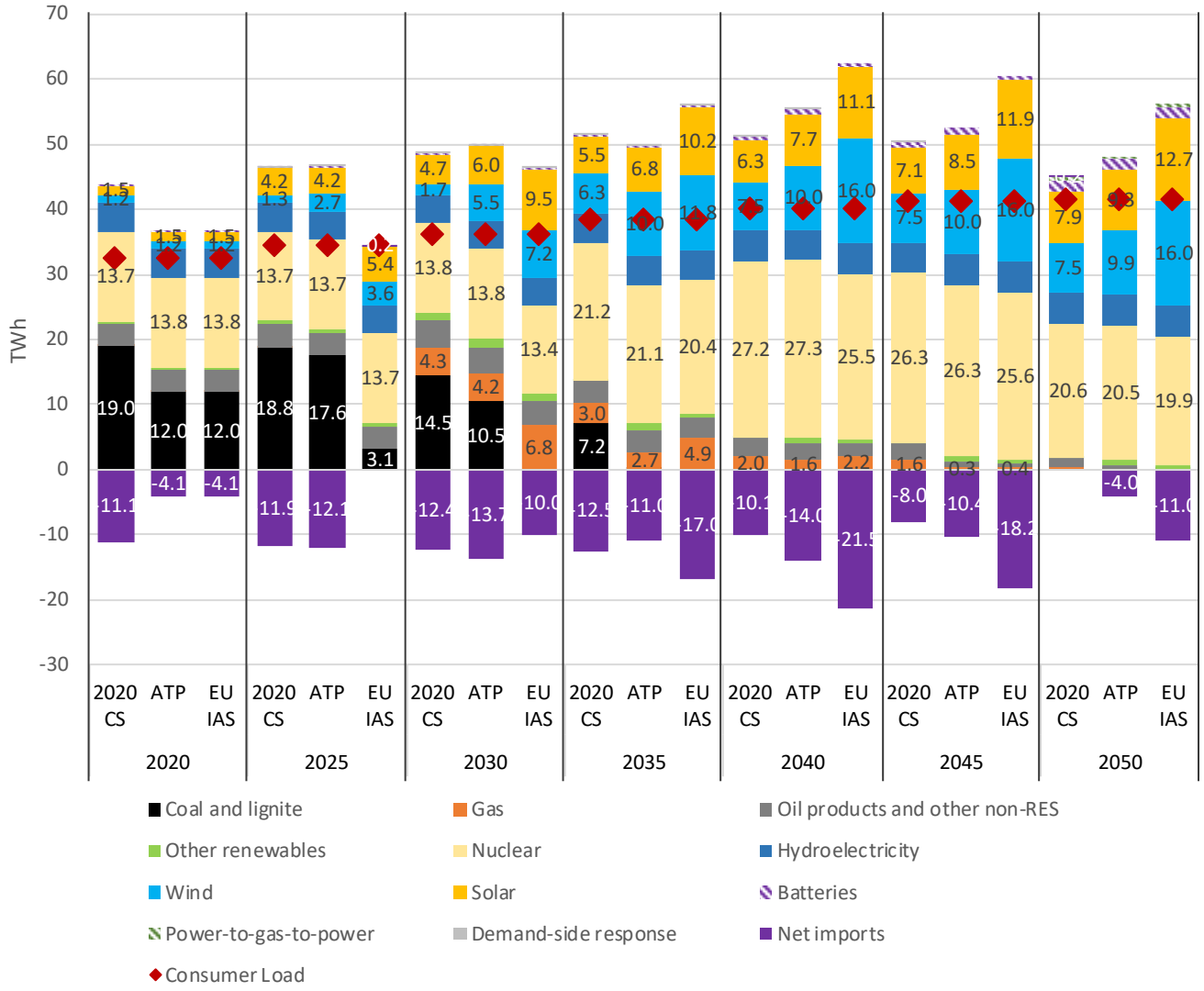


- With lower carbon prices and lower emission targets in *ATP*, lignite and gas plants are relied upon for a longer period of time than in *EU IAS* in order to maintain security of supply.
- Similarly, a low CO_2 price environment coupled with low GHG emissions targets hampers renewable deployment due to a lower need for carbon-free generation.
- In the long-run, *EU IAS* and *ATP* capacity mixes are fully decarbonised by 2050 while *2020 CS* is not.

Source: Compass Lexecon

The economic optimisation to meet 55% reduction by 2030 based on the implicit CO_2 price in *ATP* leads to intermediate lignite generation in *ATP*

Generation comparison between scenarios

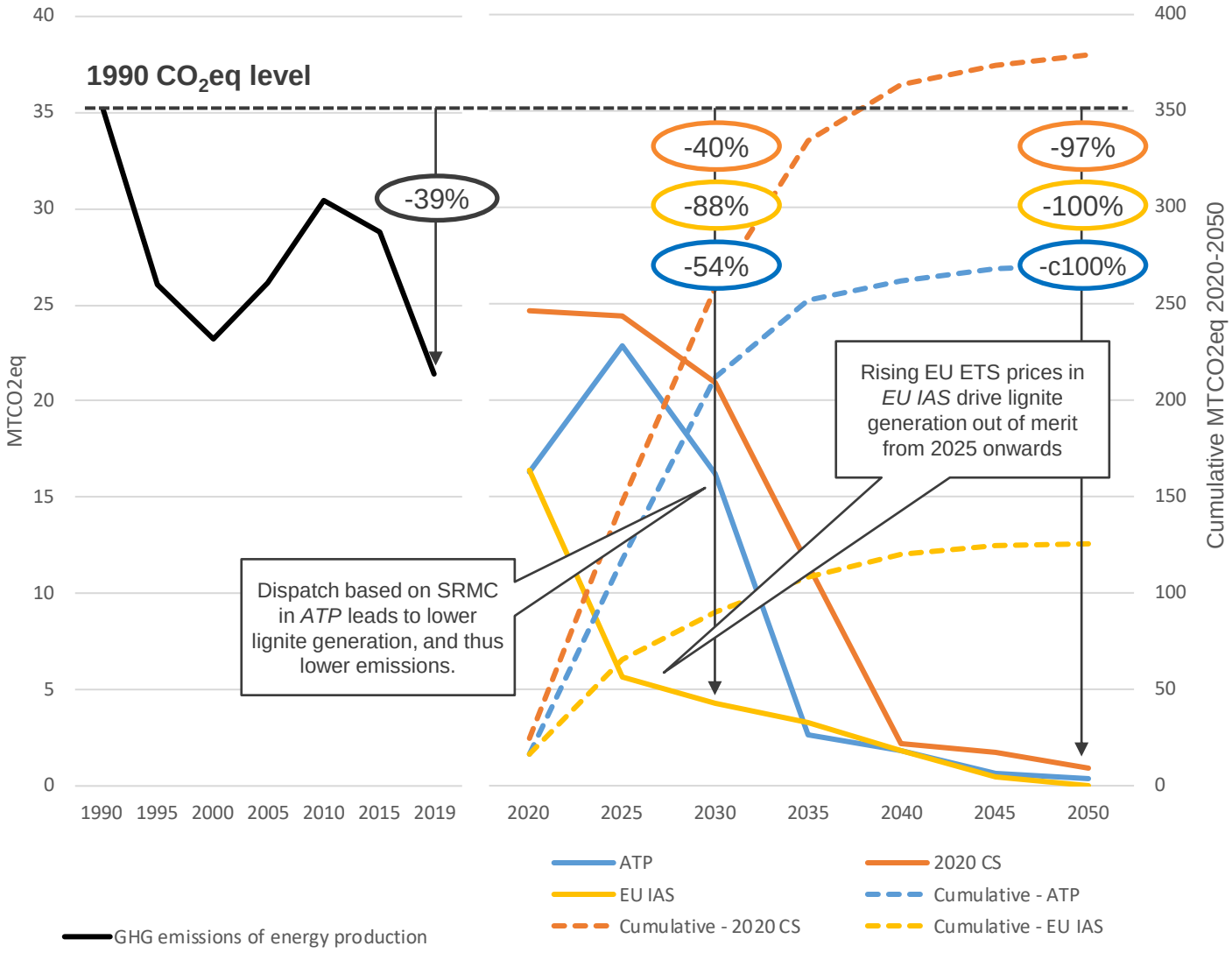


- *ATP* differs from *2020 CS* in that lignite production up until 2035 is not forced as per the Energy Strategy projection, but dispatched economically according to short run marginal cost (SRMC).
- This allows to optimize and identify the implicit CO_2 price to reach an overall 55% emission reduction by 2030 or 54% emission reduction in the energy sector.
- As a result of the economic dispatch, lignite generation in *ATP* sits in between *2020 CS and EU IAS*.
- Post 2035, the large difference in carbon free generation between *ATP*, *2020 CS,* and *EU IAS* leads to higher exports in *EU IAS* than in the other scenarios.

Source: Compass Lexecon

The economic optimisation for *ATP* leads to emission reduction of 54% in 2030 in between *2020 CS* (40%) and *EU IAS* (88%)

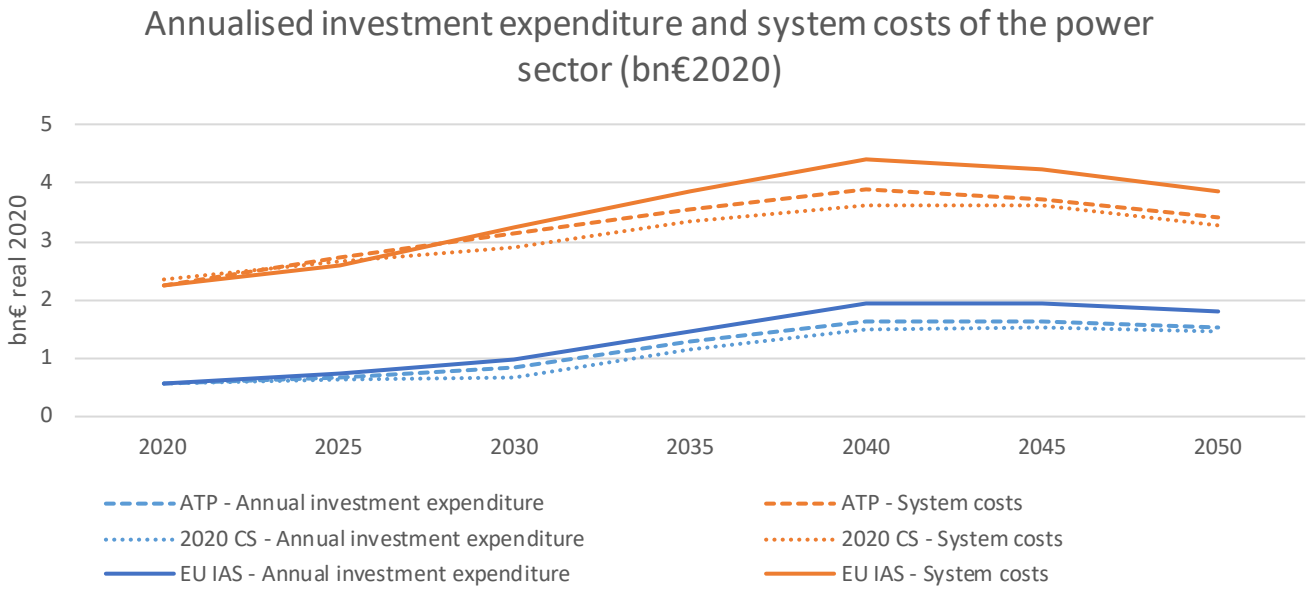
GHG emissions of the energy sector

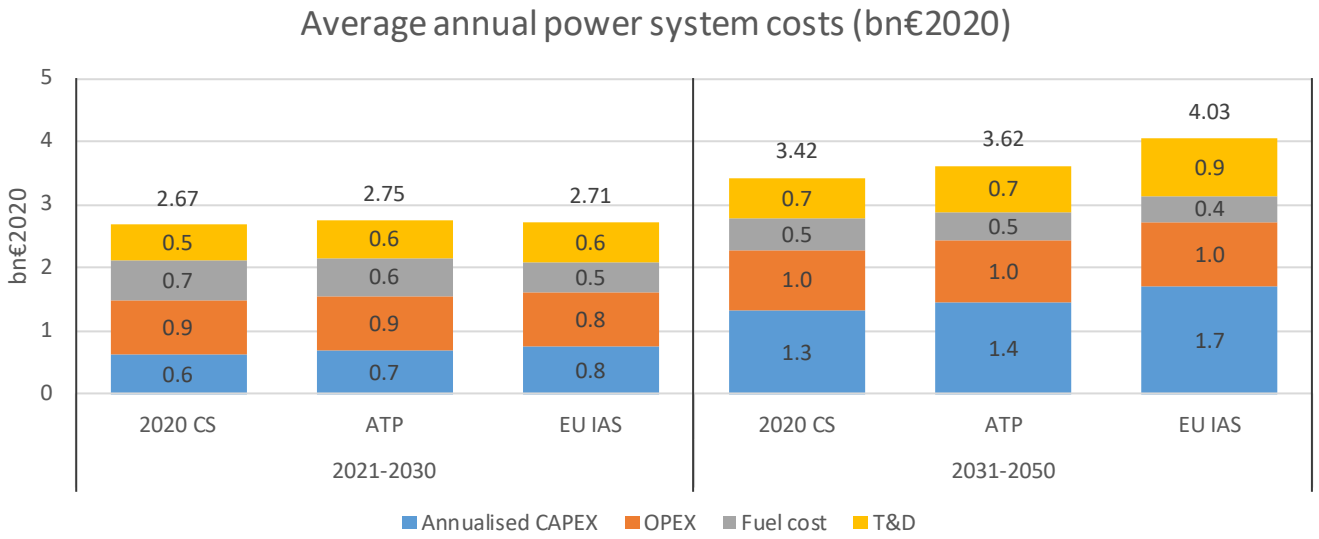


- In line with the magnitude of decrease of thermal generation in the first decade between the three scenarios, energy sector emissions drop by 2030 from 40% in *2020 CS* to 54% in *ATP* and 88% in *EU IAS*.
- The bulk of emissions reduction is staggered across the 3 scenarios, with *EU IAS* forwarding most of the emissions drop to 2025, *ATP* to 2030 and *2020 CS* to 2035.
- This indicates that *ATP* features a slower transition than *EU IAS*, yet accelerated compared to *2020 CS*, at a much lower carbon price than *EU IAS.*
- Note: The accelerated CO_2 emission reduction in *EU IAS* compared to *2020 CS* (resp. *ATP)* allows to lower cumulative CO_2 emissions of the energy sector by c67% (resp. c54%) by 2050.

Source: Compass Lexecon
Note: Historical emissions from Bulgaria's national inventory report 2021.

While CAPEX expenditures increase in all scenarios, *ATP* shows controlled average system costs while achieving decarbonisation targets



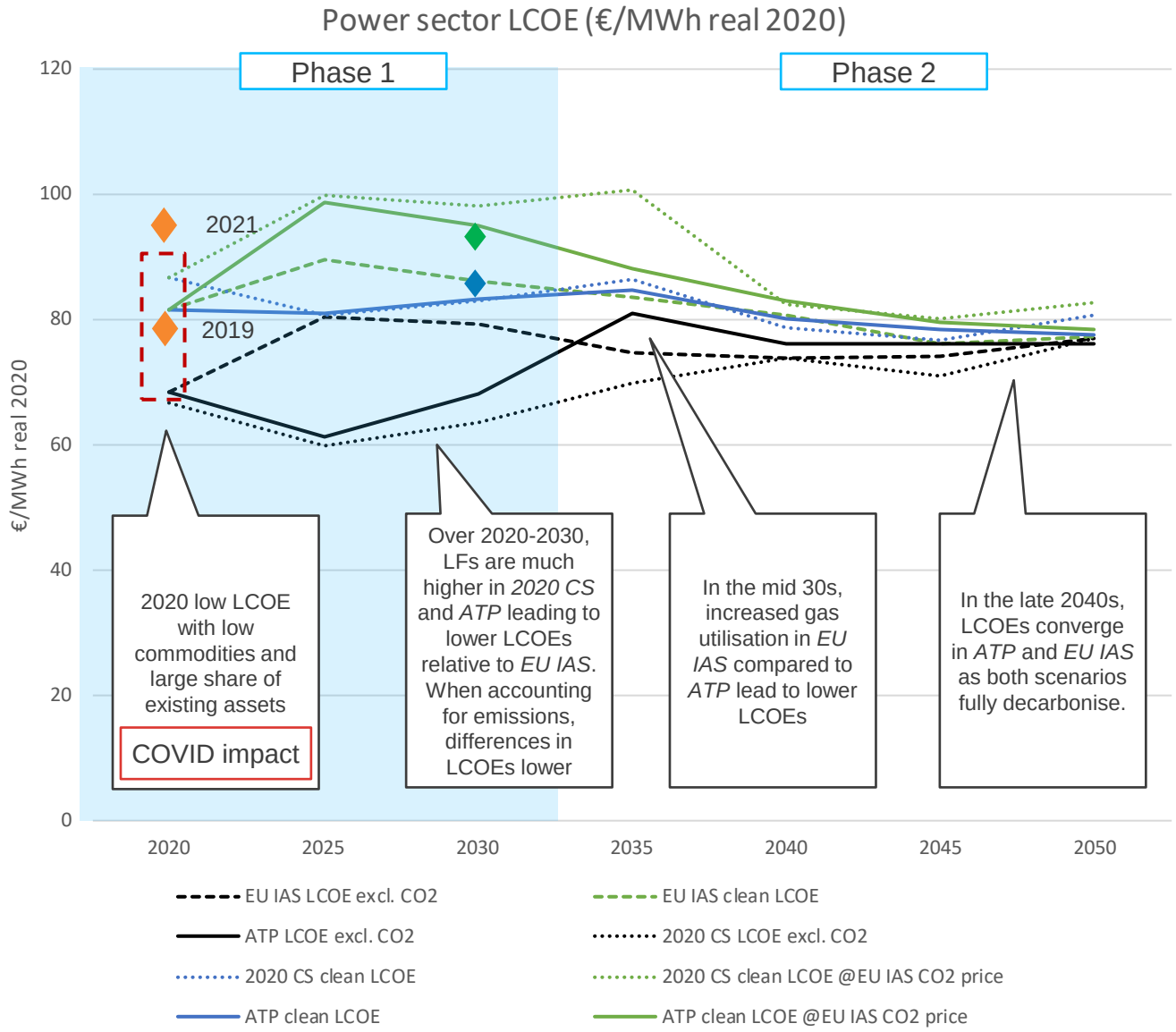


- All scenarios' power system costs becomes increasingly CAPEX intensive over time.
- However, *EU IAS* shows earlier and higher investments than other scenarios.
- *ATP* shows controlled average system costs over the 2021-2030 and the 2031-2050 period while meeting full decarbonisation of the power sector.

- Note 1: Capital expenditures are accounted for in the system costs as annuity payments. A discount of 5% is applied to compute annualised CAPEX. Power system costs do not include emission costs.
- Note 2: Power system costs include existing T&D costs as well as additional T&D costs from RES penetration and peak demand increase based on EU benchmarks. Detailed Bulgarian specific assessment of T&D costs would require separate consideration and analysis.
- Note 3: Power system costs do not include the costs associated to operating or closing lignite mines or the cost associated to the gas network.

Source: Compass Lexecon

ATP shows the most stable clean LCOEs throughout the forecast horizon, indicating a smoother transition than the other scenarios



- **Phase 1:** Up until 2035, *2020 CS* and *ATP* results in lower LCOEs than *EU IAS*, as accelerated transition translates into increased investments. However, the increase in system costs is equal to the CO_2 cost difference between scenarios, as there are sufficient decarbonisation options available to Bulgaria at that price level. It is worth noting that *EU IAS* provides greater hedging against potential future CO_2 prices increases.
- **Phase 2**: Post 2035, LCOEs between scenarios converge with further decarbonisation, but *EU IAS* features a slightly lower LCOE.
- Overall, *ATP* shows the most stable clean LCOEs throughout the forecast horizon, indicating a smoother transition than in the other scenarios.

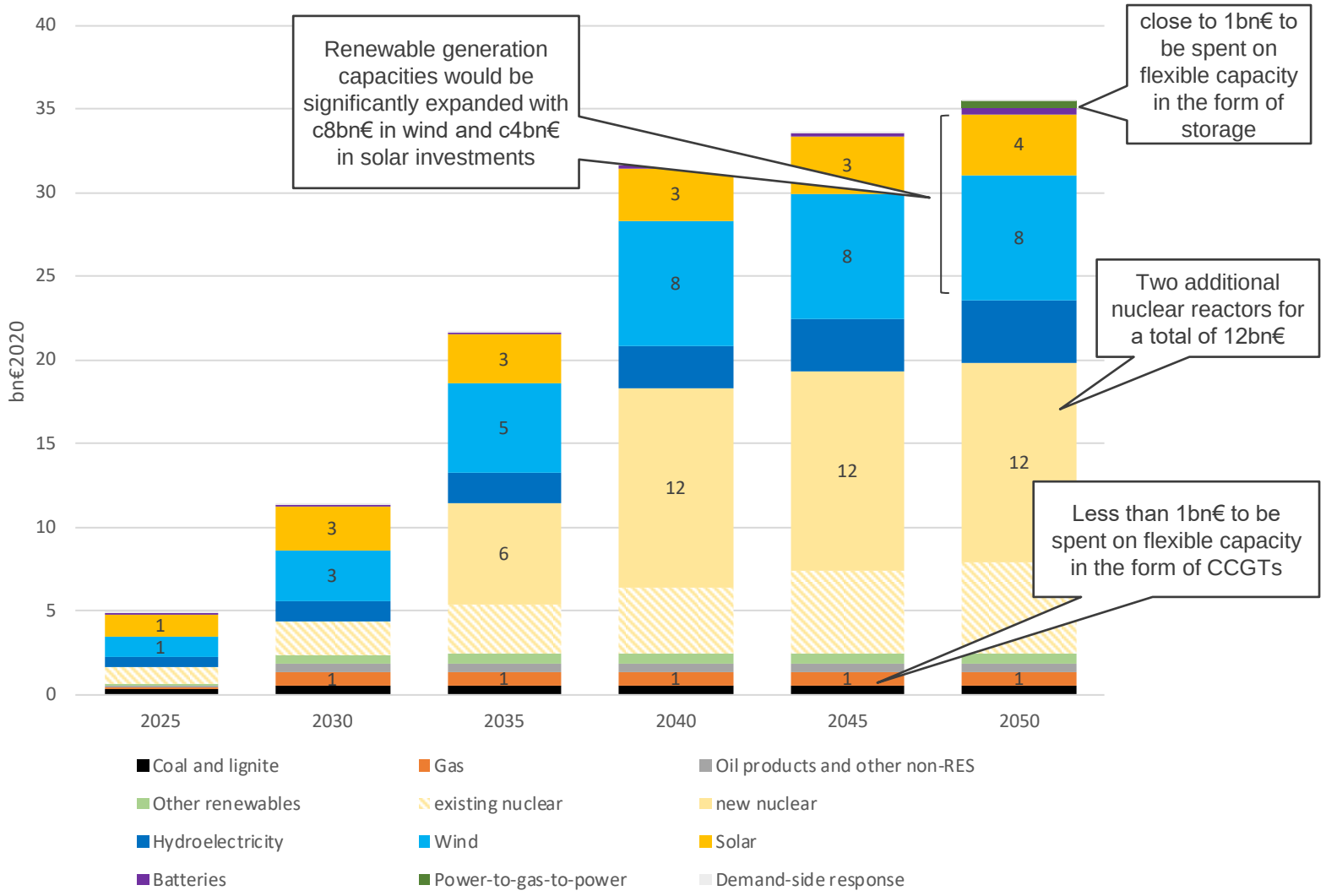
Source: Compass Lexecon
Note: Power sector LCOE corresponds to annual power system cost (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

3. Power system transition and power market design to support this transition

3.1 Power system transition and the power market design to support this transition

The decarbonisation of Bulgaria's power sector will require significant investments in generation and energy infrastructure

Bulgarian cumulative CAPEX expenditures – *EU IAS* (bn€ real 2020)



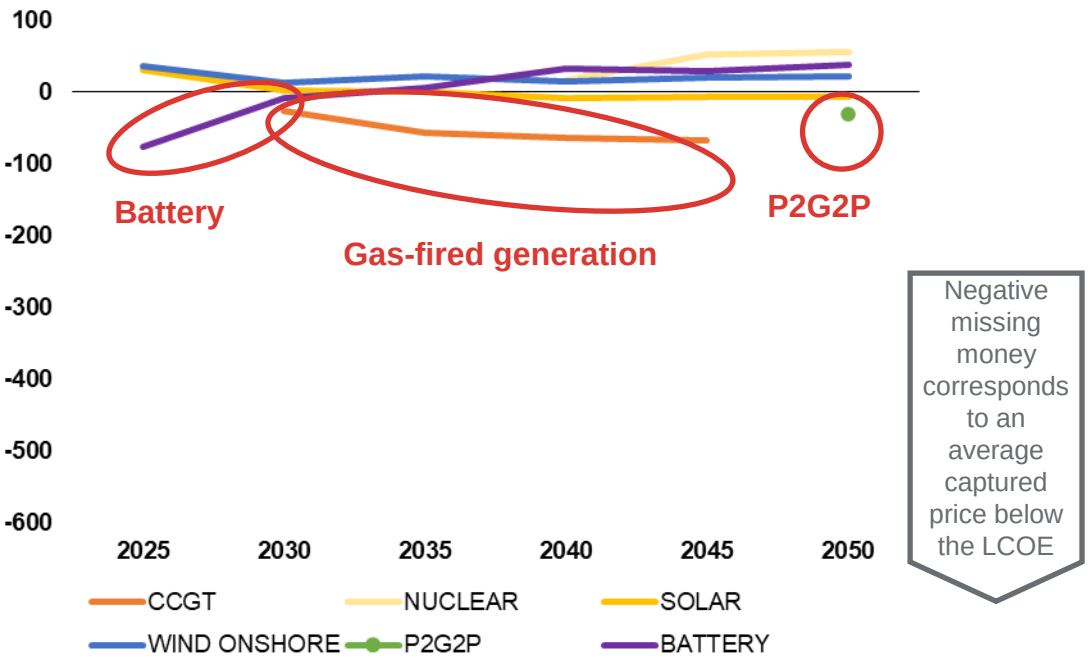
To enable the energy transition, **significant investments in the energy system** are required:

- **Electricity transmission** infrastructure to connect more decentralised wind generation
- **Gas transmission** infrastructure to supply newly required CCGT capacities
- **Electricity distribution** infrastructure to accommodate increasing demand and renewables.

