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Study for the American Chamber of Commerce in Bulgaria

Decarbonisation options for the Bulgarian power sector

Update of the IAS

August 2022

AMERICAN CHAMBER OF COMMERCE IN BULGARIA

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1. Executive summary

Updated IAS 22 assumptions

The updated *IAS* 22 includes the following updates compared to the original *IAS* 21.

Commodity prices:

- Significant increase of fossil fuel prices in the short/medium term reflecting the current energy crisis (gas increased from c20€/MWh in 2030 to c60€/MWh)
- Increase of CO2 EU ETS price in the short to medium term reflecting current EU ETS market prices (from 50€/tCO2 to +100€/tCO2 in 2030)

Capacity mix evolution

- In line with the RRP, battery development materializes from 2025 onwards with more than 1GW being commissioned by then.
- New nuclear projects earliest commissioning date is delayed from 2035 to 2040.
- CCS retrofit cost have been increased from previous estimates to reflect ongoing pilot projects and storage cost estimates.

In addition to the updated IAS 22, three sensitivities have been tested to assess their impacts on the Bulgarian power system:

Sensitivities:

- 40% emission reduction constraint by 2025
- Lignite phase out in 2030
- Earlier new nuclear commissioning date from 2035 onwards.

Source: Compass Lexecon

Key takeaways

- **Bulgaria can stay on track to decarbonize the Bulgarian power system by further developing renewable capacity combined with new flexible low carbon capacities**.
  - In the updated scenarios, a minimum of 11GW of wind and solar and 2GW of storage are developed by 2030 leading to c80% CO2 emission reduction in the energy sector compared to 1990.

- While **implementing the 40% emission reduction constraint by 2025 would come at an additional cost for the Bulgarian power system** (estimated around 1€bn/year), delaying it to later in 2030 would mitigate the future power system cost increase associated to phasing out lignite.
  - Power system cost would further increase if renewable and storage are not developed to the level projected in the updated scenarios.

- **Earlier phase-out of lignite in 2030 would come at an additional cost** for the Bulgarian power system (estimated around 560m€/year).
  - Earlier phase-out of lignite in 2030 would require additional more expensive flexible and low carbon capacity to ensure security of supply in the transition.

- **Timely new nuclear development around 2035 would help mitigate the future power system cost increase**.
  - Orderly transition between increased renewable capacity combined with storage capacity, closure of lignite and development of new nuclear would provide the least cost power system in the long term.

Source: Compass Lexecon

The updated modelling of the *IAS* provides a detailed assessment of the power sector demand, capacity, emissions and costs

Capacity and generation outlook

- **Across both the original and updated *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 11GW wind and solar capacity being developed by 2030.
- This translates into an **increasing share of variable RES generation** in both scenario from 7% in 2020 to 35% (resp. 36%) in 2030 in updated *IAS* (resp. original *IAS*) and 76% (resp. 53%) in 2050 in updated *IAS* (resp. original *IAS*).
- Besides, the **updated *IAS* projects increasing low carbon capacity by 2050** compared to the original *IAS* in the form of additional