Source: Compass Lexecon Analysis
Abbreviations: CCGT … Combined Cycle Gas Turbine; RES … Renewable Energy Sources

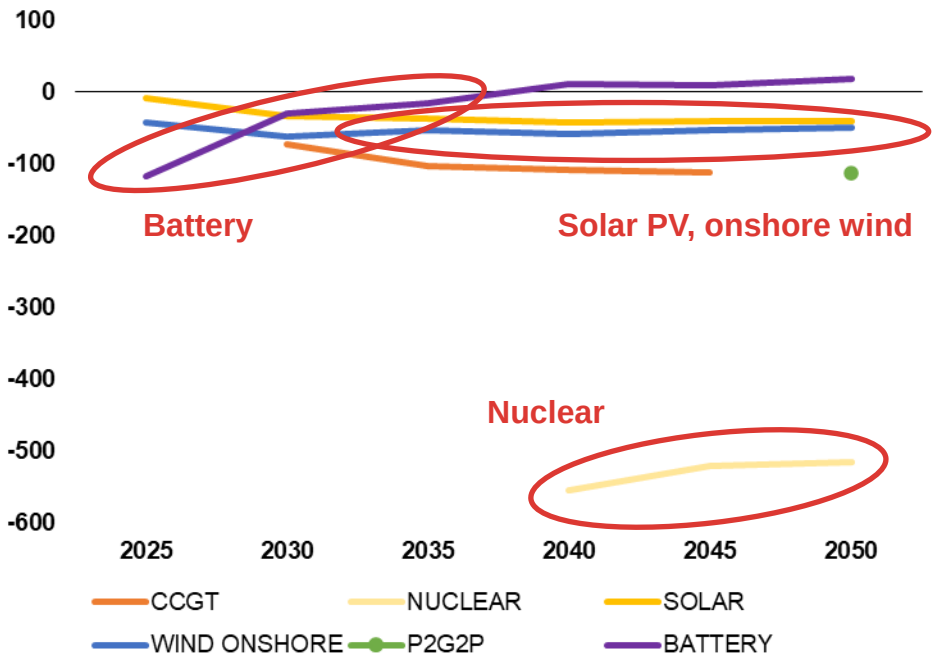
Most of the investments required are not profitable based on energy market revenue alone and merchant risk exposure would raise hurdle rates

Missing money [EUR$_{2020}$/kW/a] – *EU IAS* (WACC=5%)



Negative missing money corresponds to an average captured price below the LCOE

Missing money [EUR$_{2020}$/kW/a] – *EU IAS* (WACC=15%)



Even with a low WACC of 5%, some technologies would require support to enter the market

- CCGT's missing money ranges between 25 EUR$_{2020}$/kW/a and 70 EUR$_{2020}$/kW/a, increasing over time with the decreasing load factor.
- Battery and Power to Gas to Power capacity missing money ranges between 80 EUR$_{2020}$/kW/a and 35 EUR$_{2020}$/kW/a at different point in time

Assuming no mechanism to reduce merchant risk (with eg. a 15% WACC), all technologies would require support for investment

- Increasing the WACC from e.g. 5% to 15% accounting for merchant operation risk increases the missing money of all technologies.
- In particular, nuclear, storage, onshore wind and solar PV capacities would require support compared to a case with a reduced risk exposure

Source: *Compass Lexecon Analysis*
Abbreviations: *CAPEX … Capital Expenses; CCGT … Combined Cycle Gas Turbine; LCOE … Levelised Cost of Electricity, PtGtP … Power-to-Gas-to-Power, PV … Photovoltaics, WACC … Weighted Average Cost of Capital*

The current Bulgarian **power market design does not support an orderly transition** to achieve the decarbonisation and security of supply targets

Design element	Details on current state	Conclusion with regard to the support of the target transition
The cold reserve mechanism was phased out	■ The Bulgarian cold reserve covered dispatchable capacities (gas, lignite) ■ The cold reserve was phased out in 2021.	**Dispatchable plants covered by the cold reserve will likely not remain available for supporting security of supply in Bulgaria.**
Feed-in tariffs for Renewables were replaced with contracts for premiums	■ Since July 2019, feed-in-tariffs arrangements for renewables have been removed. ■ Renewables producers with a capacity above 0.5 MW are required to sell their output directly on the market and receive premium payment from the Electricity System Security Fund (EESF)	**RES investments are exposed to more market risk than before – likely increasing the costs of the renewables.**
Unclear framework for corporate PPA	■ The need for all Bulgarian electricity producers to sell their production on the power exchange adds a layer of difficulty to the establishment of private sector PPAs. ■ To date few corporate PPAs were concluded in Bulgaria	**The framework for de-risking investments via private sector long-term contracts is underdeveloped.**
A capacity remuneration mechanism (CRM) is still to be established	■ The implementation and the precise design of a Bulgarian CRM is still unclear.	**A new mechanism to ensure capacity adequacy in Bulgaria is not yet established.**

Source: Compass Lexecon Analysis, Bulgarian Implementation Plan
Abbreviations: PPA … Power Purchase Agreement

The **immature Bulgarian Electricity market** exposes market participants to risks and **hinders investments**

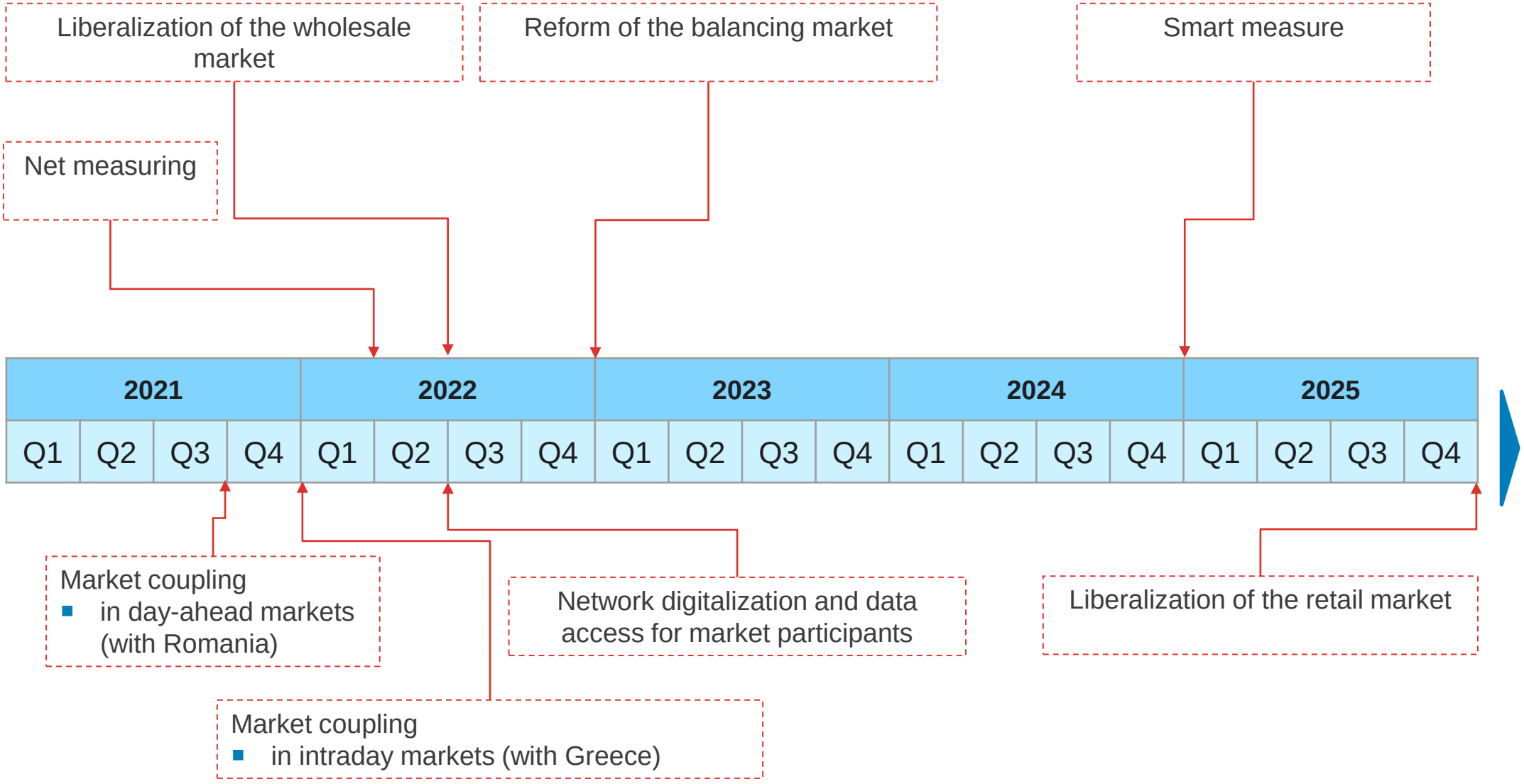
- **Despite an upwards trend, spot market liquidity remains limited**:
  - The volumes traded on the intraday and day-ahead market are on a modest but volatile upward trend.
- **Forward market liquidity is limited**:
  - Forward trading (for physical delivery) and availability of futures trading remains limited
- **Bulgaria Energy Holding (BEH) remains the dominant player in the Bulgarian electricity market**:
  - BEH is 100% owned by the Bulgarian government,
  - With a 6.3 GW installed capacity (nuclear, lignite and hydro), BEH's subsidiaries generate 60% of Bulgaria's electricity
- **Market coupling is still being rolled-out**:
  - **Day ahead market coupling:**
    - Active with Romania and Greece (since 2021)
    - In preparation with Northern Macedonia and Serbia (expected 2022)
  - Timeline for **intraday coupling**:
    - Active with Romania (since 2019).
    - In preparation with Greece (expected Q1/2022)

- **Limited ability** for market participants to **hedge** supply obligations or production
- Significant **barriers to merchant investment decisions**

Source: Bulgarian implementation plan (2021), EC (2021): commission opinion on the Bulgarian Implementation plan, BEH (2021), Energetika (2021): Greek-Bulgarian intraday market coupling planned for Q1 2022

Abbreviations: CRM … Capacity Remuneration Mechanism, BEH … Bulgaria Energy Holding

The Bulgarian market is set to undergo a deep transformation and liberalisation by implementing the EU target model



Source: National Recovery and Resilience Plan (2021)

The planned market design based on the EU target model lacks an investment framework to deliver on policy objectives

- The **Clean Energy Package (CEP)** sets out general **principles to improve the EU electricity markets** focusing **on the existing set of short-term markets**
- But does not provide an investment framework with a structured and coordinated approach for **planning across sectors** and **contracting/hedging mechanisms in order to deliver the investments required to meet the decarbonisation policy target**

Short-term markets
Implementation of EU target model sets the stage for reforms and integration of the spot and intraday / balancing markets

Current reform plans lack a **consistent framework** for **coordinating investment**

- Identification of **system needs** across sectors
- Planning of deployment of **key infrastructures with significant scale economies**
- **Cross sector** approach

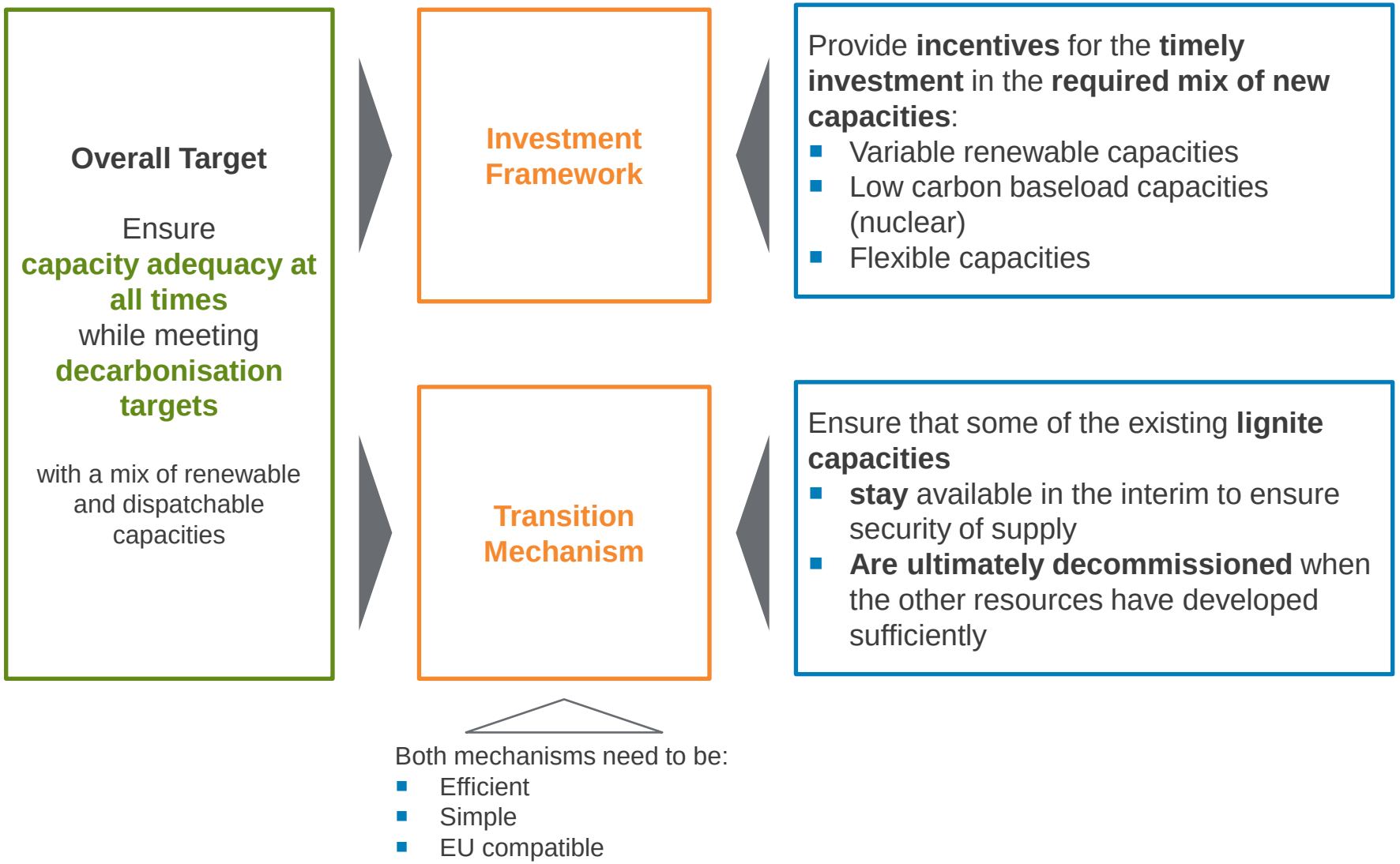
Missing: Coordinated planning

Missing: Framework for investment support mechanisms

- Current reform plans do not provide a **framework** for **supporting investment**
- It remains therefore with the member states to design and implement such support mechanisms

Source: Compass Lexecon Analysis

Two key market design requirements were identified: the need for (1) an **investment framework *and*** (2) a **transition mechanism**



3.2 The need for an Investment Framework

An investment framework plays a key role in a two step competition anchored in the planning of system needs

Key framing principles for a market framework fit for Net Zero

- **Build on existing markets** to deliver short term operation efficiency and **overlay a structured framework** to meet long term policy objectives
- **Identify the evolving system needs** and ensure that the c**ontribution of all resources is adequately rewarded**
- **Revise governance** to ensure **holistic planning** and unbiased / transparent definition of system needs
- Implement **contracting arrangements for the long term system needs** to provide credible commitment towards policy objectives

Investment (years ahead) → **Operations (days/hours ahead)**

Holistic planning of system needs

Comprehensive and transparent approach to

- Identify the evolving system needs across the dimensions
  - Adequate generation
  - Decarbonised generation
  - Flexible generation
- Ensure that the contribution of all resources is adequately rewarded

Competition "for" the market

puts competitive pressure where it matters: CAPEX

Tendering of long-term contracts

- stimulates new entrants
- stimulates the development of a competitive market for investments
- ensures coordinated system developments
- can be technology neutral or technology specific
- Can use a variety of instruments (see following slides)

Required new **Investment Framework**

Competition "in" the market

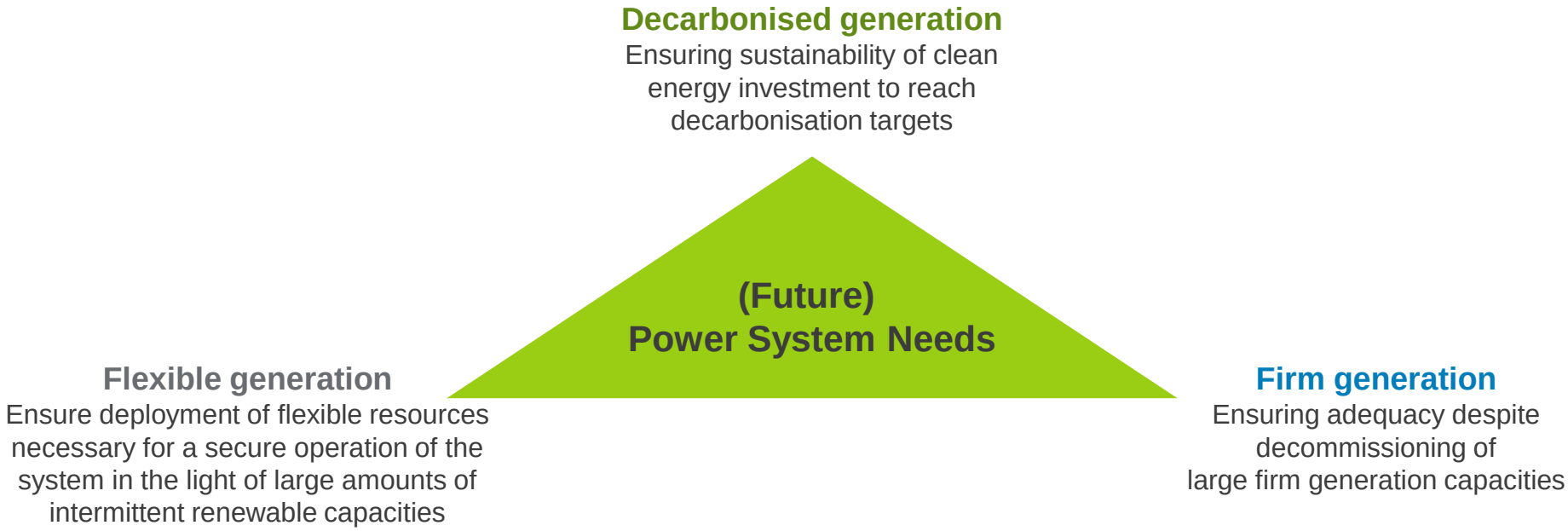
- Well integrated and liquid forward, day ahead and intraday markets
- Optimises short term dispatch and minimises costs for consumers
- Level playing field with balancing obligation for all
- Supports retail competition and development of demand response

Existing / planned short term markets

The power system needs are evolving with the growth of RES – the power market will need to remunerate flexibility and adequacy

The target to decarbonise the power system leads to new needs for the power system regarding decarbonised generation and flexible supply to balance variable renewables

- The energy sector is moving from a single energy commodity towards **differentiated system needs (decarbonised capacities, flexibility capacities** to back the renewables adding to the already traditional need of **adequacy)**
- The new market design will need to **reward capacities to reflect their contribution to these three system needs** and create a level playing field for them
- The investment framework will need to be **differentiated depending on the resources and products considered**



Source: Compass Lexecon Analysis

A number of **funding** and **de-risking instruments** are available to unlock investments required for the power sector transition

The following instruments can be used to implement investment incentives for clean power generation or flexible generation capacities to ensure they remain or enter the market. Their implementation is generally subject to a clearance under EU state aid rules.

Instrument	Key features	Example implementation
Grants or subsidised loans	■ Grants (reducing the amount of CAPEX to be financed) and subsidised loans (reducing the financing cost) can make possible investments in specific clean technologies	Batteries through InvestEU, Modernisation fund
Long-term contracts (CfDs)	■ Long-term contracts covering price risks over a significant part of a plant's lifetime reduce the WACC premium. ■ In particular, public sector long term contracts for difference (usually awarded through competitive auctions) can provide such de-risking feature. ■ CfD enable longer term revenue visibility and thereby create investment incentives.	RES in the UK or Denmark
Long term contracts (corporate PPA)	■ Long-term contracts covering price or volume risks over a significant part of a plant's lifetime reduce the WACC premium. ■ Corporate PPAs (as long as permissible under the regulatory framework) can provide such a de-risking feature.	RES in the Nordics
Capacity Remuneration Mechanism	■ Capacity remuneration mechanism can compensate market participant for their missing money. ■ This mitigation instrument can be implemented in various ways: e.g. market-wide capacity remuneration mechanism, strategic reserve, specific tenders for new capacity, targeted capacity payment.	CCGTs in Belgium or France

Source: Compass Lexecon Analysis
Abbreviations: CAPEX … Capital Expenses, CfD … Contracts for Differences, PtGtP … Power-to-Gas-to-Power, PPA … Power Purchase Agreements, WACC … Weighted Average Cost of Capital

Renewables could benefit from a range of support mechanisms for production and /or investment

RES support schemes implemented / available in Europe – implementation generally subject to clearance under EU state aid rules

Type of support	Description	Examples for implementation
Feed-in premiums / Contracts for Premium	▪ Feed-in premiums enable power producers to benefit from a complementary remuneration, in addition to the remuneration they get by participating to the energy market. ▪ Feed-in premiums, however, do not eliminate market price risks	▪ **Bulgaria**: for RES producers with capacities > 0.5 MW ▪ **France**: onshore and offshore wind, large solar PV (>500kW), biomass, biogas (>500kW)
Contract for difference (CfD)	▪ Contracts for difference enable to ensure a stable revenue to the operator with little exposure to wholesale market prices. ▪ CfDs can be provided either automatically or through tendering procedures.	▪ **UK**: New offshore wind projects, other low carbon technologies ▪ **Denmark**: onshore/offshrore wind, wave, hydro, solar PV
Investment support	▪ Support via grants can provide “missing money” to allow the build-up of capacities otherwise not profitable ▪ Preferential loans reduce financing costs.	▪ **EU** funding schemes: Invest EU fund, EU ETS Modernization fund, recovery & resilience facility, European Regional Development fund, Cohesion fund
Legacy support measure being phased out in the EU:		
Purchase price / regulated tariff / **Feed-in-tariff**	▪ The feed-in tariff is set (typically by the regulator) based on the different cost components (operating costs, re-investment, cost of capital), and the regulated assets benefit from this purchasing tariff. ▪ Feed-in tariffs can be provided either automatically or through tendering procedures.	▪ **Ukraine**: wind generation is sold at a regulated tariff. ▪ **France**: PV (<500kW), biogas (<500kW) ▪ **UK**: small renewables (solar PV, wind, hydro, anaerobic digestion (<5MW) (closed to new applicants from 2019) ▪ **Germany**: ended in 2021

Source: Compass Lexecon Analysis
Abbreviations: ETS … Emission Trading System, PV … Photovoltaics, RES … Renewable Energy Source

Nuclear could be fully regulated, benefit from regulated purchase prices, contracts for difference or investment support

Nuclear support schemes implemented / available in Europe – implementation generally subject to clearance under EU state aid rules

Type of support	Description	Example country where implemented
Full regulation: Remuneration of the Regulated asset base	Full regulation is based on the provision of an authorized revenue based on all the costs that are supported (regulated asset base remunerated at the level of a regulated WACC, depreciation and OPEX remunerated at cost)	**UK**: for the remuneration of nuclear reactor Sizewell C
Purchase price / **regulated tariff** / Feed-in-tariff	A tariff is set (typically by the regulator) based on the different cost components (operating costs, re-investment, cost of capital), and the regulated assets benefit from this purchasing tariff.	**Ukraine**: 90% of nuclear generation is sold at a regulated tariff.
Contract for difference	Depending on their structure, CfDs may ensure a (more) stable revenue to the operator by reducing/elimianteing the exposure to wholesale market prices.	**UK**: for the remuneration of nuclear reactor Hinckley point C
Investment support	For instance, EU ETS Modernization fund does not formally exclude nuclear investment, although this is not a priority investment.[1]	**EU** wide

Source: Compass Lexecon Analysis
Note: [1] several EU funds formally exclude support to nuclear energy, such as: the InvestEU Fund, the European Regional Development fund and the Cohesion fund

Flexible capacities could benefit from a capacity remuneration mechanism, investment support or free ETS allowances

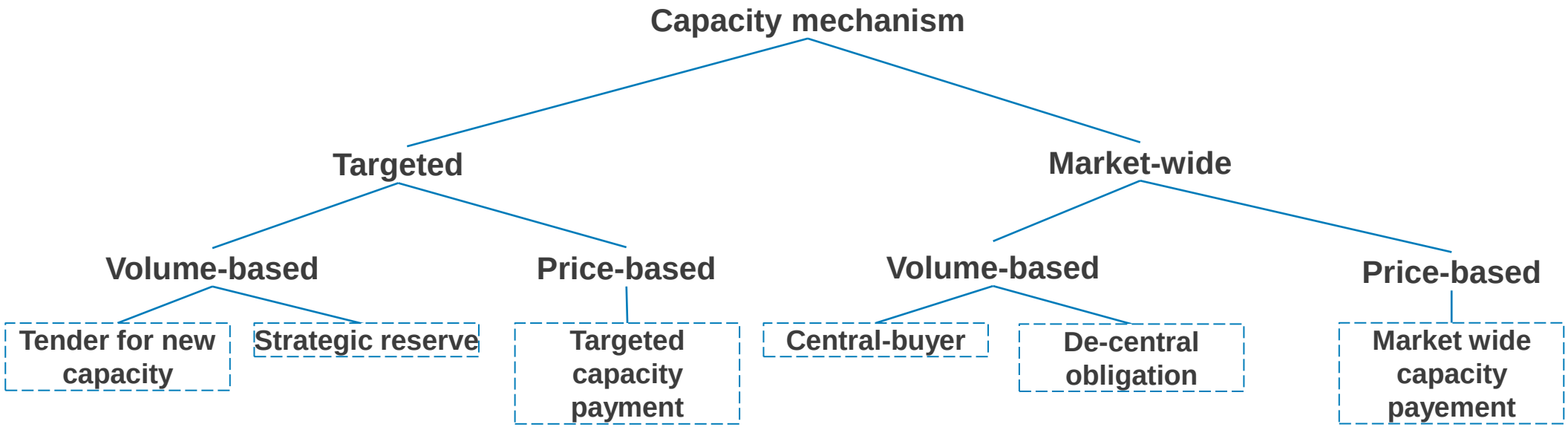
Support schemes for flexible capacities implemented / available in Europe – implementation generally subject to clearance under EU state aid rules

Type of support	Description	Example country where implemented
CRM	▪ Capacity remuneration mechanism can provide an additional remuneration to flexible capacities to compensate for the missing money they would face, if they were to participate only in the energy market. ▪ The various types of capacity mechanisms can be grouped into two broad categories: targeted mechanisms and market-wide mechanisms. Within these two categories, it is also possible to distinguish volume-based mechanisms and price-based mechanisms.	Germany, Ireland, Poland, UK, Belgium, France
Investment support	▪ Investment support can be available for flexible capacities contributing to decarbonisation investment in the form of grants or loans, through in particular the Recovery and resilience facility, the EU ETS Modernisation fund, and the InvestEU fund (although the later lacks an implementing partner in Bulgaria) – subject to certain emission limits.	**EU** wide
Free ETS allocations	▪ New flexible capacities projects (incl. CCGT or OCGT) replacing lignite could benefit from free ETS allowances (if Bulgaria executes its respective right under Art. 10c of the EU ETS directive)	Available in selected EU countries – potentially also in **Bulgaria** (to be confirmed by the new government)

Source: Compass Lexecon Analysis
Abbreviations: C/OCGT … Combined/Open Cycle Gas Turbine, CRM … Capacity Remuneration Mechanism, ETS … Emission Trading System

There is a wide range of **capacity remuneration mechanisms** (CRM) available – Overview

Capacity remuneration mechanism taxonomy



Targeted mechanism: The amount of capacity required and the amount expected to be brought forward by the market are identified centrally. The capacity mechanism then provides support only to the additional capacity (or 'top up') expected to be needed beyond what would anyway be brought forward by the market. There are three types of mechanism:

- **Tender for new capacity**
- **Strategic reserve**
- **Targeted capacity payment**

Market wide mechanism: All capacity required to ensure security of supply receives payment, including both existing and new providers of capacity. There are three types of mechanism:

- **Central buyer**
- **De-central obligation**
- **Market-wide capacity payment**

Source: *Compass Lexecon Analysis, European Commission. Report from the Commission - Interim Report of the Sector Inquiry on Capacity Mechanisms, European Commission (2016) Staff working paper on capacity remuneration mechanism*

Abbreviations: *CCGT … Combined Cycle Gas Turbine, CRM … Capacity Remuneration Mechanism*

There is a wide range of **capacity remuneration mechanisms** (CRM) available – Functioning and application

Capacity remuneration mechanism overview – implementation generally subject to clearance under EU state aid

Type of CRM	Description	Example country
Tender for new capacity	The beneficiary of such a tender receives financing for the construction of a power plant that would bring forward the identified top up capacity	▪ France ▪ Croatia (planned)
Strategic reserve	The top up capacity is contracted and then held in reserve outside the market. It is only run when specific conditions are met	▪ Germany ▪ Poland ▪ Sweden
Targeted capacity payment	A central body sets the price of capacity. This price is then paid to a subset of capacity operating in the market (e.g. a particular technology, or only to capacity providers that meet specific criteria.)	▪ Italy ▪ Poland ▪ Portugal ▪ Spain
Central buyer	The total amount of required capacity is set centrally, and then procured through a central bidding process in which potential capacity providers compete so that the market determines the price.	▪ Ireland (since 2017) ▪ Italy (planned) ▪ Poland (since 2018) ▪ United Kingdom (since 2014) ▪ Germany ▪ Belgium (since 2021)
De-central obligation	An obligation is placed on electricity suppliers / retailers to contract with capacity providers to secure the total capacity they need to meet their consumers' demand. The difference compared to the central buyer model is that there is no central bidding process, but market forces should still establish the price for the required capacity volume.	▪ France (since 2016)
Market-wide capacity payment	The price of capacity is set centrally, based on central estimates of the level of capacity payment needed to bring forward sufficient total capacity and then paid to all capacity providers in the market.	▪ Ireland

Source: *Compass Lexecon Analysis, European Commission. Report from the Commission - Interim Report of the Sector Inquiry on Capacity Mechanisms, European Commission (2016) Staff working paper on capacity remuneration mechanism*

Abbreviations: *CCGT … Combined Cycle Gas Turbine, CRM … Capacity Remuneration Mechanism*

Gas capacities could benefit from **EU investment support** options, incl. the RRF, the modernization fund and (with limitations) the InvestEU fund

Support schemes potentially available for a gas capacities investment in Bulgaria

Support scheme	Eligibility for C/OCGT funding[1]	Possibility to combine with other support mechanism	Support type available	Max. project budget / max. share of invest	Total budget [EUR bn]	
					EU	Bulgarian share
Recovery and Resilience Facility (RRF) (Part of the ERRM)	**YES**	n.a.	grant and/or loan for the C/OGGT: **grant**	for the C/OGGT: **30%**	**723.8** 338 in grants 385.8 in loans	**~10.7** ~6.2 in grants ~4.5 in loans
EU ETS modernisation fund	**YES**	**YES**	**Unclear** if grant or loan (to be aligned between the BG government and the EC)	No absolute limit; up to 70% of investment up to **40%** for the C/OCGT investment, if combined with the RRF	Depending on auction results currently ~22	Depending on auction results currently ~0.8
InvestEU[2] (Part of the EU Recovery & Resilience Mechanism – ERRM)	Theoretically but **Bulgarian implementation partner missing**	**(YES)**	**Loan** or equity participation	No absolute limits (up to 50% of investment sum) for the C/OGGT: **30%**	**~400**	

Source: *Compass Lexecon Analysis based on:*
EC (2021) Recovery plan. Available at: https://ec.europa.eu/info/strategy/recovery-plan-europe_en
EC (2021) The RRF, Available at: https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en
EC (2021) About the InvestEU fund. Available at: https://europa.eu/investeu/investeu-fund/about-investeu-fund/how-does-fund-work_en .
EC (2021) FAQ about Invest EU Fund. Available at: https://europa.eu/investeu/investeu-fund/frequently-asked-questions-about-investeu-fund_en
EC (2021) InvestEU launch event – summary, Available at: https://ec.europa.eu/info/investeu-launch-event-summary-sessions_en
Modernisation Fund (2021) What can be financed. Available at: https://modernisationfund.eu/investments/;
EU ETS Directive – consolidated version available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02003L0087-20180408&from=EN#tocId27

Notes: *[1] preliminary assessment based on published information; several EU funding mechanisms formally exclude support to gas fired generation; these include: the European Regional Development fund, the Cohesion fund, the Just transition fund, public sector loan facilities under the Just transition mechanism. The LIFE program does not formally exclude investments in gas-fired generation, but has very limited budget for such funding. [2] InvestEU can theoretically provide support to CCGT but there is no implementing partner in Bulgaria that could do so.*

Abbreviations: *C/OCGT … Combined/Open Cycle Gas Turbine*

The required Investment Framework needs to balance a broad set of requirements

New capacities require an **Investment Framework**

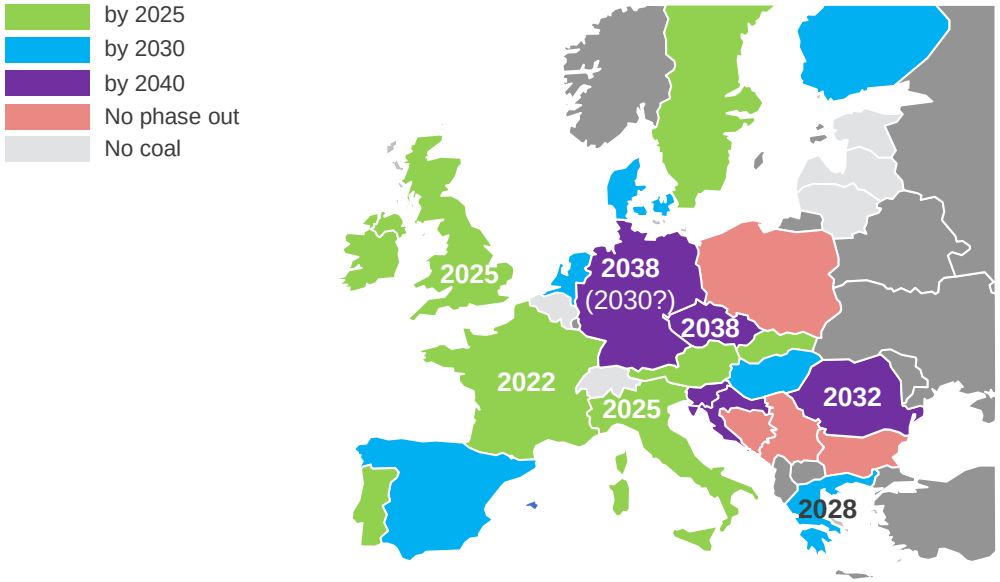
1	**Policy-efficient investment signals**	Provide incentives for investments based on their merit towards **fulfilling adequacy, flexibility and decarbonisation objectives**
2	**Cost-efficient and reliable investment signals**	Establish reliable incentives for investments that **minimize long-term costs** to customers and **avoid stranded investments** (emphasis on **no-regret investments)**
3	**Cost-efficient risk allocation**	**Allocate risks to parties** that are **best placed to manage / bear** them (e.g. reduce hard to predict/hedge risks for power sector investors to bring down risk premia and capital cost)
4	**Provide "missing money"**	Provide **funding for technologies necessary but not profitable** from market revenues alone
5	**EU compatibility**	Ensure **compatibility with the EU framework** (inter alia the clean energy package)
6	**Minimize complexity**	Minimize **transition costs** required and changes to the existing markets and governance

Source: Compass Lexecon Analysis

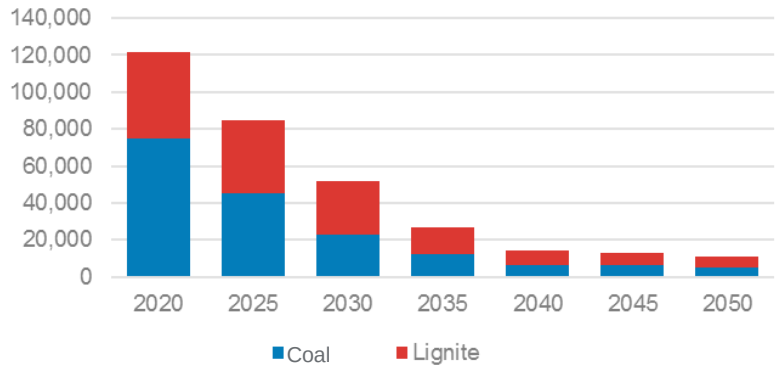
3.3 The need for a Transition Mechanism for existing resources

A number of European countries have committed to **phasing out coal/lignite** – generally these **transitions are supported by support mechanisms**

Coal/lignite phase out plan in Europe



EU-27+UK coal/lignite capacity evolution [MW]



- Several European countries have announced **coal and lignite phase-out plans**.
- These plans are **generally underpinned by support mechanisms** for the transition.
- These transition mechanisms have generally two focus areas:
  - **Ensure the availability** of coal/lignite generation (capacities) for an interim period
  - **Dampen the economic and social effects** of decommissioning

Source: Compass Lexecon Analysis of National energy and climate plans (NECPs)

Several **aid options** are available to support the prolonged operation and subsequent phase-out of coal/lignite generation capacities

Aid option category	Aid option	Description	Relevant in short-term or medium term?
Service of general economic interest (SGEI)	n.r.	SGEI refers to a service that has widespread socioeconomic benefits (i.e. a public good) but cannot be provided by the market. A SGEI would be entitled to time-limited aid measures	Can be implemented relatively quickly, as Slovak example shows
Capacity Remuneration Mechanisms ("CRM")	Capacity payment / local adequacy issues	CRMs are designed to ensure that power generators are available during peak demand periods (i.e. to ensure security of supply) through capacity payments for availability.	Can be implemented quickly, as Normandy example shows
	Strategic reserve		Complexity is limited, so could be implemented quickly as well.
	Capacity market		A market-wide capacity market would require longer than a year to prepare and is more suitable for the medium-term.
Closure aid	Exceptional costs for closure of plants & mines	Support for (broadly defined) exceptional costs for closure of coal mines & plants	Would only be needed once a closure appears unavoidable
	Closure aid	Closure aid for coal plants & mines (i.e. a remuneration for lost profits)	Available only for profitable plants
More general aid	Aid for companies in difficulties	In principle the European Commission allows aid for companies in difficulties.	Being company in difficulty has several disadvantages
	Green investment aid	In particular following the Green Deal and Fit for 55, investment aid for new green investments appears attainable.	Only relevant technologies are actually deemed green

Source: Compass Lexecon Analysis

German coal phase out - Direct compensation and competitive tenders were implemented to support coal and lignite phase out by 2038

In Germany, the use of coal for the production of electricity will have to phase out by 2038, according to German coal phase out law (June 2020). Several plans and aids have been implemented (either approved or being investigated by the commission).

2015 lignite phase out plan approved by the EC

- In **2015**, **Germany decided to shut down eight lignite blocks** with a total nominal capacity of **2.7GW** (representing 13% of total installed lignite-fired generation capacity in Germany), operated by three companies: RWE, Vattenfall and Mibrag.
- Before being decommissioned, the power plants were to be kept on standby for four years as an emergency reserve. **Germany provided a compensation scheme** with a total budget of **€1.6 billion to be granted to the operators** during the four-year standby period.
- The measure expected to realise emission savings of 12.5 million tonnes of CO_2 per annum as of 2020 (when all plants are mothballed).
- **The Commission approved the aid** on the basis that, overall, the positive effects of the aid in terms of reducing CO_2 emissions would outweigh any distortions to competition and trade.
- The support – while initially planes as a CRM scheme – was approved as environmental aid.

2020 plan for hard coal phase out approved by the EC

- In **2020**, Germany established a scheme to incentivise the early closure of hard coal fired power plants and to compensate the businesses that leave the market via **competitive tenders**.
- Germany expect around **23.6 GW** of hard coal and small lignite (below 150 MW) installation to be eligible to participate to the tenders.
- The German energy regulator (BNetzA) will publish seven tenders between 2020 and 2026, for closures of hard coal-fired and small lignite-fired power plants.
- **The commission has decided not to raise objections to the measure**.

2020-2021 lignite phase out plan currently investigated by the EC

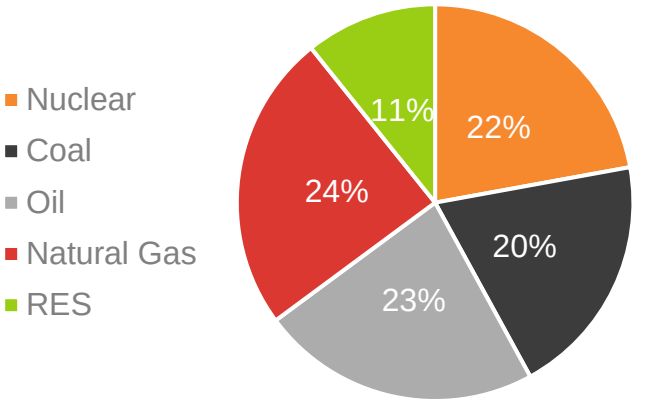
- In **2020-2021**, Germany has decided to enter into agreements with the main producers of lignite-fired electricity, RWE and LEAG, to encourage the early closure of lignite-fired power plants.
- **It plans to compensate** these operators for **foregone profits** and **additional mine rehabilitation costs resulting from early closure**. Total compensation is planned to amount to **€4.35 bn**.
- There is a concern that these compensations that might violate state aid rules.
- **The European Commission has opened an in-depth investigation** to assess whether German plans to compensate lignite-fired power plants for phasing out earlier than foreseen, are in line with EU State aid rules and to determine whether its initial concerns are confirmed.

Abbreviations: *EC … European Commission*

Source: *Compass Lexecon analysis based on: EC (2021) State aid: commission opens an in-depth investigation into compensation for early closure of lignite-fired power plants in Germany, EC (2016) State Aid SA 42536 – Germany closure of German lignite fired power plants, Robins, N., Burger, A., Puglisi, L. (2020) "The Role of state aid in promoting environmental sustainability", EC (2020) State aid: Commission approves competitive tender mechanism to compensate for early closure of hard coal-fired power plants in Germany, Euractiv (2020) Brussels approves German hard coal exit tender. SA.58181 (2020/N) Tender mechanism for the phase-out of hard coal in Germany. State Aid SA.53625 (2020/N) – Germany – Lignite phase-out.*

Slovakia coal phase out -The coal phase out by 2030 will be supported by subsidies under the Service of general economic interest scheme

Slovakia's current (2017) energy mix is dominated by fossil fuels and nuclear…



…But coal generation has been decreasing over the past years

Since 2013, 1,210 MW of coal generation capacity has been decommissioned:

- In 2013, the EVO 2 power plant (4x110 MW) was decommissioned,
- Since 2014, blocks 1 and 2 of the Vojany 1 power plant have not been in operation.
- In late 2015, blocks 3 and 4 of the Nováky power plant have been phased out (due to non-compliance with emission limits and technical obsolescence).
- In 2016, another 2 blocks of the Vojany power plant and one block of the Nováky power plant were decommissioned.

Slovakia coal phase out is planned for the end of the decade…

- Resolution no. 336/2019 on the Action plan for the transformation of the Upper Nitra coal region was approved by the Slovak Government on 3 July 2019.
- The resolution provides that the **support for electricity generation from coal and lignite will be abolished from 2023 onwards**.

…But Slovakia ensures a smooth transition via SGEI

- In **2018**, the Slovak Republic notified the European Commission a State Aid measure to provide compensation to Slovenske Elektrane (SE), the owner & operator of the Novaky coal power plant, for the provision of a public service obligation.
- Novaky power plant is considered as key to ensure security of supply in a relatively isolated area.
- Slovakia considers that SE provides clearly a **Service of General Economic Interest (SGEI)** and the compensation measures (compensation for the production from indigenous coal) are necessary to ensure security of supply until the completion of a grid investment in the area.
- **Compensation will terminate** once the grid investment is completed, and **in any case by the end of 2023**.
- The **EU Commission approved the plan** in 2019, considering that the measure fulfils the conditions laid down in the 2012 SGEI Framework.

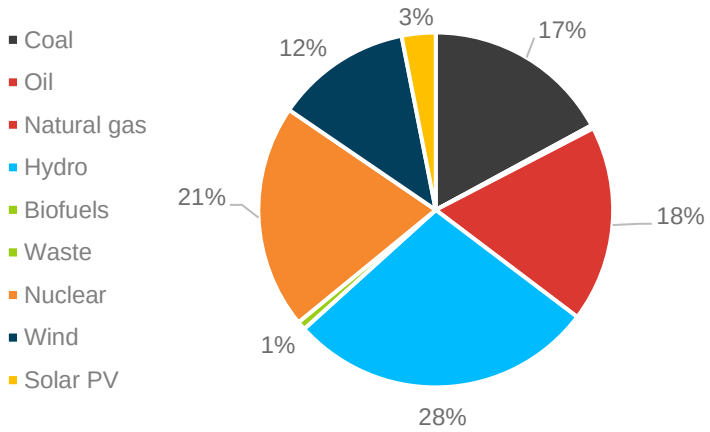
Note: Energy mix in 2017 as presented in the Slovakian National Energy and Climate Plan.
Source: Compass Lexecon analysis based on: Slovakia NECP, Slovenské Elektrane (2021) Novaky brown coal power plant, Slovenské Elektrane (2021) Vojany black coal power plant. SA.52687 Electricity production from indigenous coal in Slovakia.

Romanian coal phase out - Romania plans to phase out coal power generation by 2032

Romania's current electricity mix is dominated by hydro, nuclear power, natural gas and coal.

- Coal usage has decreased in Romania since 1990, in parallel with an increase in nuclear and gas capacity.
- **Coal accounts for 15% of Romania installed capacity** (8 thermal plants, 4,590MW), and for **17% of electricity production**
- 90% of Romania's coal capacity is operated by CE Oltaniea, a state-owned power company

Romania electricity generation mix (2019)



Romania has committed to phase out coal and lignite power production by 2032 in its National Resilience and Recovery Plan (NRRP) endorsed in September 2021 by the European Commission

- The national plan sets targets for the decommissioning of coal capacity:
  - 1,695MW by the end of 2021 (37% of total capacity)
  - 2,355MW by the end of 2022 (51% of total capacity)
  - 3,780MW by the end of 2025 (82% of total capacity)
  - 4,590MW by the end of 2032 (100% of total capacity)
- A **law on decarbonisation is planned to be passed by Q2 2022.** This law will include:
  - An implementation schedule for the decommissioning of the coal and lignite installed capacity
  - Measures for the rehabilitation of mines to be closed (E.g. landscape, topsoil and vegetation restoration)
  - Socio-economic measures to support coal communities (e.g. training measures)
- In addition, **other measures will be taken to support coal phase-out, as provided in the NRRP**:
  - Development of *County Development strategies* (to assess the impact of coal phase out at a local level). Implementation of ***Just Transition Territorial Plans*** **(funded by the EU Just Transition Fund**)
  - Revision of the *National Energy Strategy* to model the different energy mix scenarios
  - Implementation of a restructuring plan for CE Oltaniea
  - 300m€ allocated between 2022 and 2026 to develop 1.3 GW of gas production capacity (still under review by the European Commission)

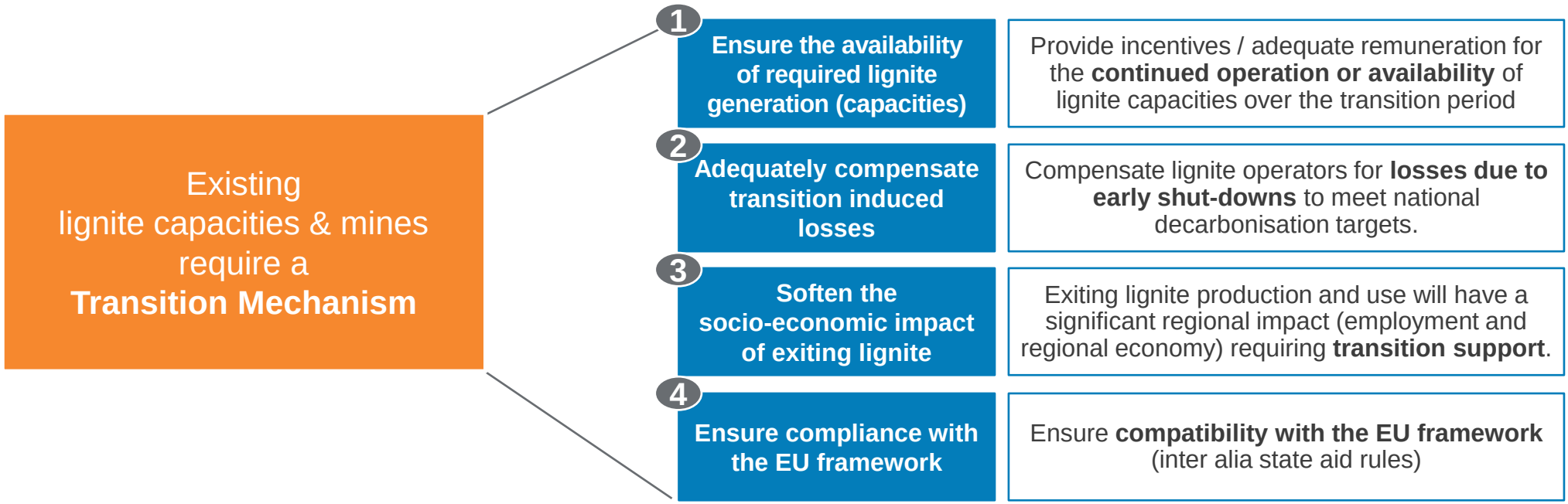
Source: Compass Lexecon Analysis based on: National Resilience and Recovery Plan 2021, Enerdata (2021) Romania pledges to exit coal at the latest by 2032, IEA (2021) Romania country profile, Euroactiv (2021), Romania commits to phase out coal by 2032, Restructuration Plan CE Oltaniea

The EU framework for Services of General Economic Interest (SGEI)

Basis for this aid	**Framework** ▪ "Altmark" judgement **Precedence** ▪ Slovakia (SA.52687) ▪ Spanish precedent may have been superseded by Sector investigation on capacity markets and might not be cleared in that form any more. **Rationale for clearance** ▪ SGEI refers to a service that has widespread socioeconomic benefits (i.e. a public good) but cannot be provided by the market.	There are **two key steps** required to receive aid as a SGEI 1. Classifying the provision of electricity by an installation as a SGEI i.e.: proving that there is a **market failure** where the market is unable to provide the required public services (e.g. meeting the "N-1 security standard"); and that no other electricity producer can address the market failure (i.e. proving the **exclusivity situation**) 2. Specifying a compensation mechanism and proving that compensation is set at a reasonable level without overcompensation or any resulting distortions to competition (e.g. cross-subsidisation).
Timing	**How fast could the aid be available?** ▪ Can be procured relatively quickly, as Slovak example shows	**For how long could the aid be available?** ▪ In principle an SGEI can be non-limited, but following the Slovakian precedent, the SGEI support would have to be time-limited.
Eligible costs and magnitude	▪ Slovak example shows that – in contrast to CRMs – compensation for energy produced (MWh) could be accepted by commission.	▪ The design must ensure that the compensation does not exceed what is necessary and that it is equivalent to the theoretical amount if the market failure can be provided by a competitive solution
Summary evaluation	**Key benefits** ▪ Recent success in the provision of aid in Slovakia ▪ More flexibility compared to CRMs (carbon limits, form of compensation and dispatch) ▪ Potentially a cheaper cost option from customer perspective than CRMs (if the compensation is tightly defined)	**Key limitations** ▪ Time-limited measure; must show how the market failure can be addressed through other means ▪ Requires a strong case to define specific generation as a SGEI ▪ Strict requirements for compensation mechanism

Source: Compass Lexecon Analysis

The required Transition Mechanism needs to balance a broad set of requirements



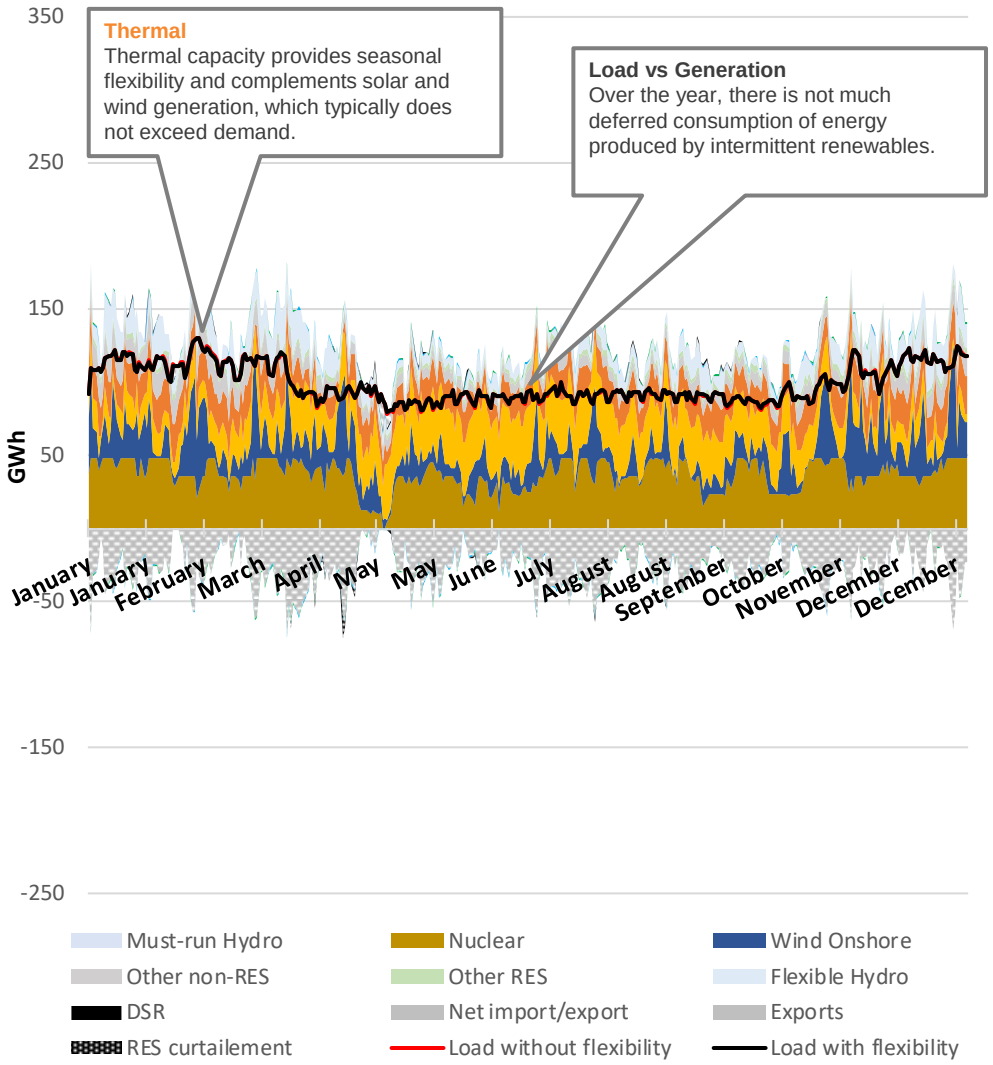
Source: Compass Lexecon Analysis

Annexes

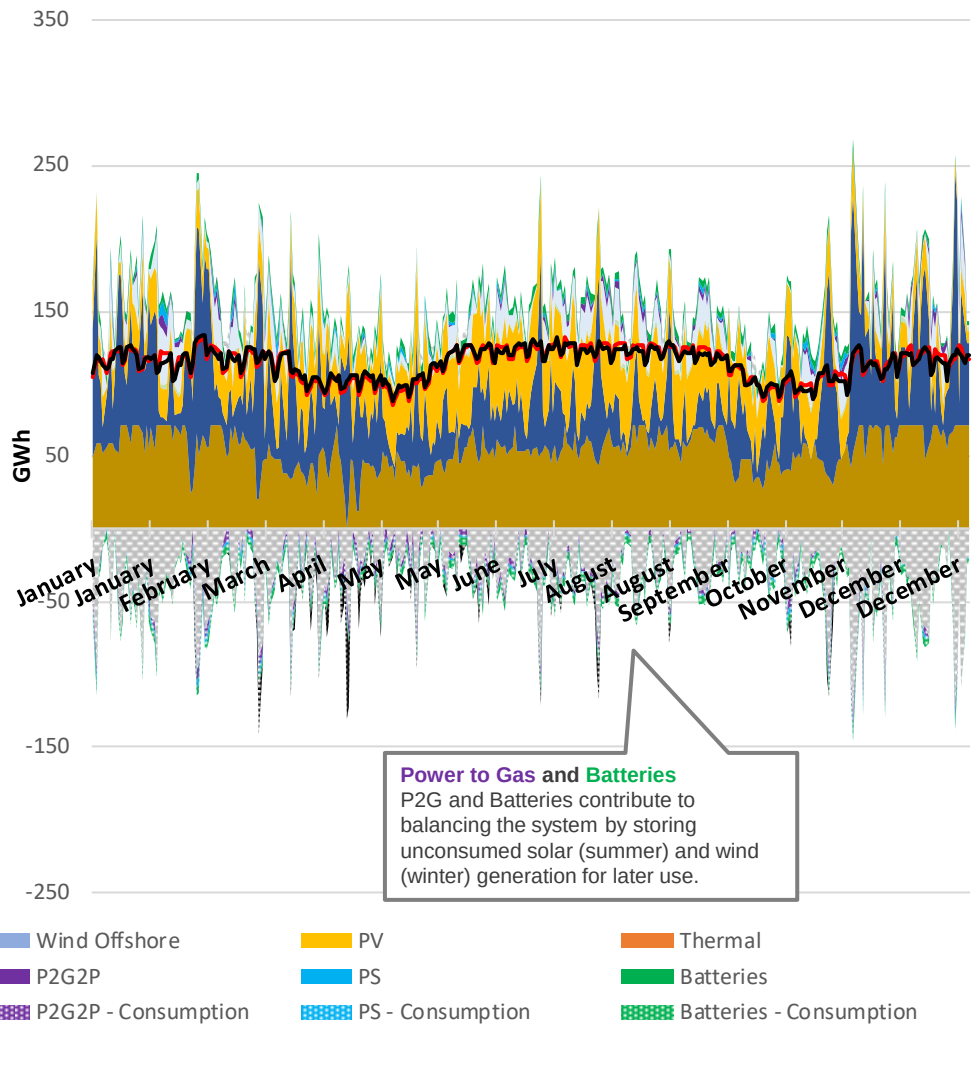
Annex A - Market modelling hourly dispatch - EU IAS scenario

While thermal capacities provide seasonal flexibility in 2030, long-term storage provides seasonal flexibility in 2050

Daily generation mix in 2030



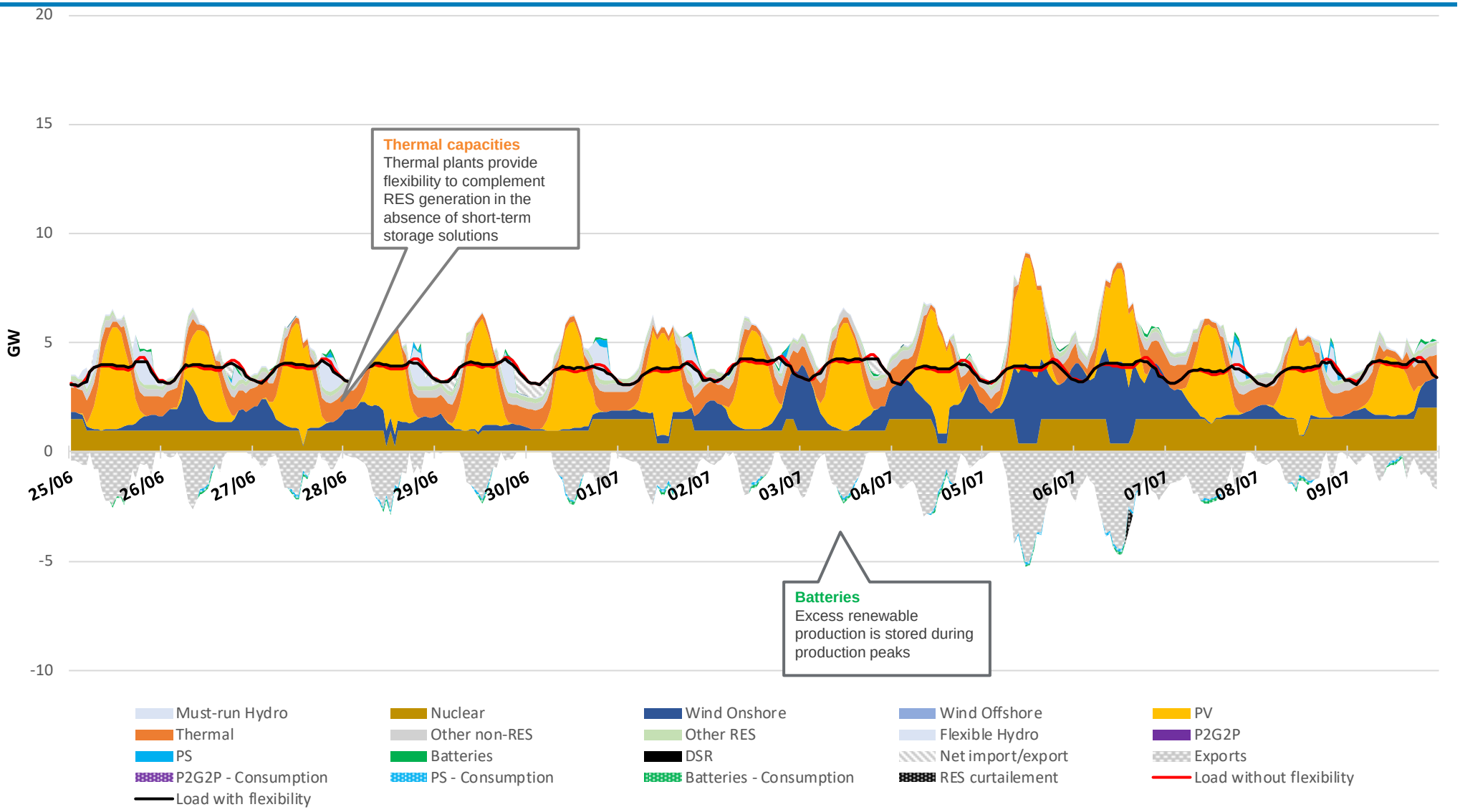
Daily generation mix in 2050



Source: Compass Lexecon

During peaks of solar production in 2030, thermal capacities provide day flexibility to complement RES production

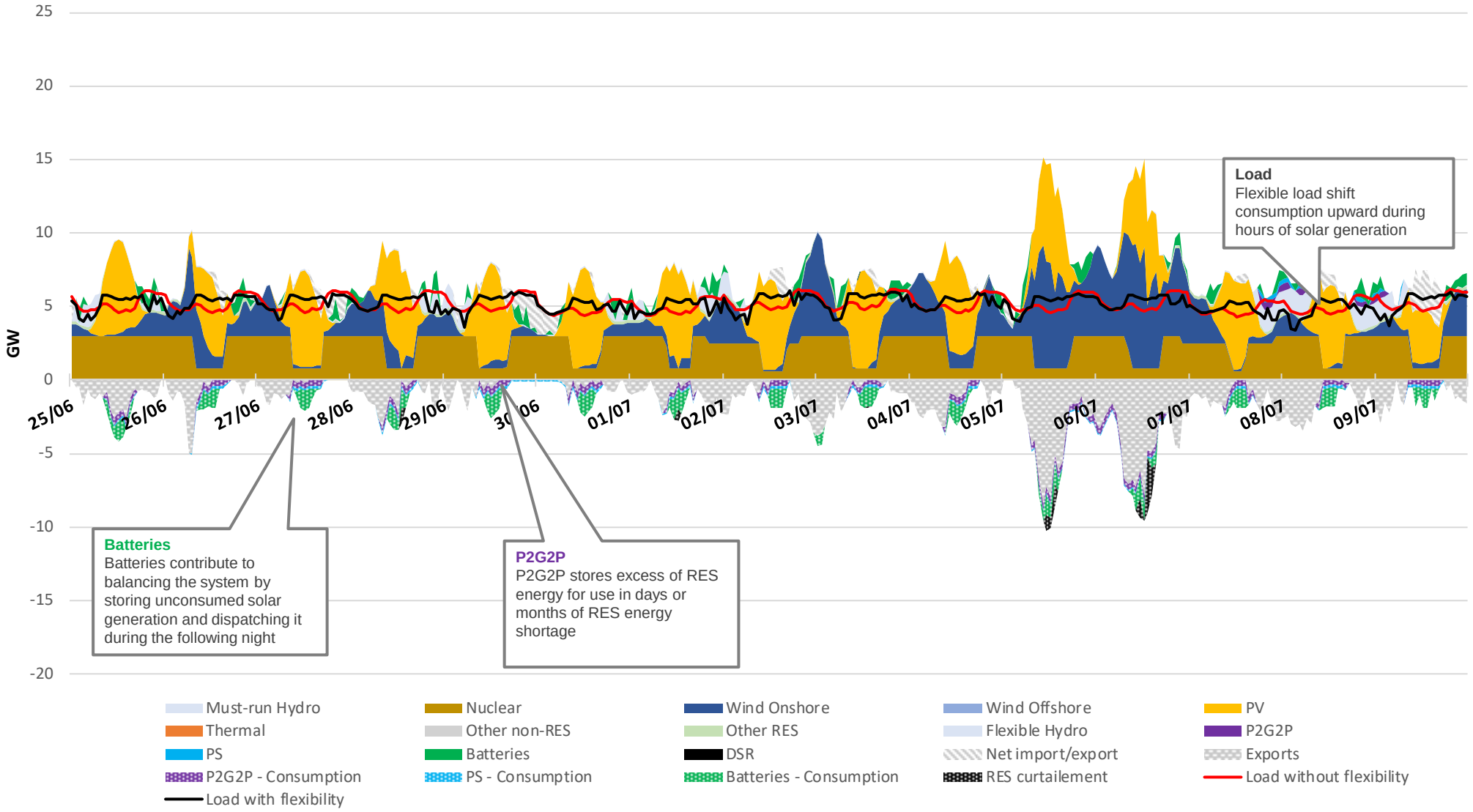
Hourly generation mix during summer peak production in 2030



Source: Compass Lexecon

During peaks of solar production in 2050, batteries, P2G storage and flexibility of demand absorb the surplus of RES generation

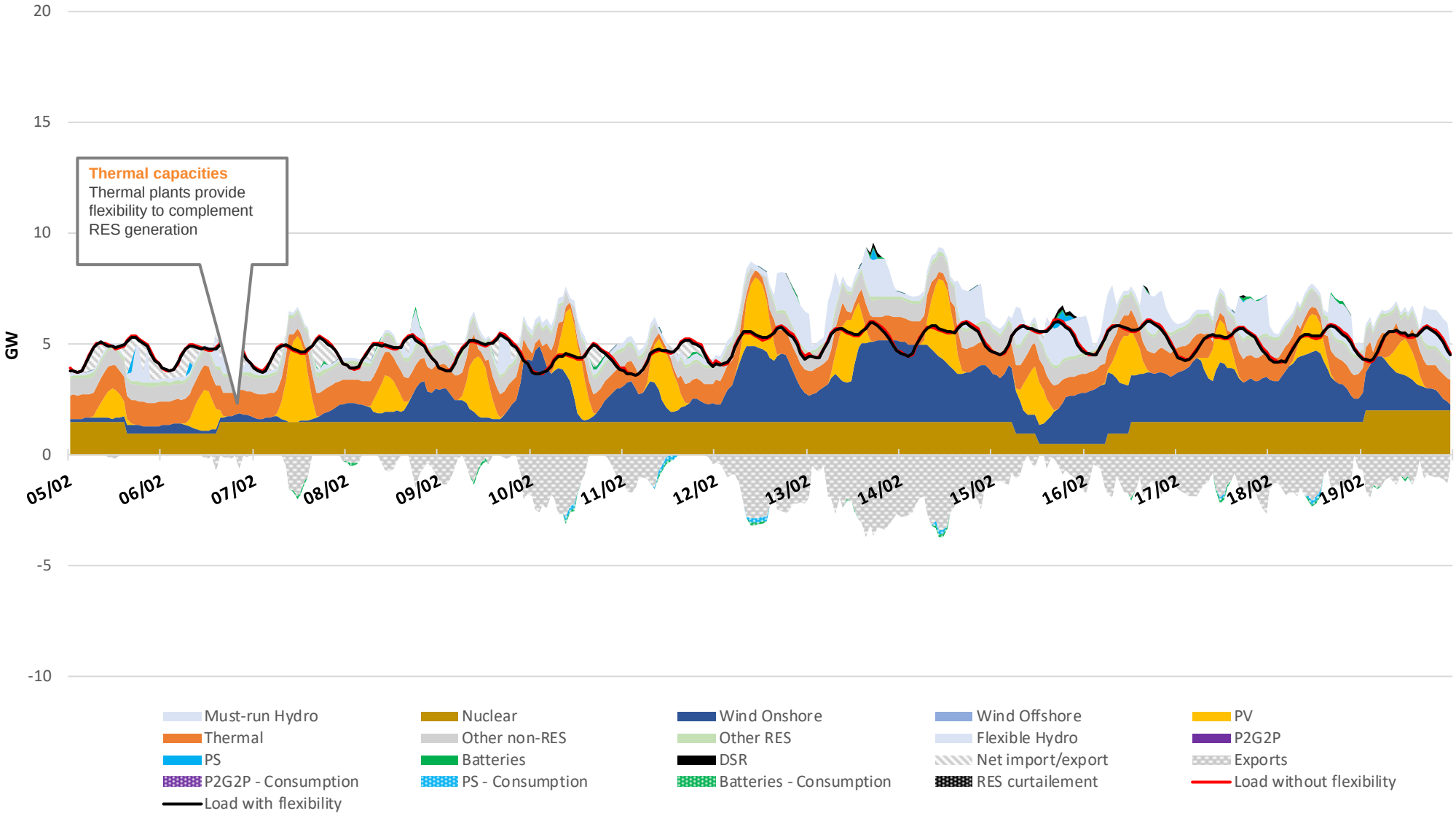
Hourly generation mix during summer peak production in 2050



Source: Compass Lexecon

During peaks of wind production in 2030, thermal capacities provide day flexibility to complement RES production

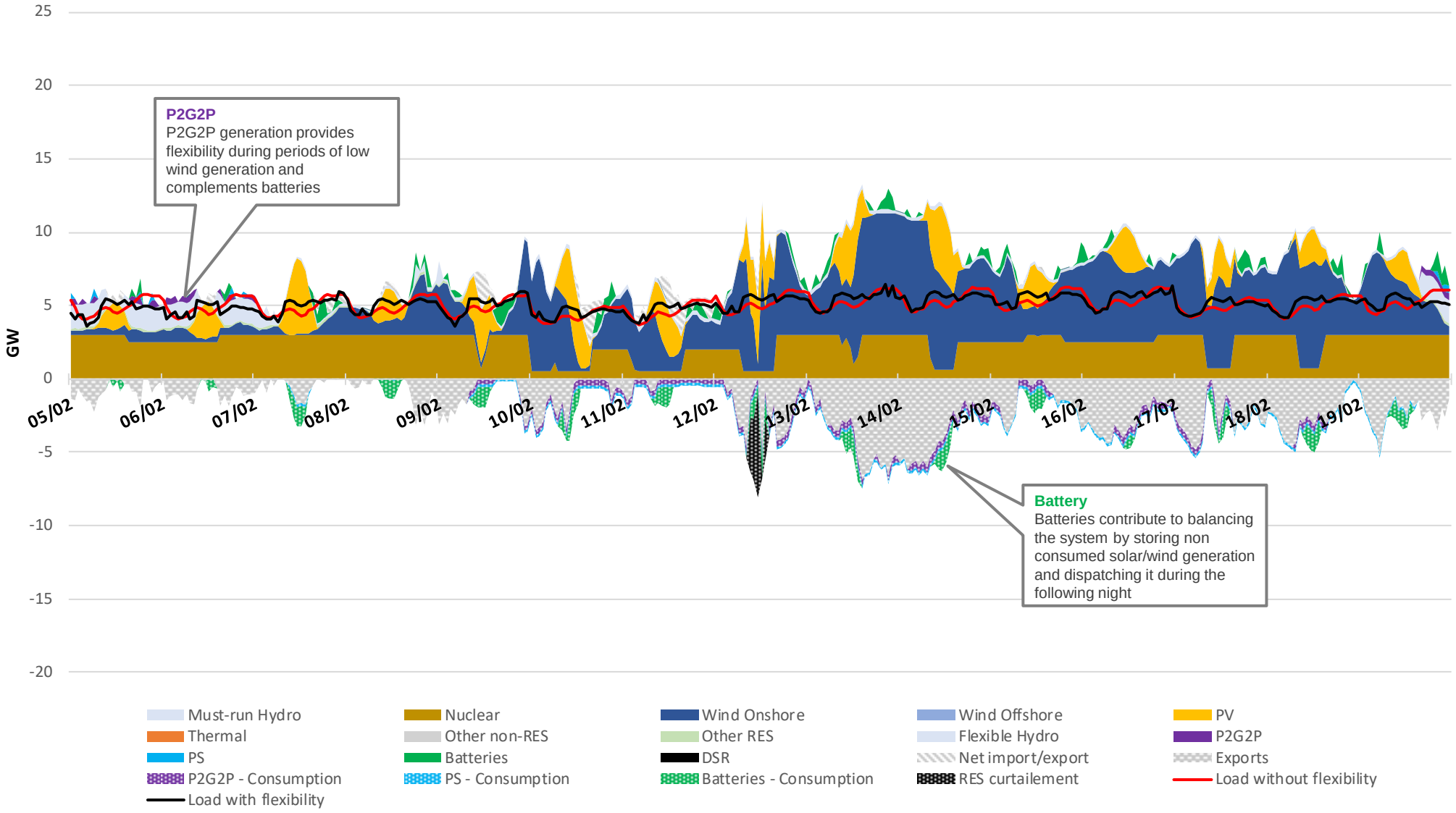
Hourly generation mix during winter peak production in 2030



Source: Compass Lexecon

During peaks of wind production in 2050, increased batteries, P2G storage and flexibility of demand absorb the surplus of RES production

Hourly generation mix during winter peak production in 2050

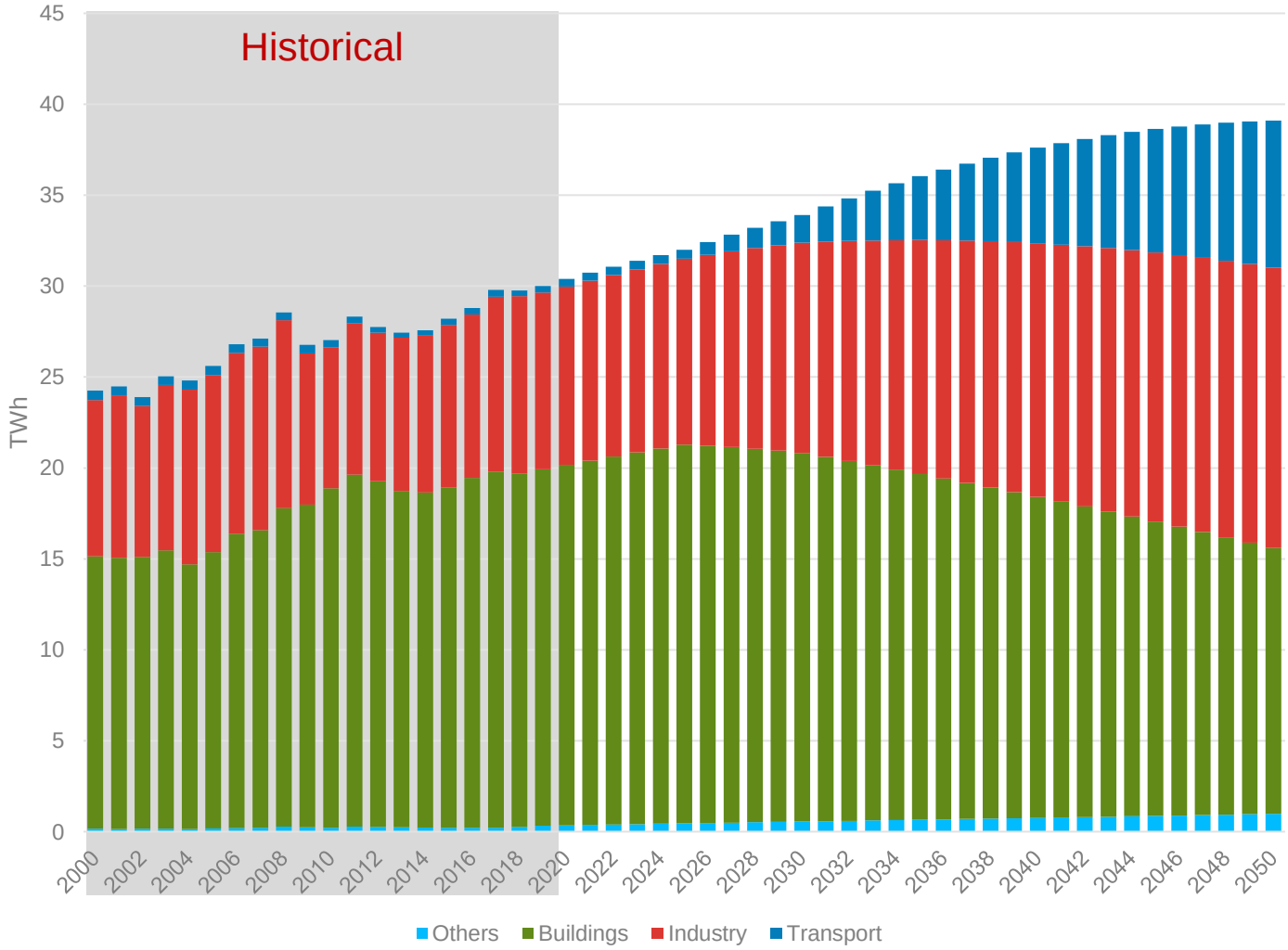


Source: Compass Lexecon

Annex B – Power market modelling detailed assumptions

Driven by the electrification of various sectors, Bulgaria's electricity consumption is expected to rise across the forecast horizon

Final electricity demand (net) forecast[1]



- Bulgaria's final electricity demand is projected to reach c.39TWh by 2050, a 28% increase from 2020.
- The increase in power demand is primarily driven by the electrification of the transport sector, accounting for c.20% of the total final electricity demand by 2050 and to a lesser extent the electrification of the industry, accounting for c.40% of the total final demand by 2050.

Source: Compass Lexecon
Notes: 1. Historical data from the National Statistical Institute of Bulgaria; 2. Other includes agriculture and forestry and fishing

The electricity demand from transport is expected to increase materially due to EVs, while that of buildings to drop due to energy efficiency

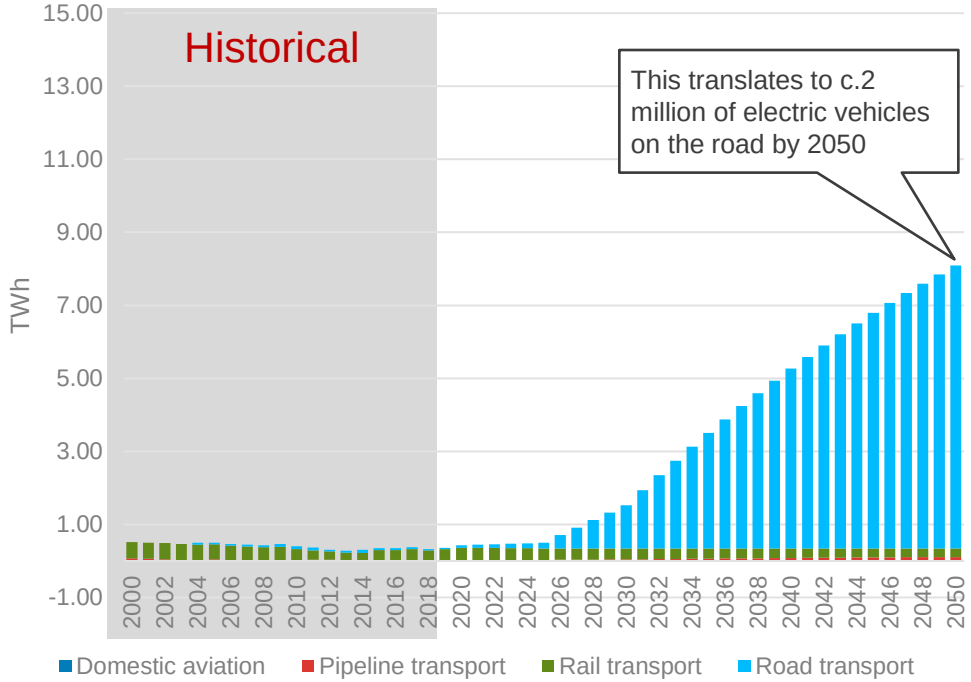
- Road transport electrification is expected to drive electricity demand from the transport sector.

	2019[1]	2030	2050
Transport average electrification rate (%)	1%	10%	84%

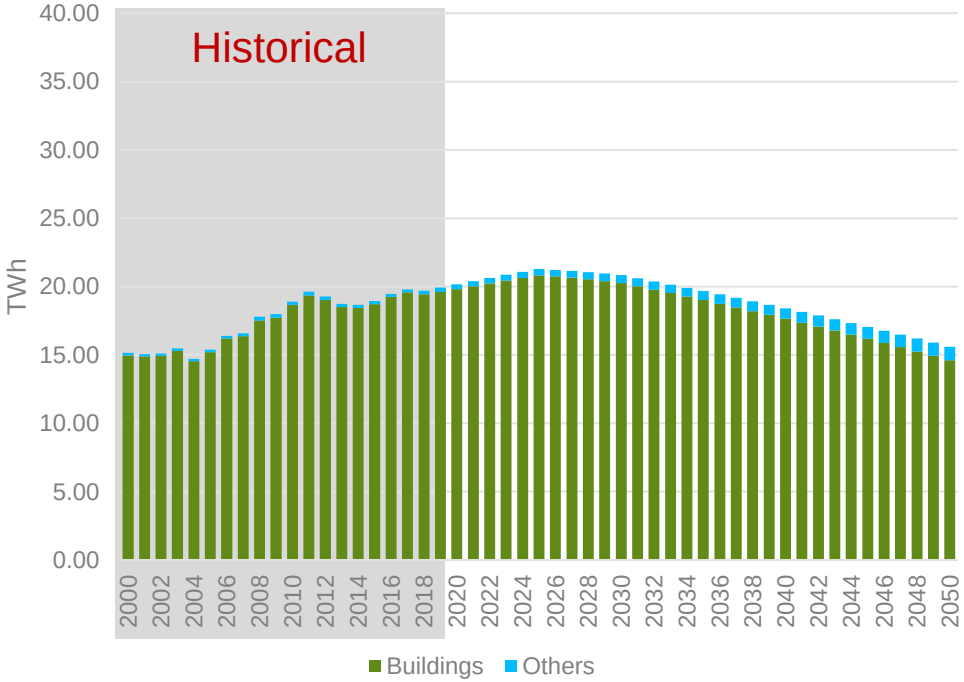
- Buildings energy efficiency is expected to improve materially over the forecast horizon, lowering overall energy needs. The yearly renovation rate of existing households required starts at 0.5% in 2025 and reaches 2.5% by 2050.

	2019[1]	2030	2050
Other sectors average electrification rate (%)	47%	58%	64 %

Bulgaria final electricity consumption (net) in the transport sector[1]



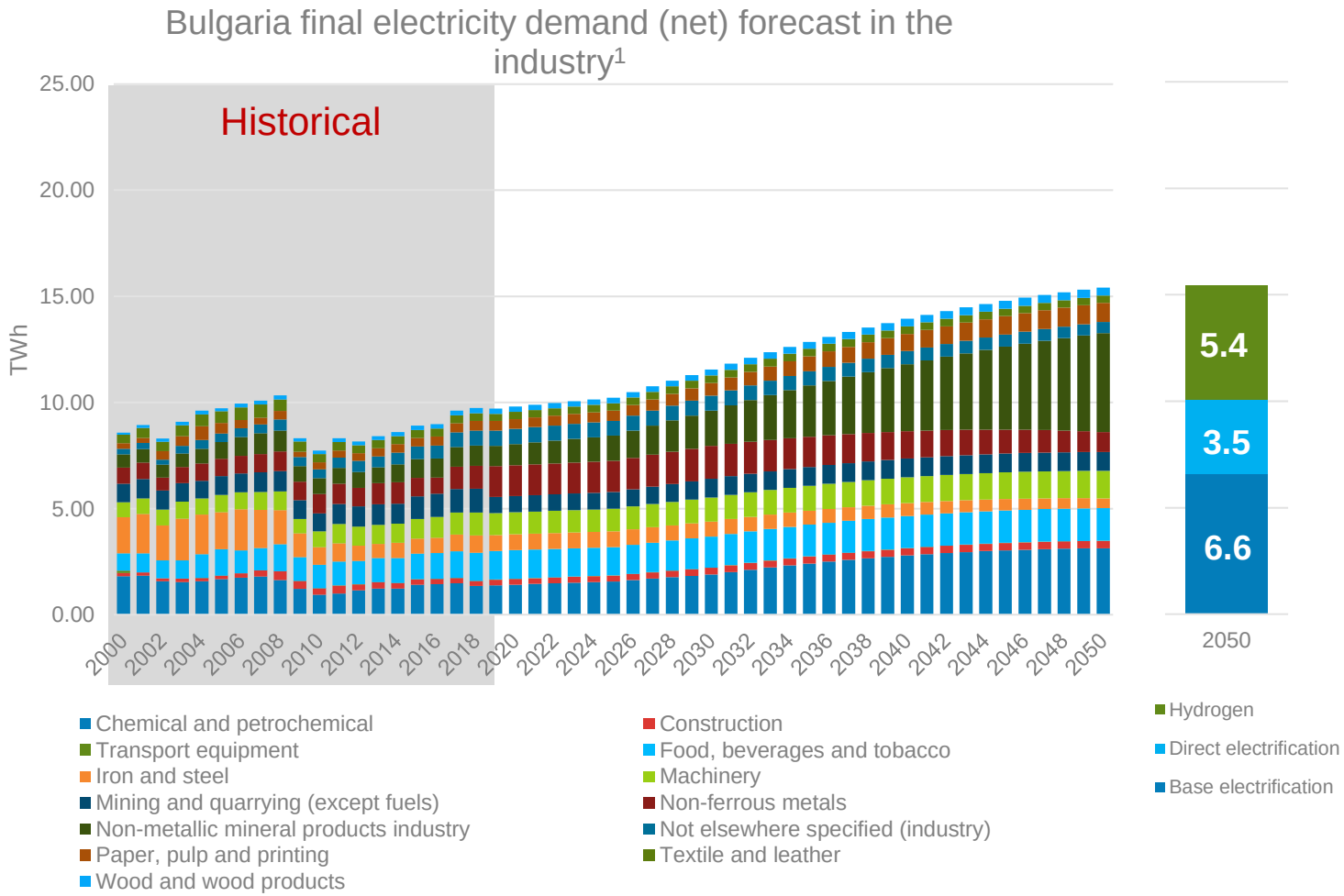
Bulgaria final electricity consumption (net) in Buildings and other sectors[2]



Source: Compass Lexecon
Notes: 1. Historical data from the National Statistical Institute of Bulgaria; 2. Other includes agriculture and forestry and fishing

Direct and indirect electricity consumption in the industry is expected to reach c.15.4TWh by 2050, a 56% increase from 2020

	2019[1]	2030	2050
Industry average electrification rate (%)	31%	40%	70%



- Electrification of the industry is expected to come primarily from the chemical and petrochemical industry, and the non-metallic mineral products industry.
- In the chemical industry, electricity is expected to have an increasing use: (i) to generate heat; (ii) for direct chemical transformations via hydrogen; and (iii) for direct chemical transformations via electrochemical methods.
- In the non-metallic mineral products industry, electricity is expected to play an increasing role in process heat.

Source: Compass Lexecon
Notes: 1. Historical data from the National Statistical Institute of Bulgaria;

New end-uses of electricity will provide additional flexibility which is reflected in the modelling of power demand

Power demand modelled flexibility

DSR of last resort

- DSR from existing end-uses (from EC DSR study 2016) can be activated 40 hours per year.

Electric vehicles

- In addition to day/night optimisation, 25% of the vehicles are capable of optimising their load in response to the market price, making possible the modulation of consumption over about ten hours.

Heat pump and cooling

- In addition to day/night optimisation, 50% of the heat pumps are dynamically controlled in response to the market price, making possible the modulate of consumption over 2-3 hours.

Direct Electrification industry

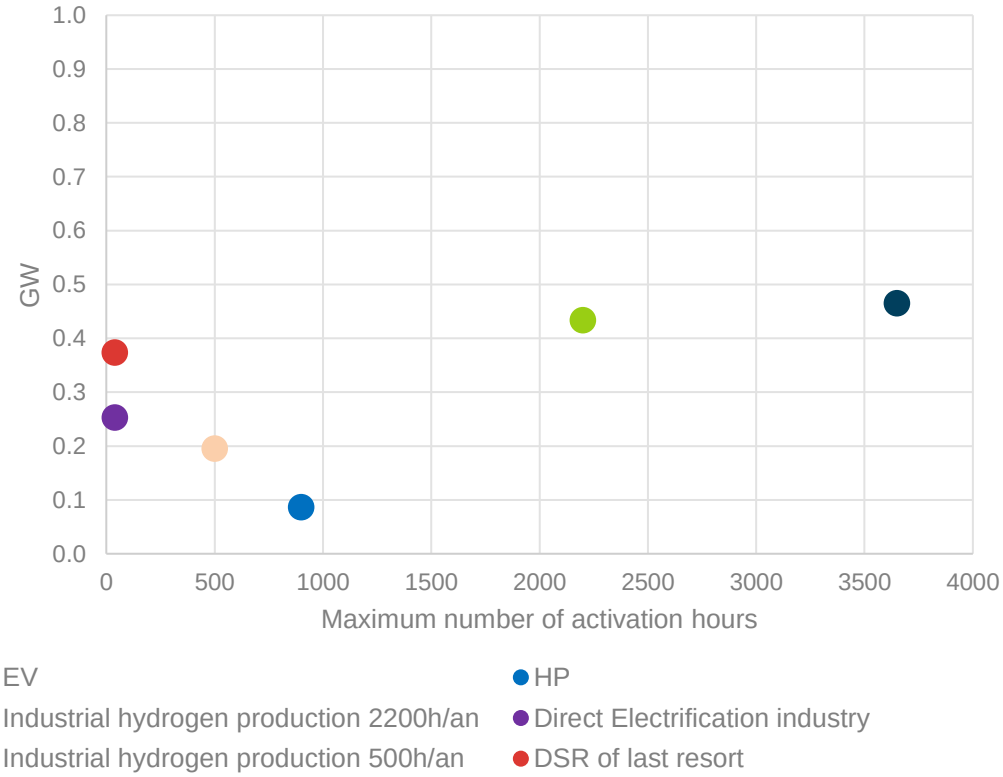
- New industrial electricity demand can be reduced 40 hours per year at 60% of its power

Industrial hydrogen production

To reflect the future potential for flexibility provided by hydrogen production for industry:

- 50% of industrial hydrogen production can be reduced 500 hours per year at 60% of its power.
- 50% of industrial hydrogen production can be stopped 2200h per year

Capacity of demand flexibility in Bulgaria - 2050



Note:
40 hours corresponds to minimum availability for 100% CRM derated factor
EV 25% is based on industry insights and RTE EV study
HP 50% applies to power HP only, based on industry insights and previous EU wide decarb study
Hydrogen 50% is based on industry insights on Electrolysers development (RTE Hydrogen study)

Source: Compass Lexecon

Investment decisions in existing and new plants are driven by investment costs outlook and WACC assumptions

CAPEX for the different technologies (€/kW)

Category	2020	2030	2040	2050	Source/comments
Nuclear	6000	6000	6000	6000	EU REF 2020
Long term storage (Power to gas to power)	5080	2786	1860	935	Calc. based on EU REF 2020
Natural gas CCGT	600	579	575	570	EU REF 2020
Natural gas OCGT	400	386	383	380	EU REF 2020
CC(US) retrofit (Lignite)	2650	2490	2400	2300	Calc. based on EU REF 2020 (to reflect lignite plant age)
Lignite refurbishment	119	119	119	119	
Lignite conversion to biomass	500	500	500	500	Based on round 1 feedbacks
Lignite conversion to steam gas turbine	150	150	150	150	
CCGT CCS	1750	1652	1500	1500	EU REF 2020
Onshore wind	940	910	880	845	EU REF 2020
Offshore wind	2420	2295	2225	2160	EU REF 2020
Solar	476	442	408	393.5	EU REF 2020
Battery (1h)	118	52	47	42	BNEF 2019/20
Run of river (RoR)	3500	3500	3500	3500	Local hydro associations

Source: EU Technology pathways 2020
Notes: PtGtP corresponds to the hydrogen used for power system balancing. CCUS: Carbon capture and Usage or Storage

Estimates of transmission and distribution costs

Literature review

- A number of studies have been conducted to estimate grid costs in various European countries:
  - A study of grid integration costs of PV commissioned by the European Commission in 2014 and carried out by the Imperial College London ;
  - A study of the integration of the RES commissioned by the European Commission in 2014 carried out by KEMA/Imperial College London/NERA/DNV GL;
  - A study of the full costs of electricity provision carried out by the Nuclear Energy Agency in 2018.

- The total grid costs include:
  - **T&D costs**: Costs for building or upgrading transmission networks and distribution networks. It includes annualized CAPEX and OPEX
  - **Connection costs** : the costs of connecting the power plant to the nearest connecting point of the transmission/distribution grid

Average T&D costs from literature review

- The literature shows large variations reflecting the specific features of each individual site and different power systems.
- However based on the literature review, we can infer the following estimates, which represent an “average” of different estimates found in the literature.

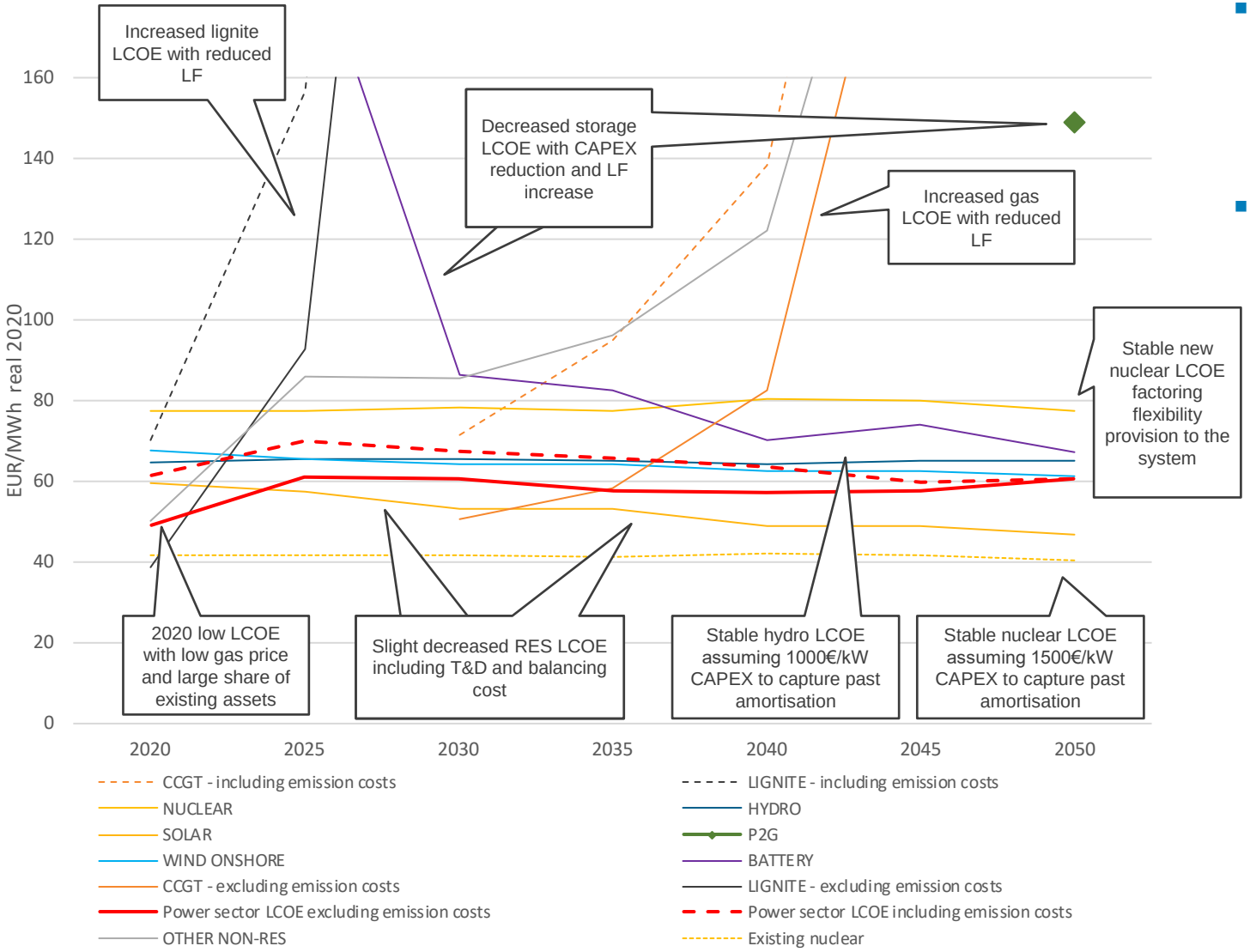
€/MWh	Transmission cost	Distribution cost	Connection cost	Total
Rooftop PV	1.5	2.5		4
Ground-mounted PV	1.5	6	12	19.5
Wind onshore	5	6	5.5	16.5
Wind offshore	5	n/a	30	35

- On the demand side, T&D costs are estimated at 38€/kW of final peak demand based on “2016, EC, DSR impact assessment study”. This estimate is broadly in line with currently observed operating costs of the Bulgarian transmission and distribution power network extracted from the financial statement of network operators.

Source: Compass Lexecon analysis based on Agora (2015) The Integration Costs of Wind and Solar Power; Nuclear Energy Agency (2018) The Full Costs of Electricity Provision; DNV-GL (2019) Cost of offshore transmission

The average LCOE of the power system combines the contribution of each different generating technology and T&D cost

Power system LCOE excluding T&D costs vs Technology LCOE



- The average LCOE of the power system combines the contribution of each different technology as well as the Transmission and Distribution network cost.
- For comparison purposes, the chart compares the Power sector LCOE excluding existing T&D cost with Technology LCOEs.
- The straight comparison of LCOEs between technologies does not provide the full picture. Indeed, comparing directly LCOEs across technologies is not straightforward as the LCOE metric does not encompass the timing of production. Renewables are typically cheap on a LCOE basis, but do not provide the same service as a dispatchable plant such in term of security of supply.

Source: Compass Lexecon
Note: LF stands for Load factor

Modelling considers exogenous interconnection net transfer capacity (NTC) increase based on ENTSOE MAF/TYNDP grid expansion

Max flow (MW)

	2020	2025	2030	2035	2040	2045	2050
BG-GR	550	1350	1350	2350	2350	2350	3250
BG-MK	350	400	500	500	800	800	1300
RO-BG	400	2100	2100	2100	2300	2300	2300
RS-BG	400	400	400	1200	1850	1850	1850
BG-TR	434	434	900	1400	1900	2400	2900

Min flow (MW)

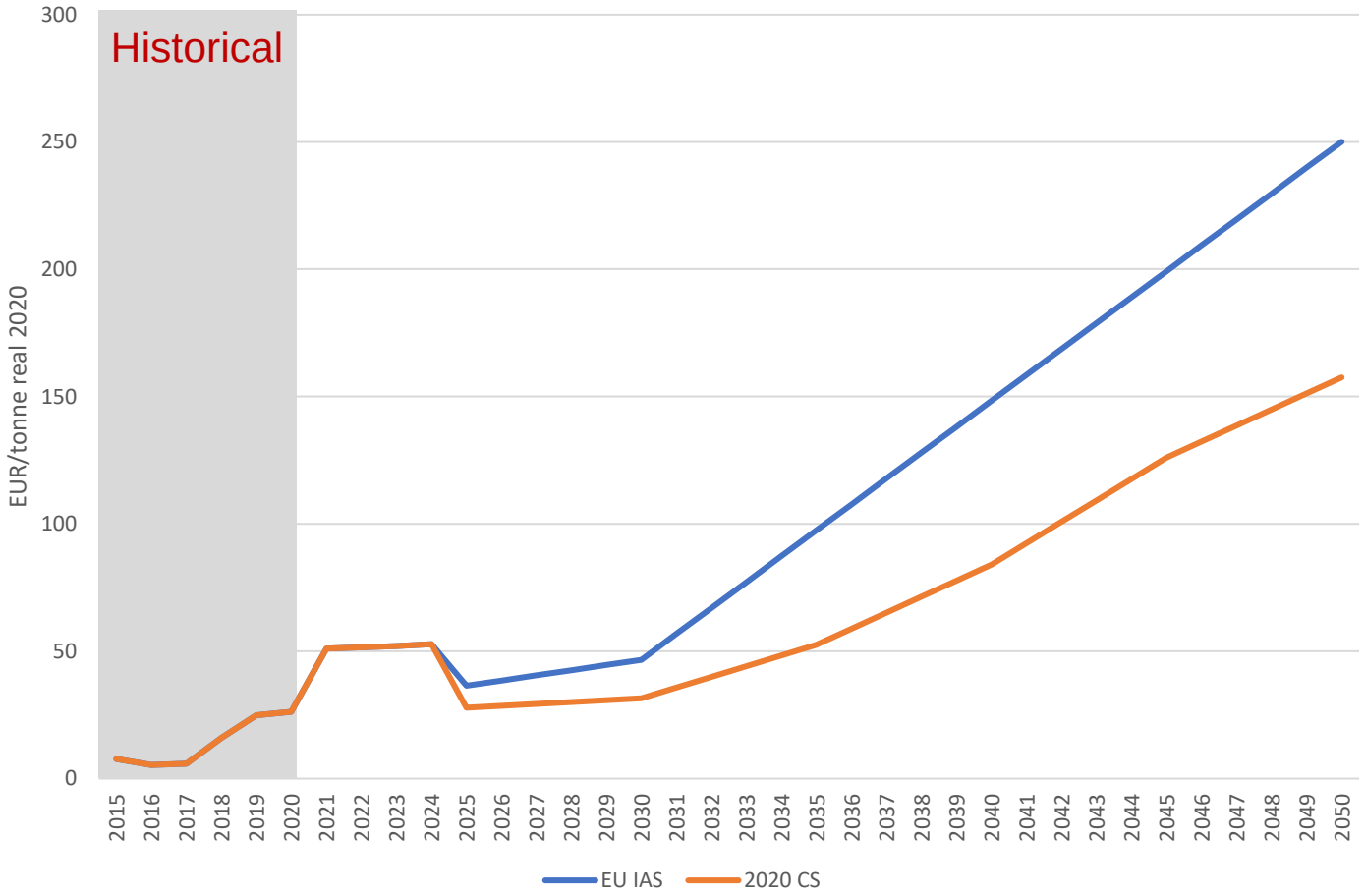
	2020	2025	2030	2035	2040	2045	2050
BG-GR	-400	-800	-800	-1800	-1800	-1800	-2550
BG-MK	-350	-400	-400	-400	-700	-700	-1200
RO-BG	-500	-2100	-2100	-2100	-2400	-2400	-2400
RS-BG	-400	-400	-400	-1300	-2100	-2100	-2100
BG-TR	-500	-500	-1200	-1200	-2400	-2400	-2400

- Interconnections capacity are based on MAF 2020 and ENTSO-E / TYNDP 2020 scenarios.
- Interconnection outlook features an increase of capacity interconnection with neighbouring countries in line with the EU guidelines.

Source: Compass Lexecon and feedbacks from AmCham members

CO_2 prices differ significantly between both scenarios, reaching 250€/tonne in *EU IAS* and 150€/tonne in *2020 CS*

CO_2 price (€2020/tonne)

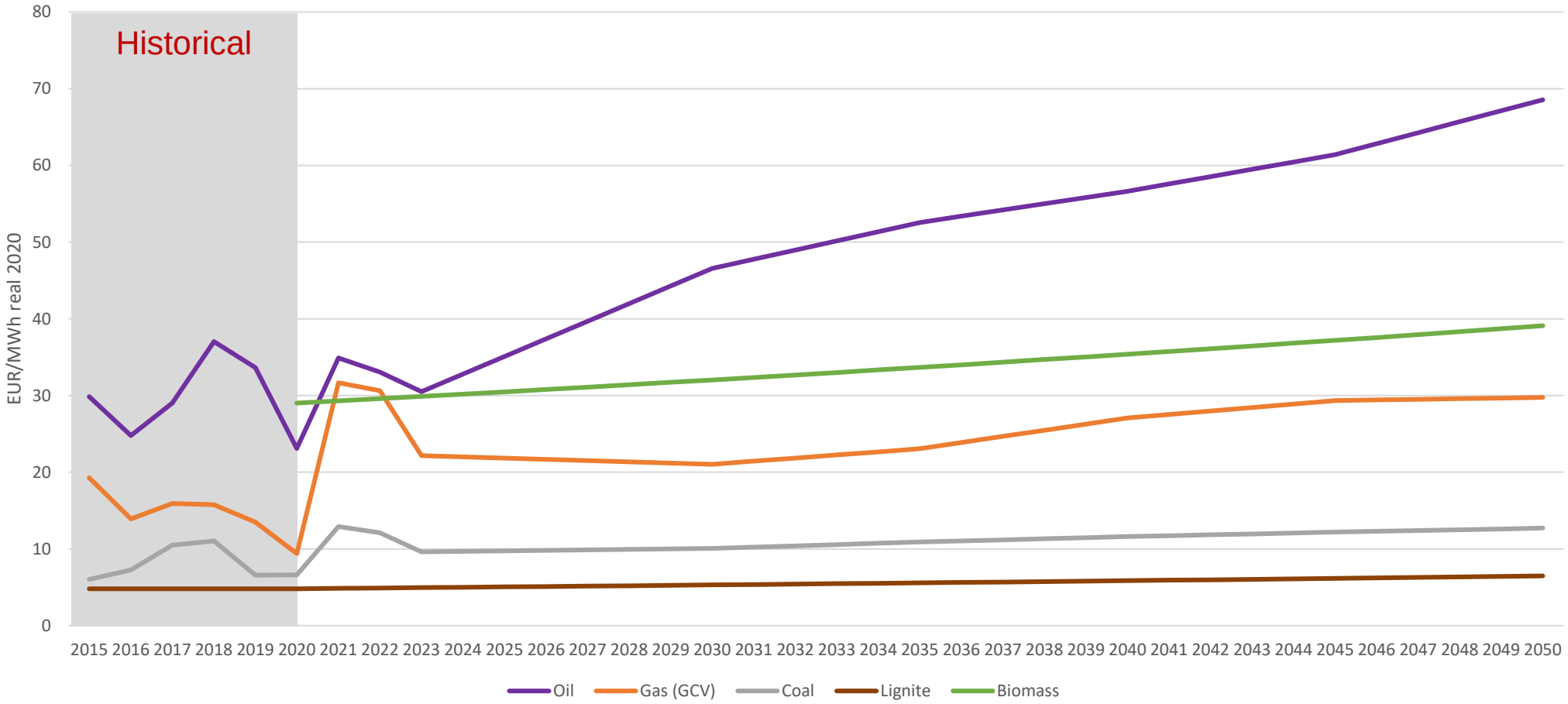


- CO_2 prices in *2020 CS* are based on the 2020 EU Baseline scenario (30€2015/tonne in 2030, 150€2015/tonne in 2050).
- CO_2 prices in *EU IAS* are assumed to converge to EC MIX scenario in 2031 (56.7€/tonne) and EC 2018 Energy Roadmap lower range of decarbonisation scenarios in 2050 (250€/tonne)

Source: EU Reference scenario 2020, EU Ff55 Impact assessment, Forwards as of August 2021

In line with EC Baseline 2020 scenario, imported coal and gas prices are expected to reach c.12.7€/MWh and c.29.7€/MWh by 2050

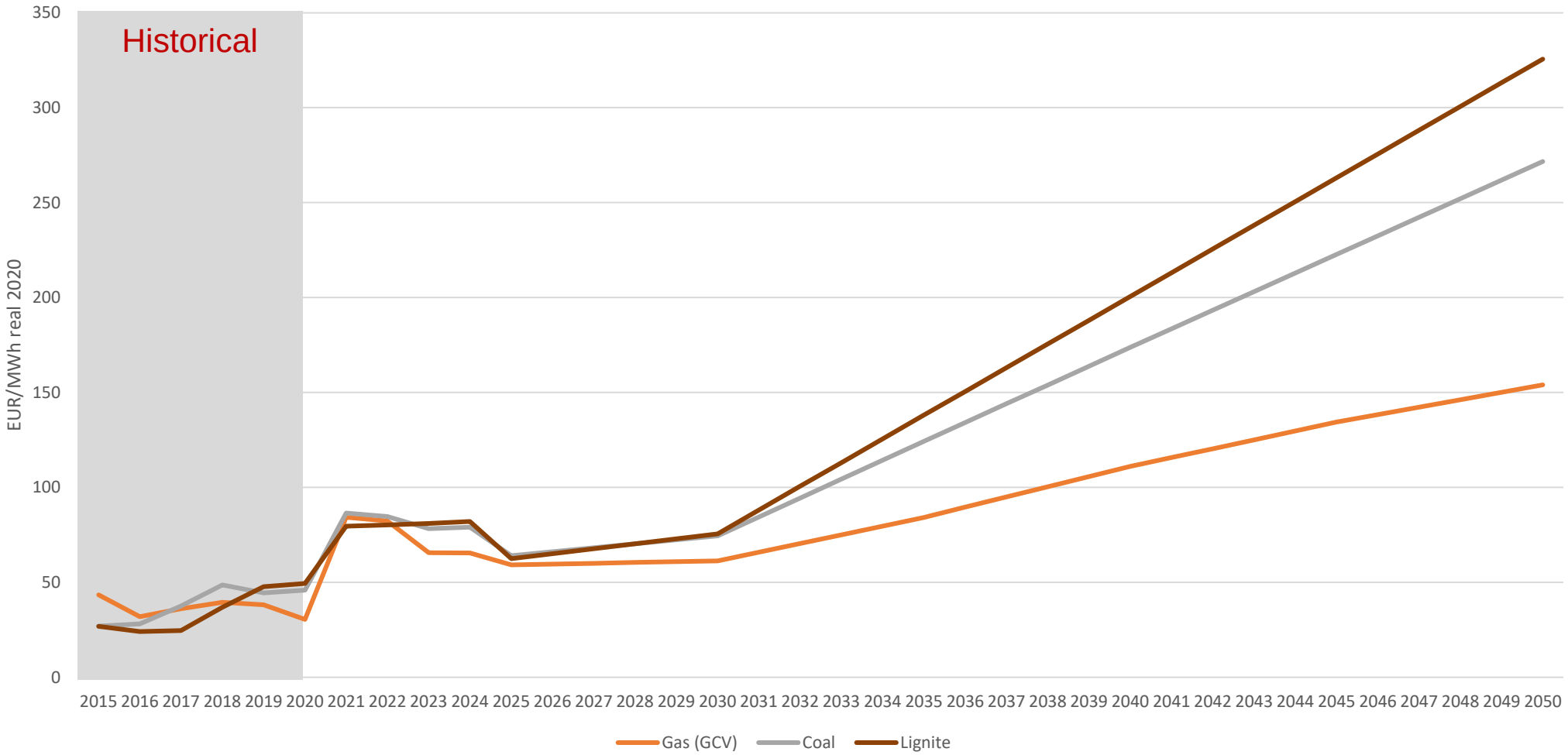
Commodity prices (€/MWh real 2020)



Source: EU Reference scenario 2020, ENTSOE TYNDP 2020, Forwards as of August 2021, Compass Lexecon analysis

With fast rising carbon prices, lignite and coal plants generation costs increase substantially in EU IAS

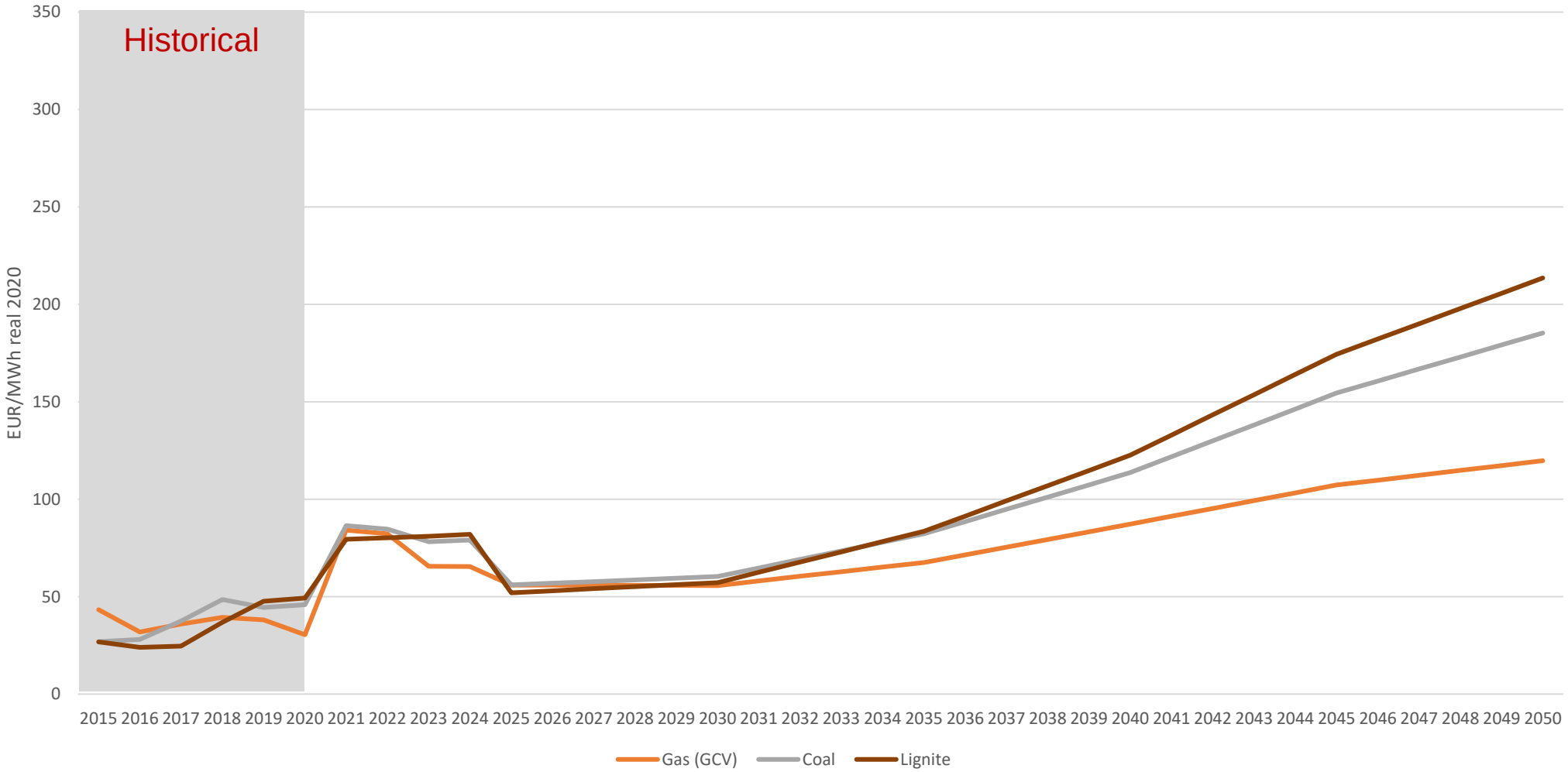
SRMC of thermal plants in *EU IAS* (€/MWh real 2020)



Source: EU Reference scenario 2020, ENTSOE TYNDP 2020, Forwards as of August 2021, Compass Lexecon analysis

Lignite and coal plants SRMCs in the 2020 CS scenario

SRMC of thermal plants in *2020 CS* (€/MWh real 2020)



Source: EU Reference scenario 2020, ENTSOE TYNDP 2020, Forwards as of August 2021, Compass Lexecon analysis

Annex C - EU IAS sensitivities detailed results

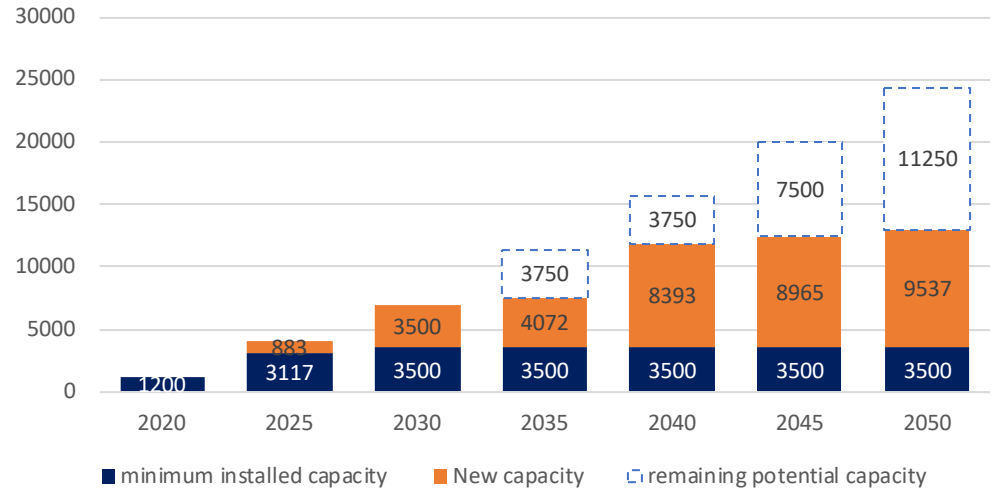
In addition to the core scenarios, five sensitivities of *EU IAS* were analysed to assess key decarbonisation options uncertainties

The "***EU Increased Ambition scenario***" is completed with a range of sensitivities to explore the impact of potential constraints on the deployment of different low carbon technologies, depending on (i) whether nuclear is being built; and (ii) the rate of RES deployment.

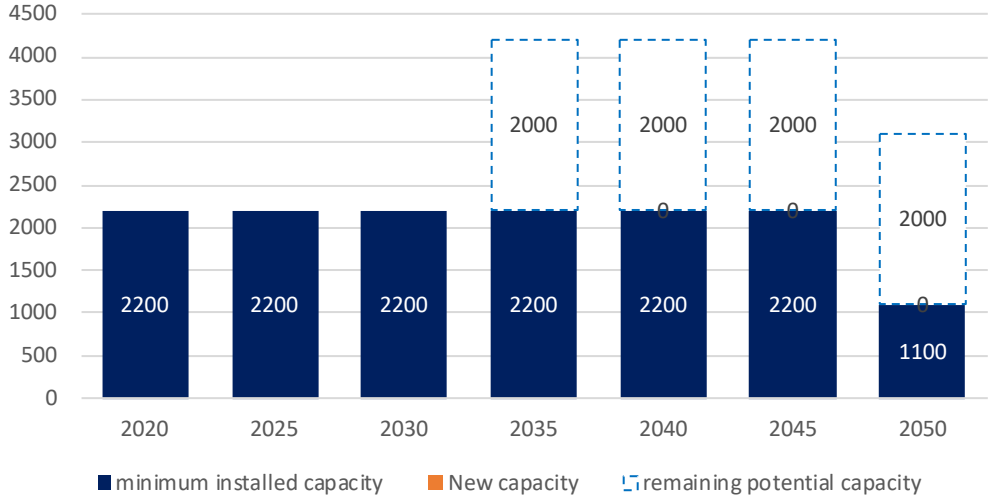
Ff55		Nuclear	Renewables	CO_2 price	Dispatch
A	EU IAS	Investment framework in place to support nuclear buildout	Central buildout potential (11 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
1	EU IAS - without nuclear	No investment framework in place to support nuclear buildout	Central buildout potential (11 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
2	EU IAS - high RES potential	Investment framework in place to support nuclear buildout	High buildout potential (16.1 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
3	EU IAS – low RES potential	Investment framework in place to support nuclear buildout	Low buildout potential (7.5 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
4	EU IAS - without nuclear and high RES potential	No investment framework in place to support nuclear buildout	High buildout potential (16.1 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
5	EU IAS – without nuclear and low RES potential	No investment framework in place to support nuclear buildout	Low buildout potential (7.5 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch

In a scenario without new nuclear capacity, the system relies more heavily on renewables and gas throughout the horizon

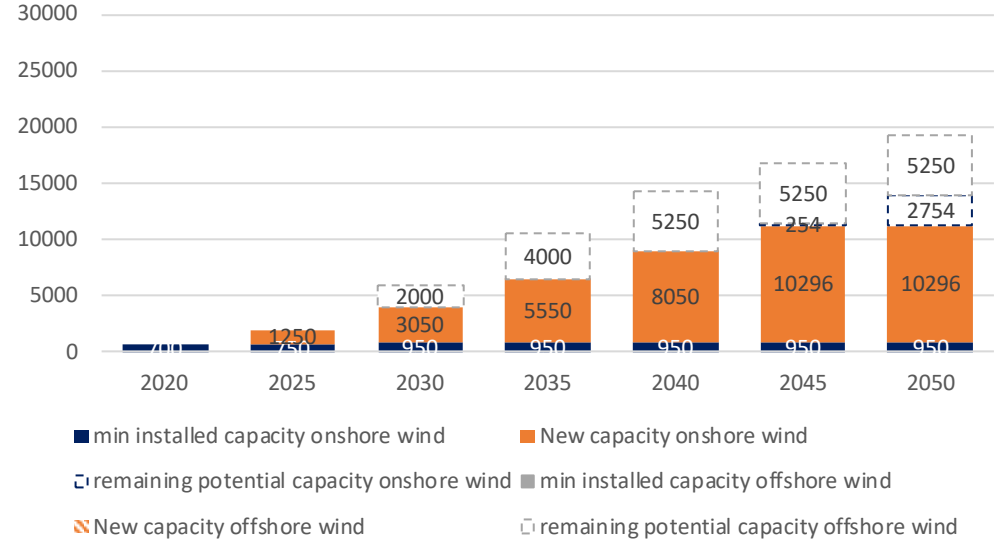
Solar PV – min cap. built, newbuild and remaining potential (MW)



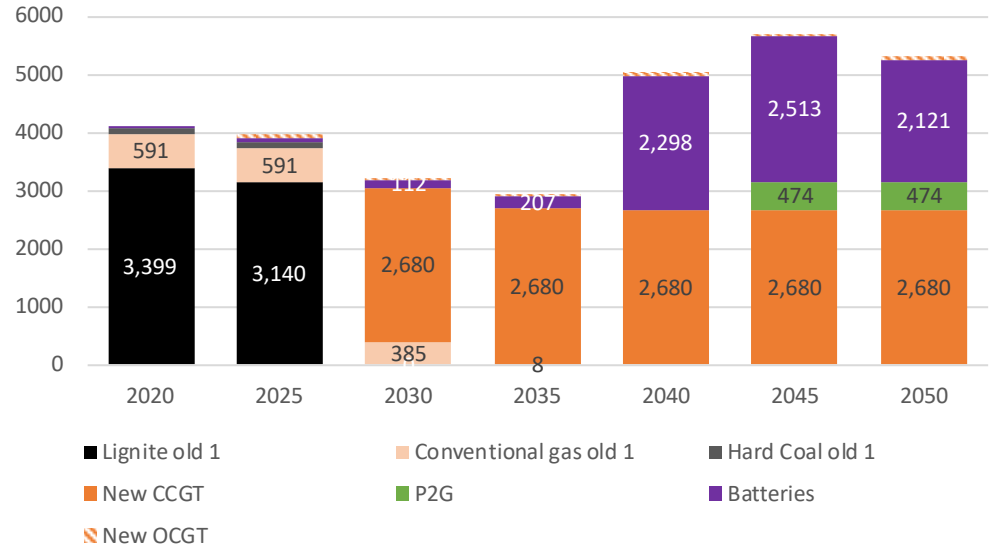
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



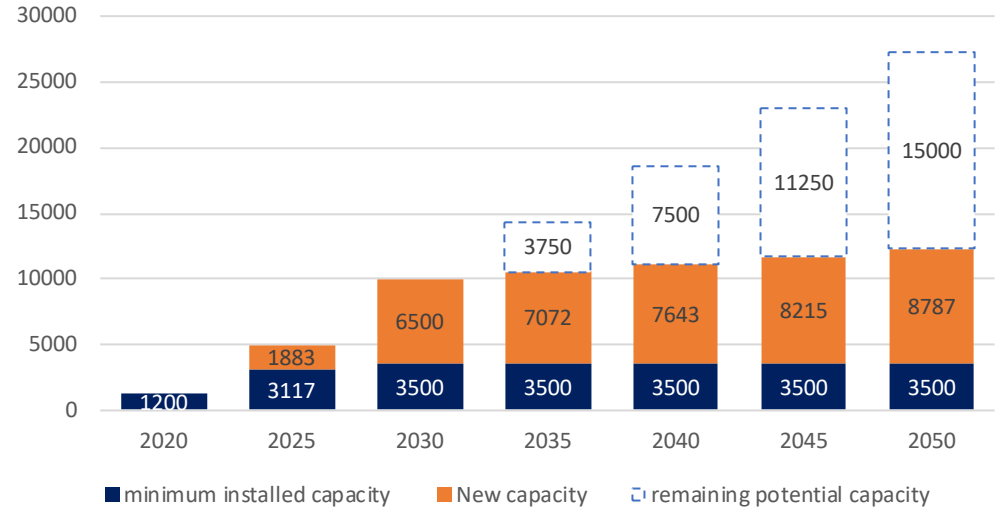
Thermal capacity outlook (MW)



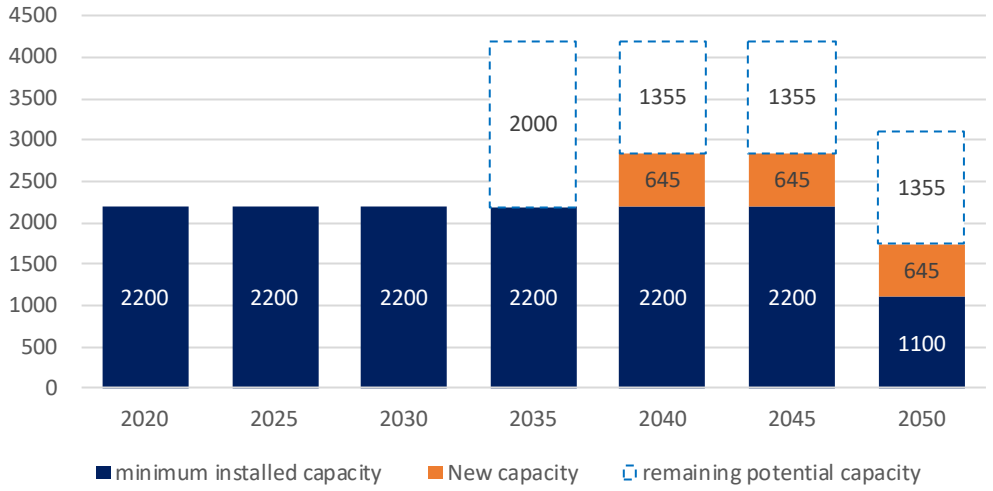
Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

With a higher renewable potential batteries and P2G become more competitive, and less nuclear is required to decarbonise Bulgaria by 2050

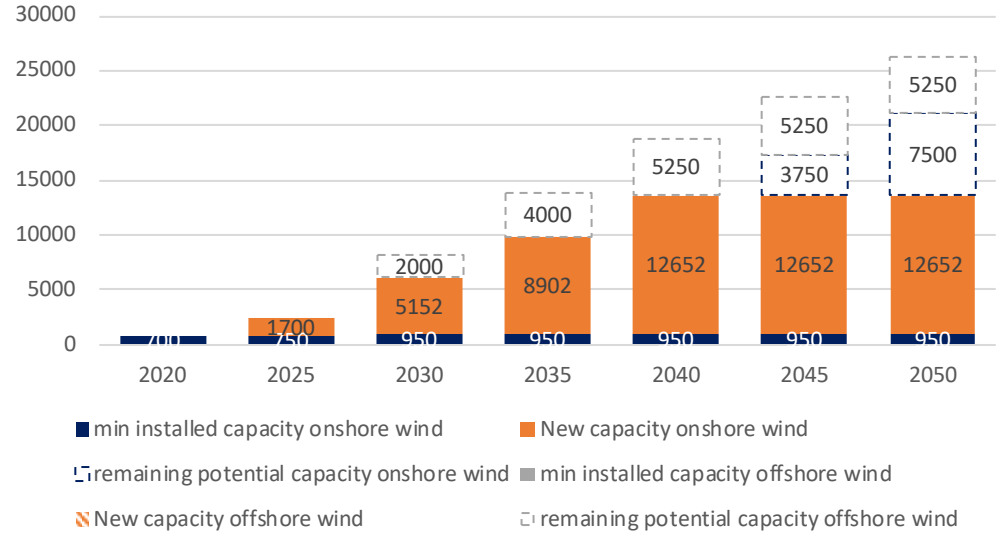
Solar PV – min cap. built, newbuild and remaining potential (MW)



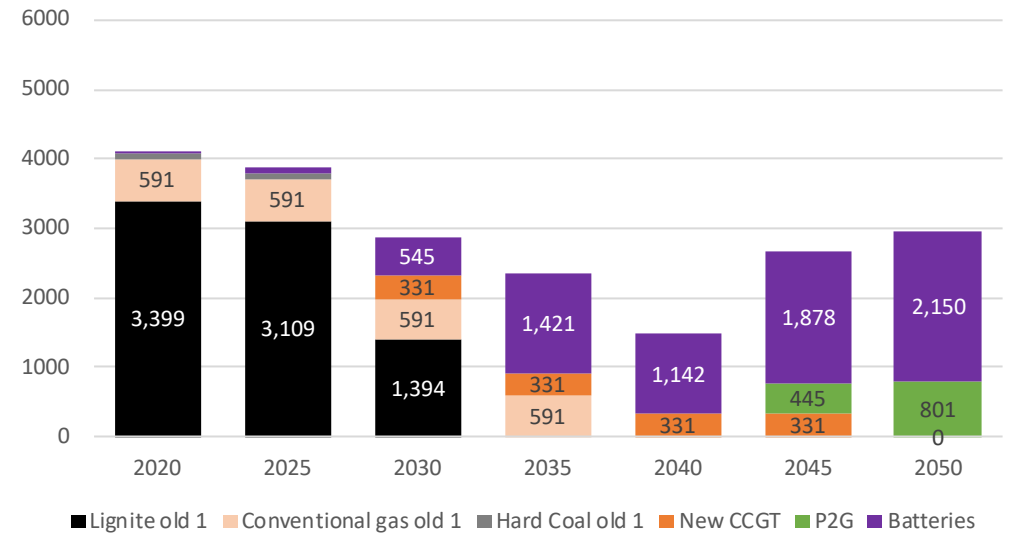
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



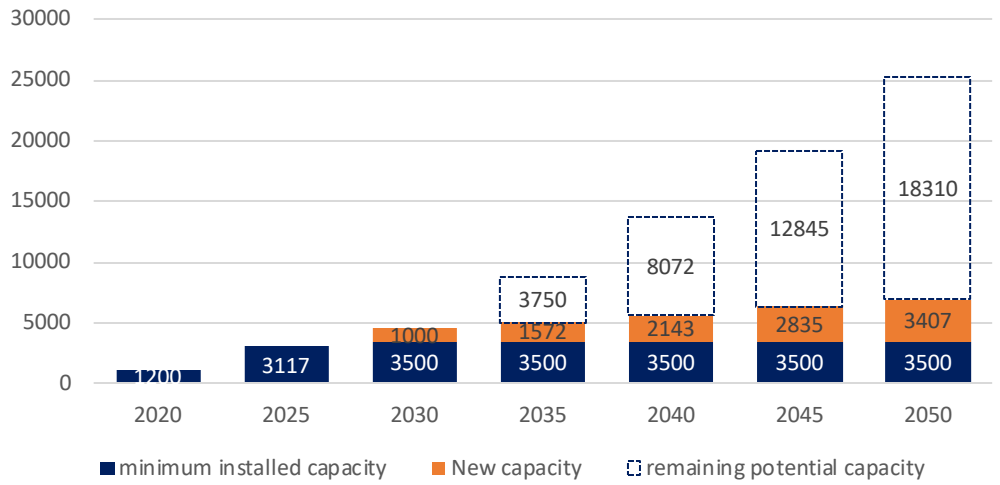
Thermal capacity outlook (MW)



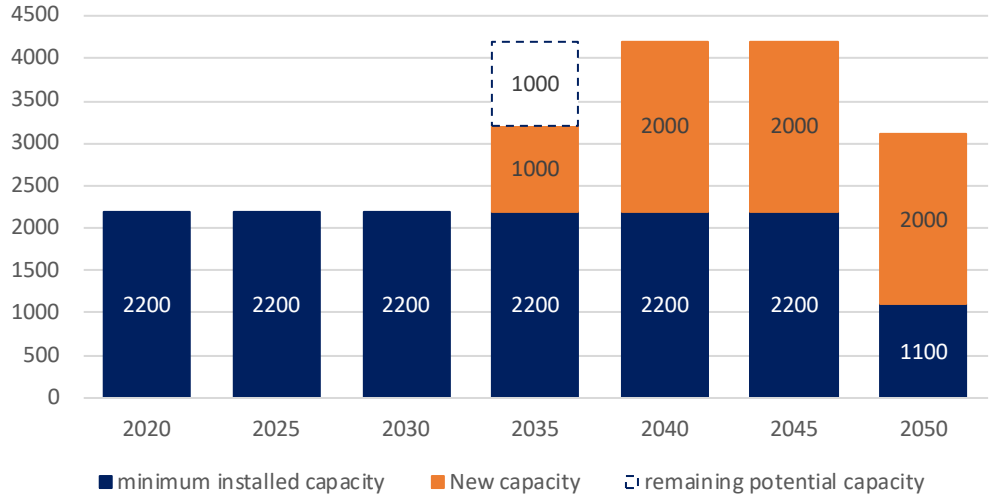
Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

With a lower renewable potential, gas becomes more prominent in the system

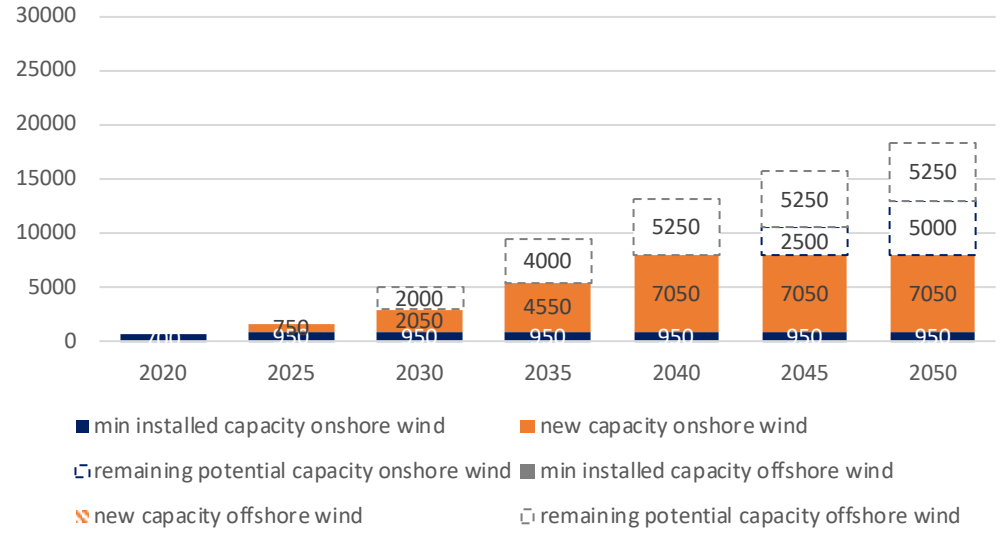
Solar PV – min cap. built, newbuild and remaining potential (MW)



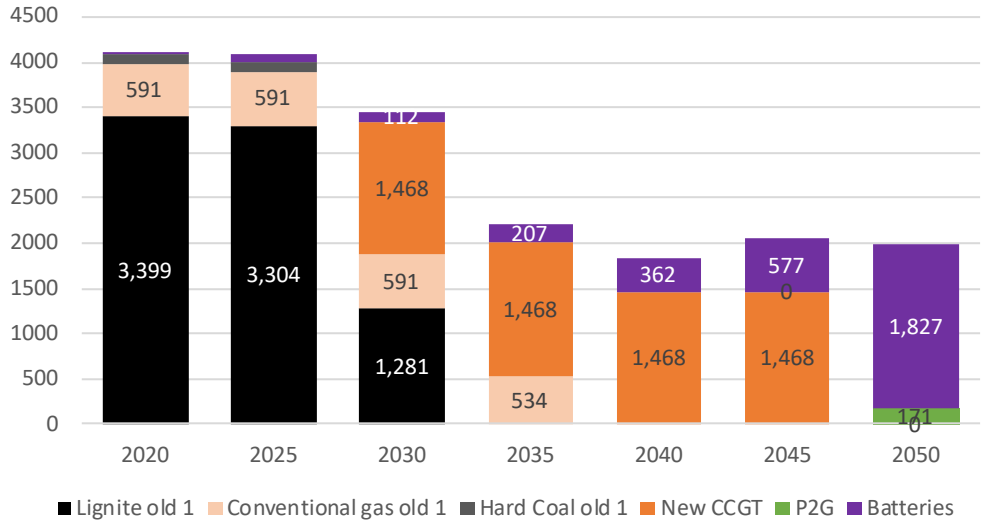
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



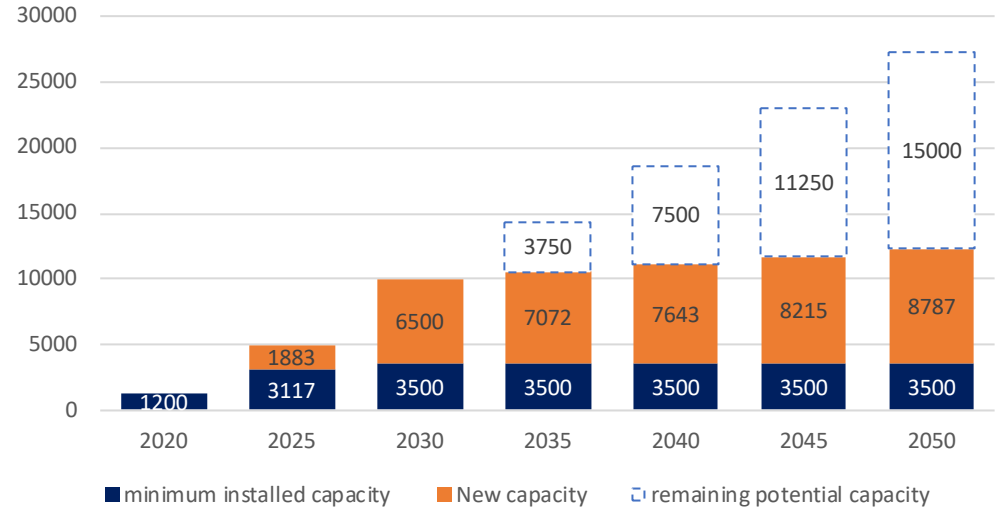
Thermal capacity outlook (MW)



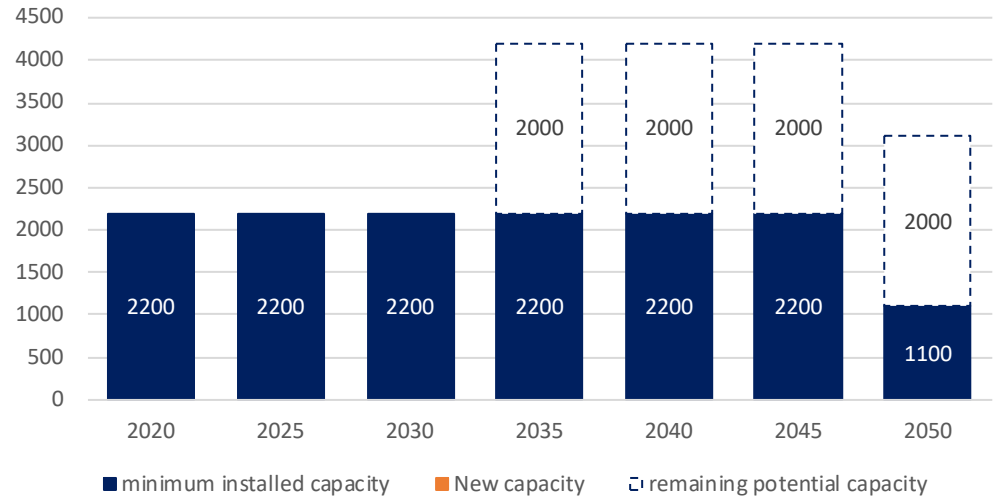
Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

In the absence of nuclear capacity, new CCGTs are required to ensure security of supply, forcing earlier lignite retirement

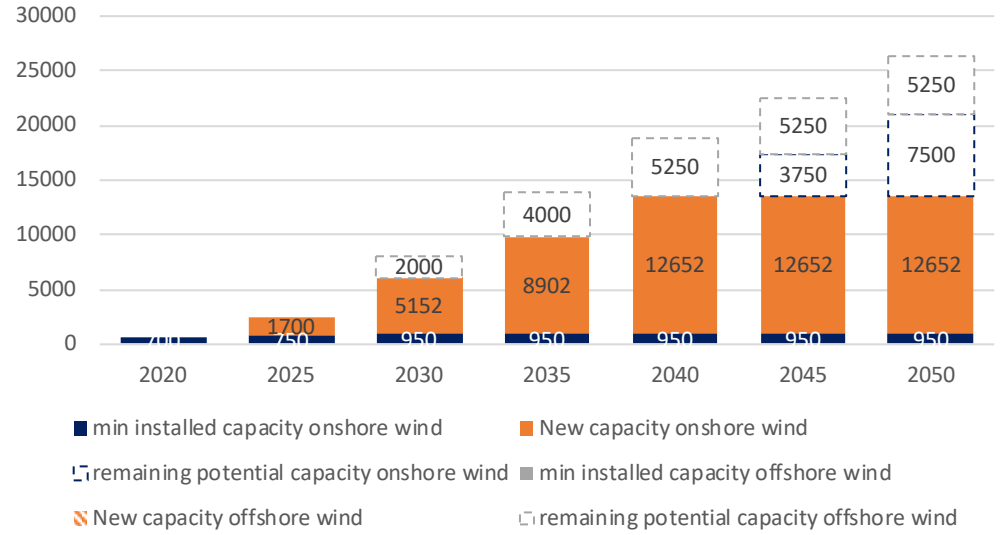
Solar PV – min cap. built, newbuild and remaining potential (MW)



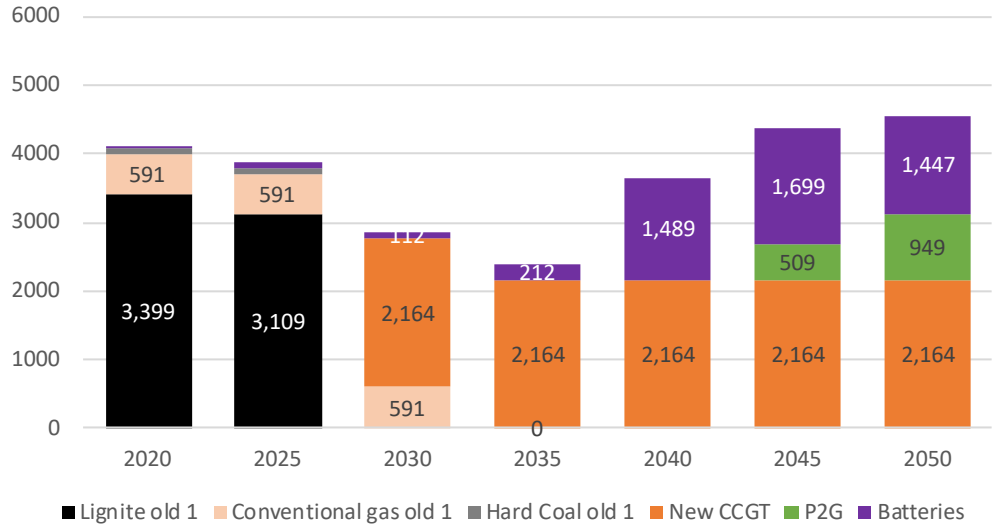
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



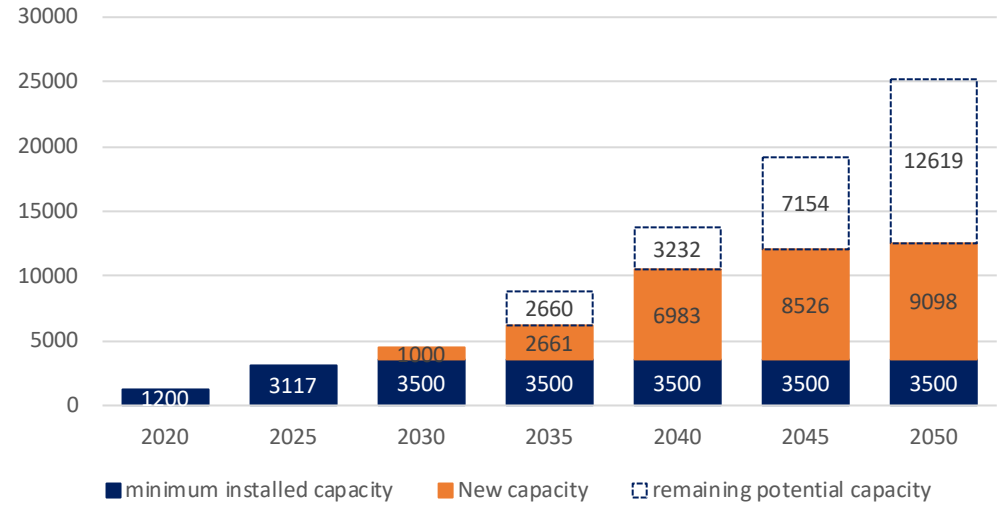
Thermal capacity outlook (MW)



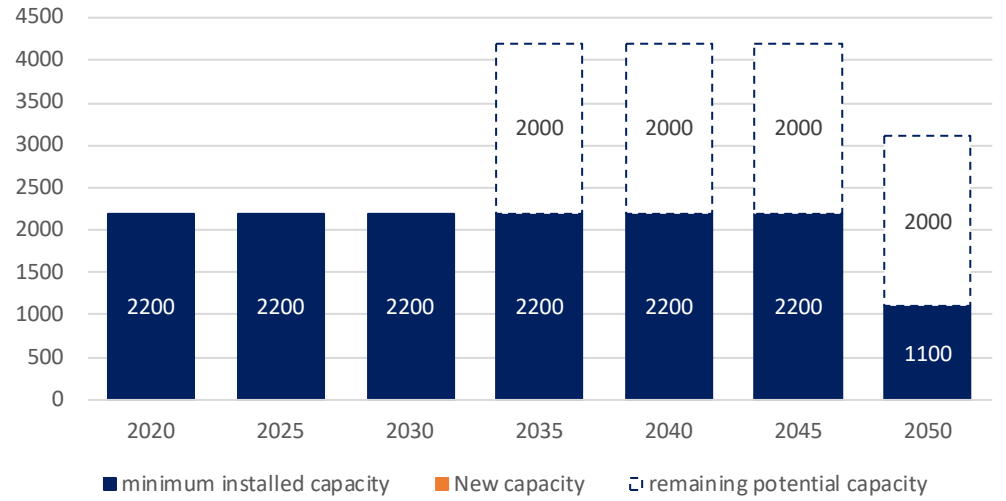
Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

In the absence of new nuclear and with a low RES potential, the system relies more heavily on gas and batteries

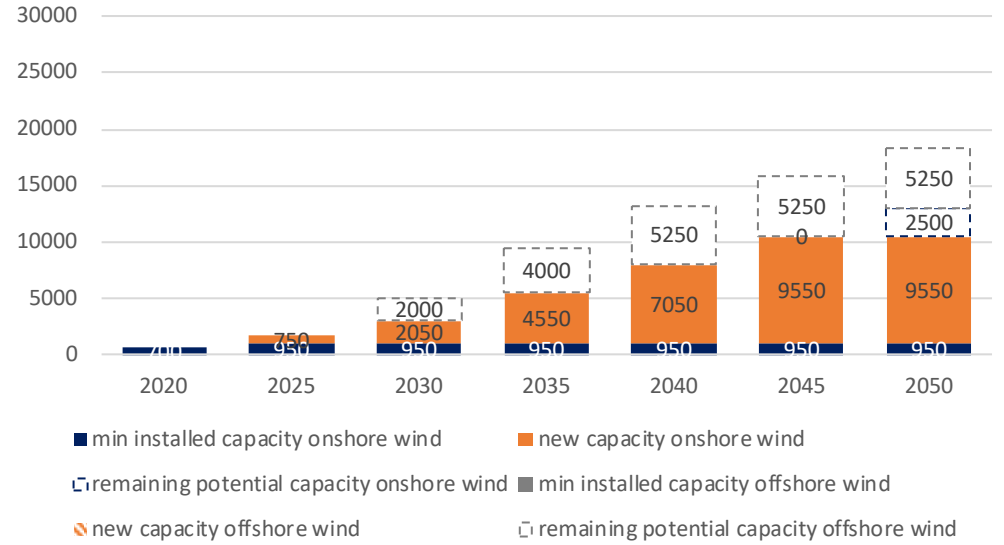
Solar PV – min cap. built, newbuild and remaining potential (MW)



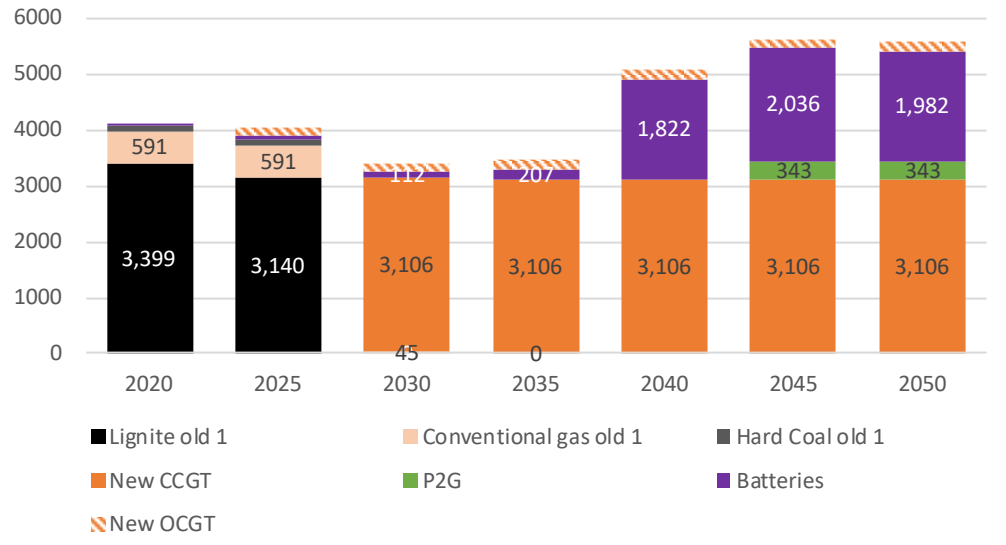
Nuclear – min cap. built, newbuild and remaining potential (MW)



Wind – min cap. built, newbuild and remaining potential (MW)



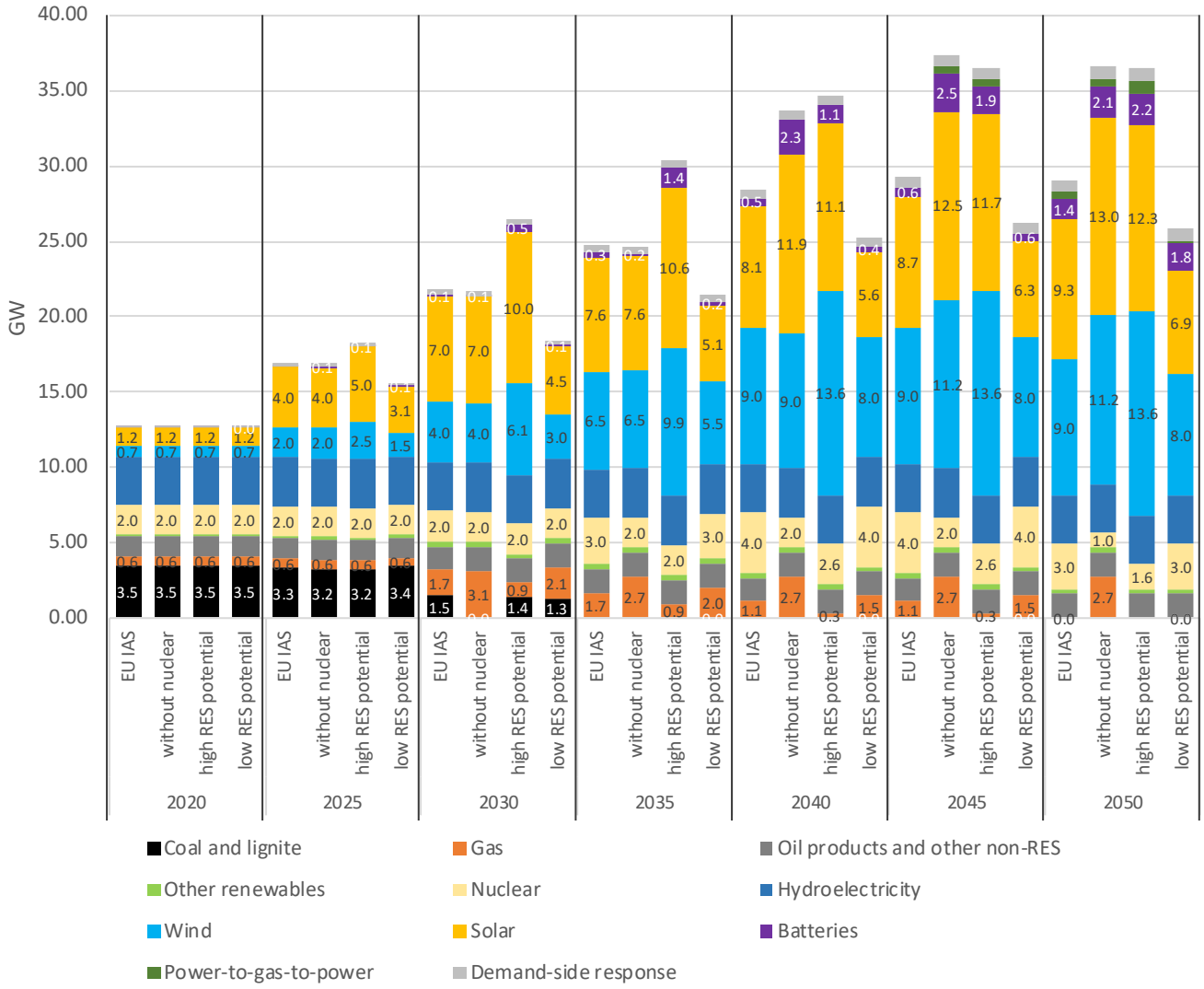
Thermal capacity outlook (MW)



Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River

Sensitivities point to the critical role of an orderly transition keeping a sizeable base of thermal plants available to ensure security of supply in the transition…

Capacity comparison between sensitivities

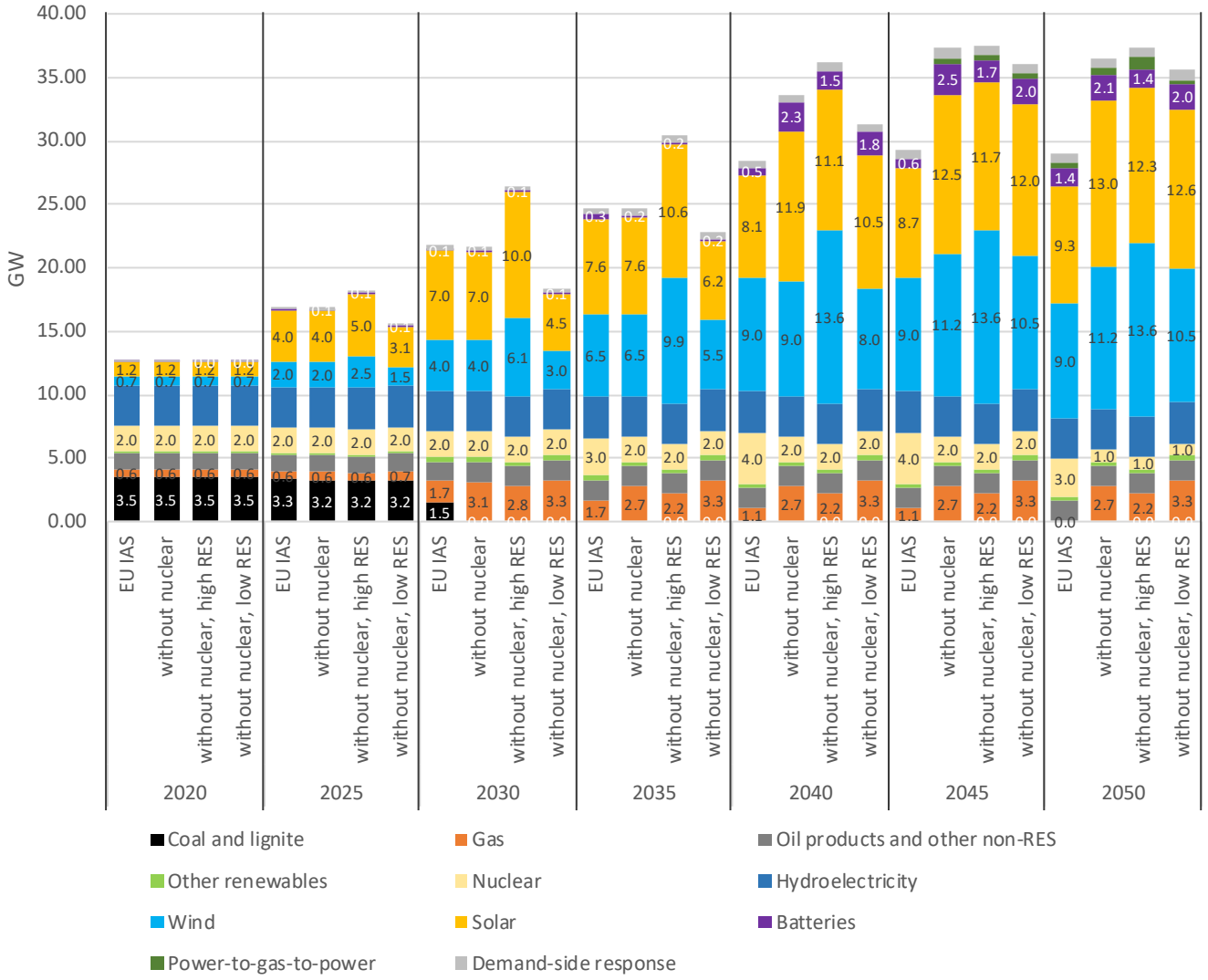


- In the sensitivities without new nuclear, additional CCGT capacity is required to ensure security of supply, forcing earlier lignite closure.
- In the sensitivity with higher RES buildout potential, less nuclear capacity is built by the model relative to *EU IAS*. This entails a higher need for flexible capacity such as batteries and P2G2P.
- In the sensitivity with lower RES buildout potential, new nuclear is necessary to decarbonise the power sector while ensuring security of supply.
- These sensitivities highlight the option values of keeping some existing lignite capacities to manage delays in new gas or nuclear development or bottleneck in ramping up RES development.

Source: Compass Lexecon

… this is particularly true in sensitivities where new nuclear is not an option with additional CCGT capacity being required to ensure security of supply

Capacity comparison between sensitivities

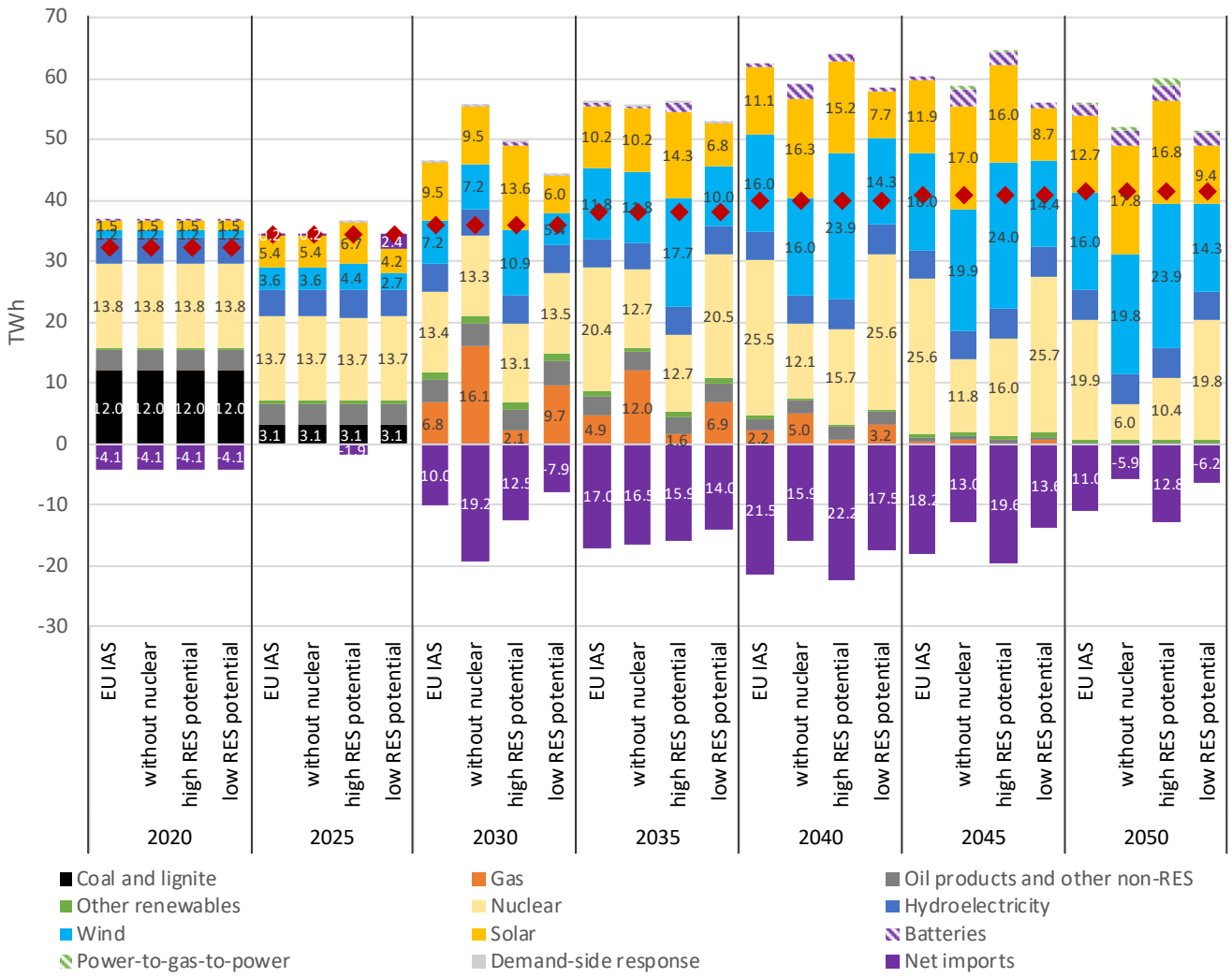


- Sensitivities point to the critical role of an orderly transition keeping a sizeable base of thermal plants available to ensure security of supply in the transition.
- In the sensitivities without new nuclear, additional CCGT capacity is required to ensure security of supply, forcing earlier lignite closure.
- The sensitivity without nuclear with a high RES potential requires less CCGT capacity than both the sensitivity without nuclear and the one with low RES and low nuclear.

Source: Compass Lexecon

A higher RES potential would lead to less thermal production in the 2030s, while no new nuclear would lower exports in the 2040s

Generation comparison between sensitivities

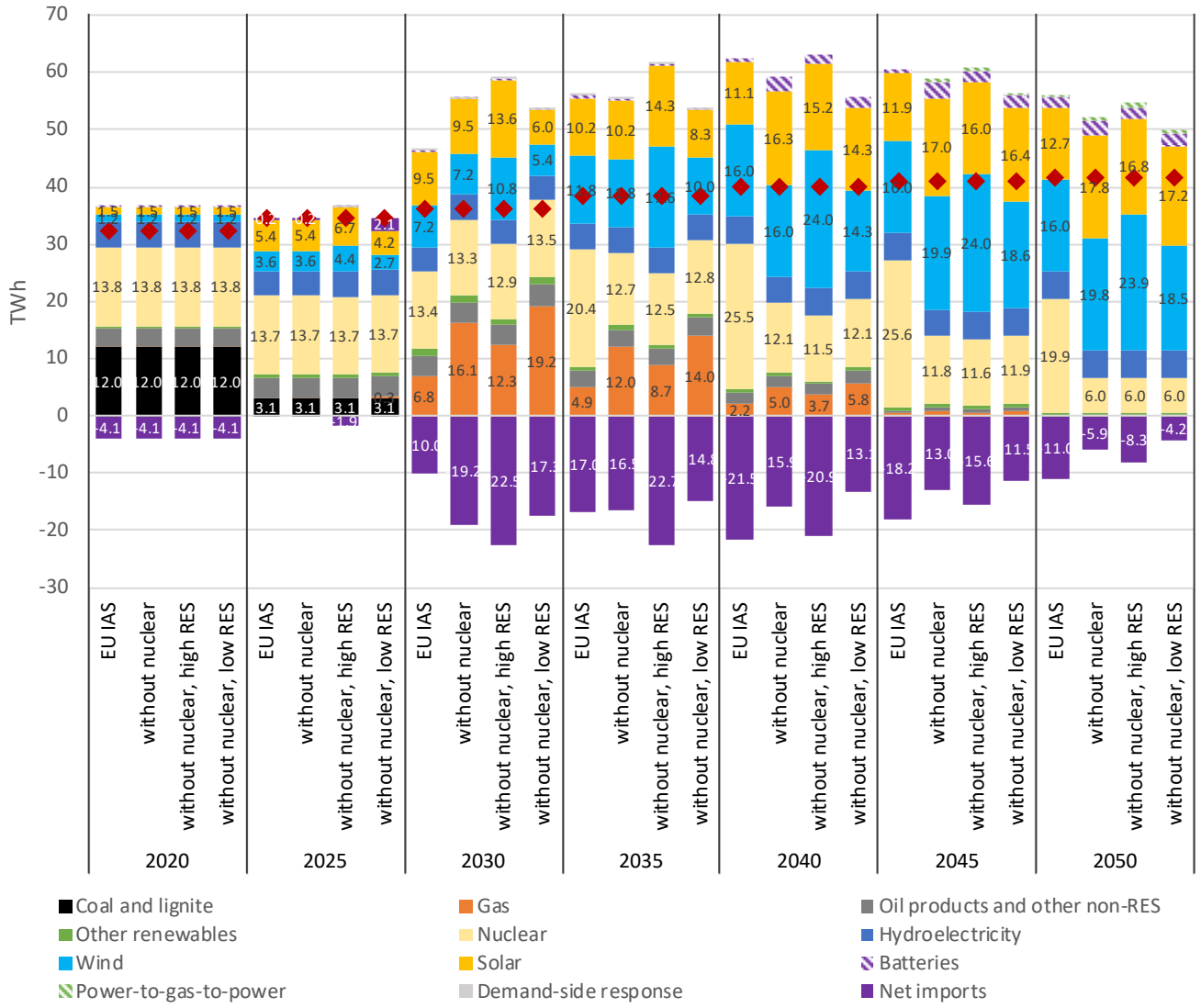


- Generation mirrors the evolution of installed capacity, with a significant increase in RES production over the forecast horizon.
- In the sensitivity without new nuclear, gas generation is much higher in the 2030s.
- With the addition of new nuclear reactors into the power mix, production increases in the 2040s leading to higher exports relative to the sensitivity without new nuclear.
- Both the sensitivities without nuclear and with low RES potential leads to lower exports relative to *EU IAS* and the high RES potential scenario.

Source: Compass Lexecon

In the absence of new nuclear, exports would be lower and gas generation higher during the transition

Generation comparison between sensitivities

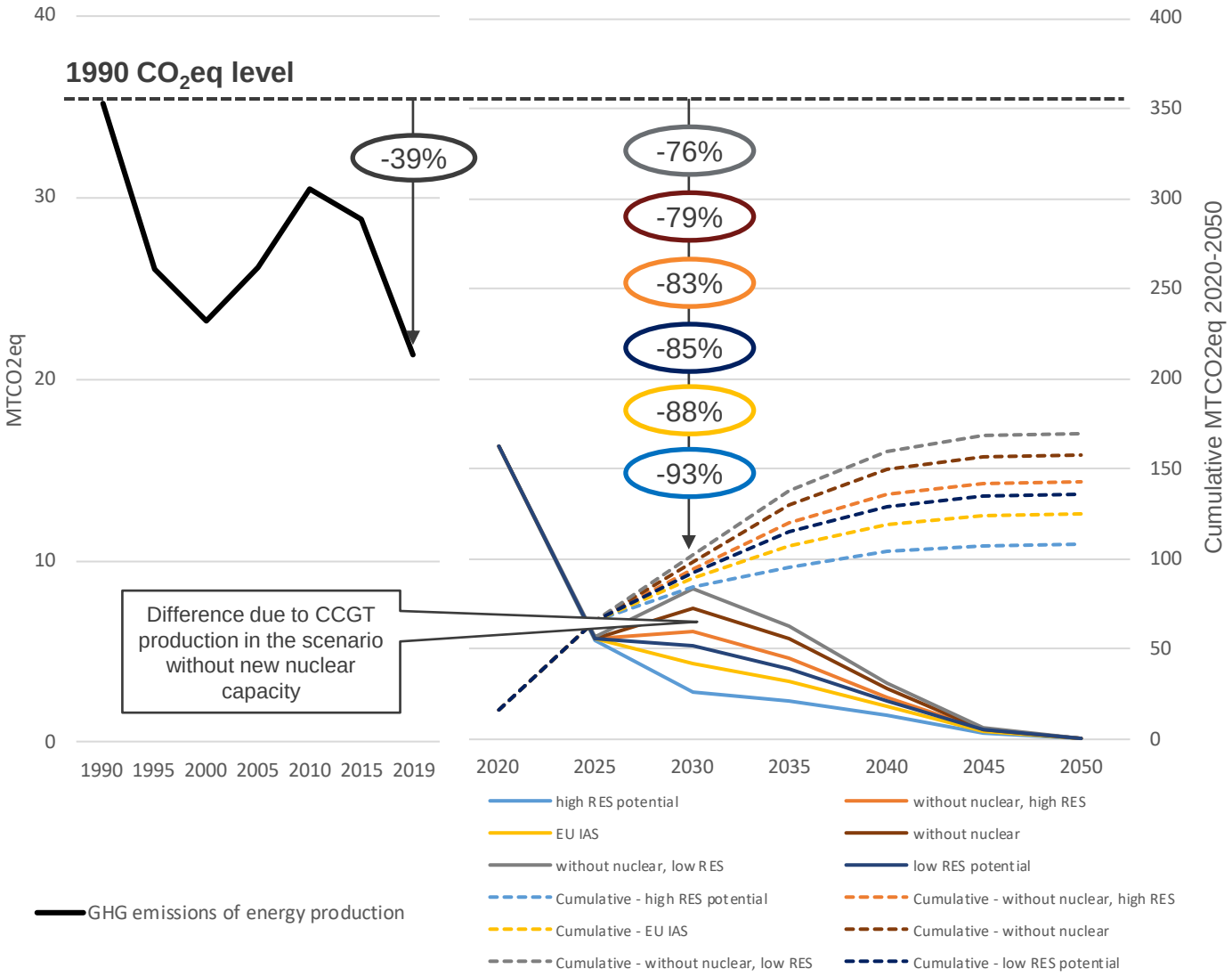


- Generation mirrors the evolution of installed capacity, with a significant increase in RES production over the forecast horizon.
- Nonetheless, lower nuclear capacity entails additional gas production during the transition
- In the sensitivity without new nuclear, gas generation is much higher in the 2030s.
- The level of gas production between sensitivities depends on the renewable buildout.

Source: Compass Lexecon

Emissions from the power sector are reduced by at least c.76% by 2030 relative to 1990 level in all *EU IAS* sensitivities

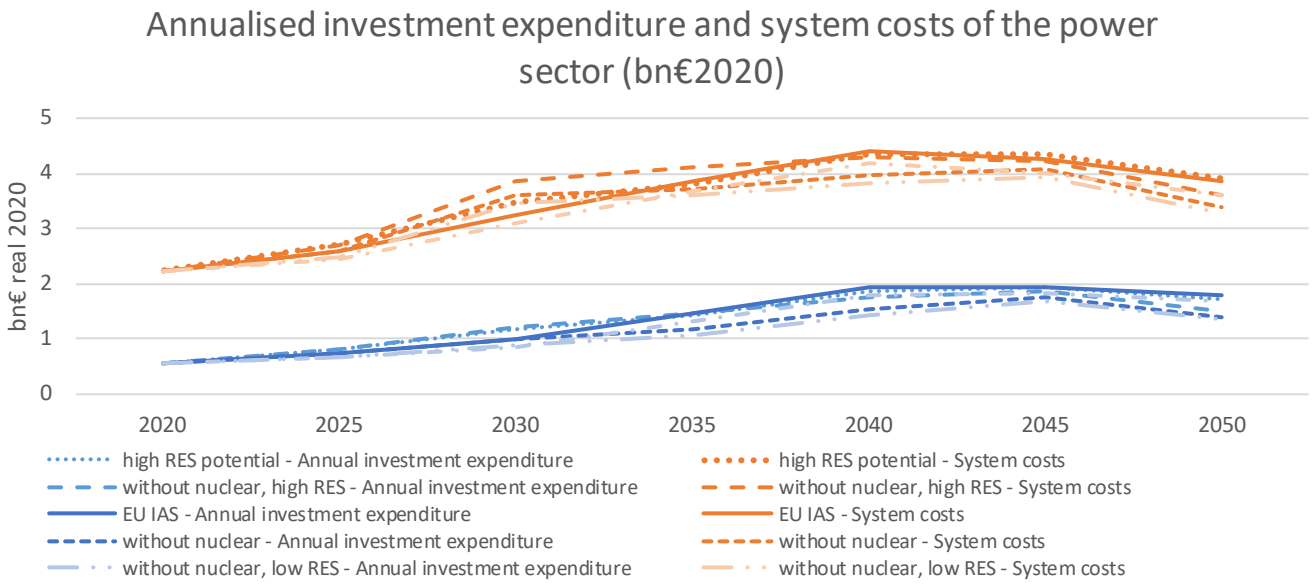
GHG emissions of the energy sector

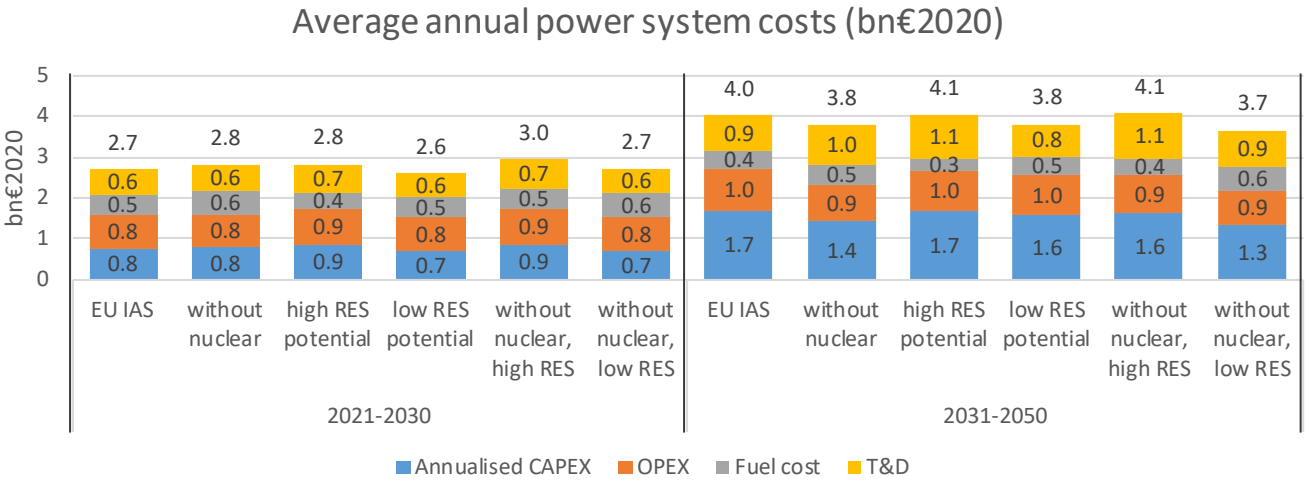


- Historically, carbon emissions from the energy sector dropped by 39% over the 1990-2019 period.
- From the generation mix results presented in the slide above, we can infer the associated projected CO_2 emissions.
  - With the increasing penetration of renewable production into the Bulgarian power mix and the decommissioning of lignite plants, emissions drop significantly in the 2020s.
  - Differences observed in emissions can be attributed to differences in thermal and RES production.
  - By 2050, the Bulgarian power sector is fully decarbonised.

Source: Compass Lexecon
Note: Historical emissions from Bulgaria's national inventory report 2021.

Power system costs rise notably across all EU IAS sensitivities, reflecting increased investments in low carbon technologies to reach net-zero



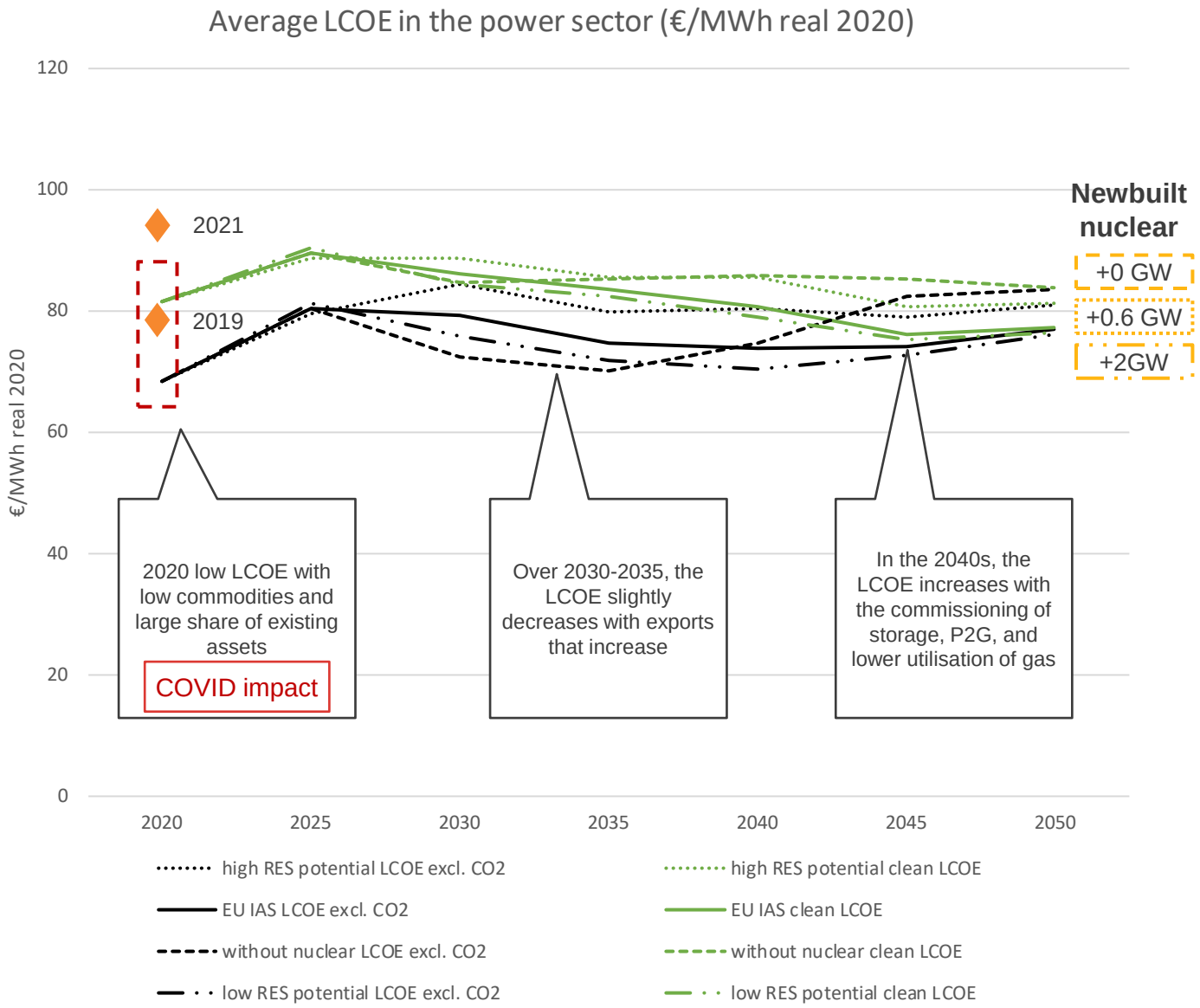


- After 2030, decarbonisation objective translates into increased RES penetration and electrification of the economy, requiring additional investments.
- Annualised investment costs more than double by 2050 relative to 2020 and overall system costs increase by 73% over the same period in *EU IAS*.
- While CAPEX and OPEX increase materially (given the significant volume of new investments), fuel costs share reduces overtime with the increased RES penetration and the reduced dependence on fossil fuels.

- Note 1: Capital expenditures are accounted for in the system costs as annuity payments. A discount of 5% is applied to compute annualised CAPEX. Power system costs do not include emission costs
- Note 2: Power system costs include existing T&D costs as well as additional T&D costs from RES penetration and peak demand increase based on EU benchmarks. Detailed Bulgarian specific assessment of T&D costs would require separate consideration and analysis.
- Note 3: Power system costs do not include the costs associated to operating or closing lignite mines or the cost associated to the gas network.

Source: Compass Lexecon

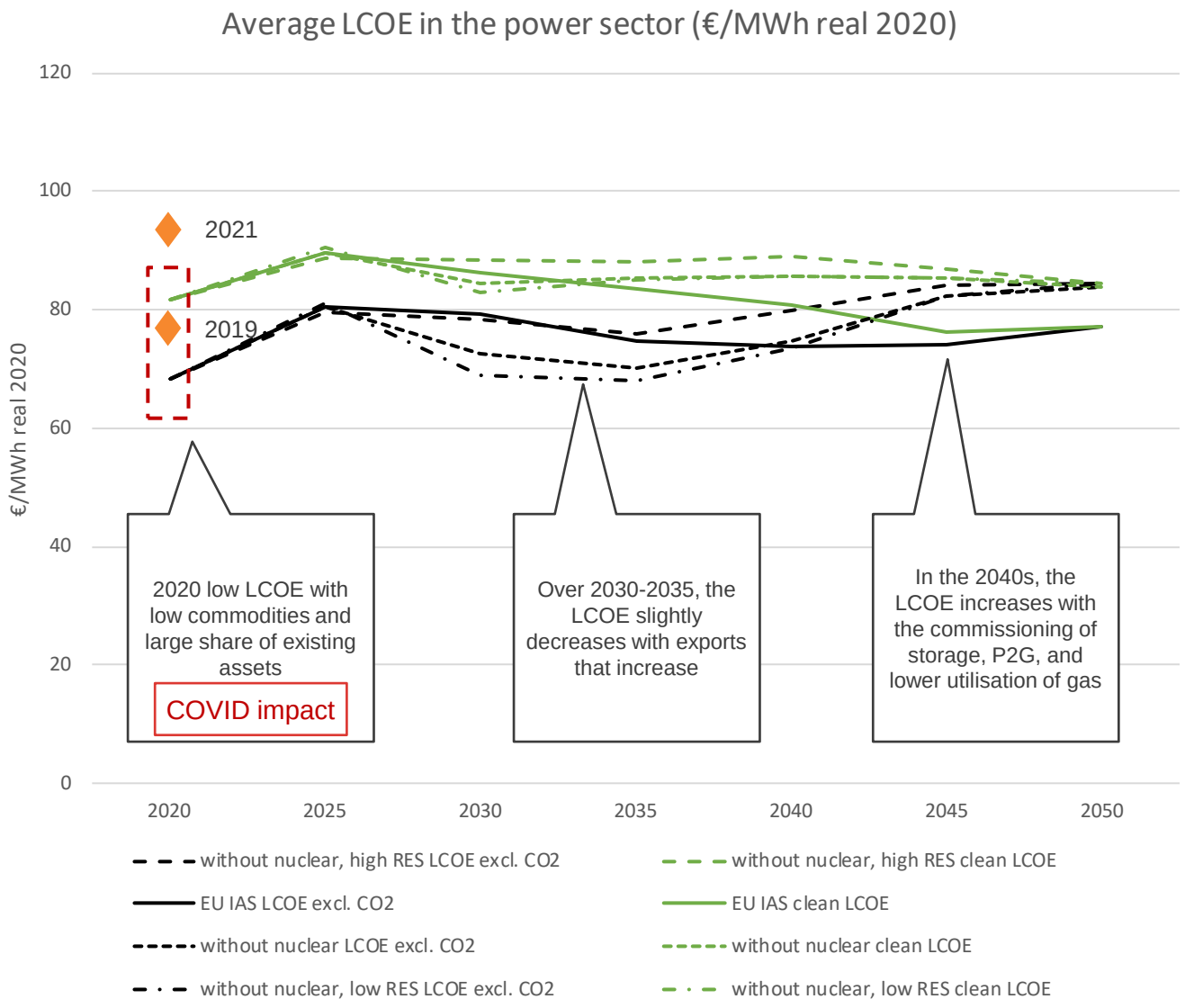
EU IAS sensitivities without or low new nuclear lead to higher average power sector LCOEs, as additional investments in flexibility are required



- Average LCOEs remain relatively stable over time, as the decrease in renewables costs is offset by the need of additional flexible capacity in the system.
- In the long-term, full decarbonisation of the power sector leads to a convergence of LCOEs and clean LCOEs.
- When comparing the various sensitivities, LCOE outlooks are comparable throughout the horizon but strongly depend on: (i) the investment framework that would be put in place; and (ii) the potential of low carbon technologies available to deliver emissions reduction objectives.
- Note: Power sector LCOE corresponds to annual power system cost (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

Source: Compass Lexecon

The *EU IAS* core scenario shows lower power sector LCOEs as part of the necessary flexibility is ensured by nuclear



- Average LCOEs remain relatively stable over time, as the decrease in renewables costs is offset by the need of additional flexible capacity in the system.
- In the long-term, full decarbonisation of the power sector leads to a convergence of LCOEs and clean LCOEs.
- When comparing the various sensitivities, LCOEs are lower when considering new build nuclear but this strongly depends on: (i) the investment framework that would be put in place; and (ii) the potential of low carbon technologies available to deliver emissions reduction objectives.
- Note: Power sector LCOE corresponds to annual power system cost (see previous slide) per unit of electricity consumption, thus excluding emission costs. Clean LCOE includes emission costs valued at projected EU ETS price.

Source: Compass Lexecon

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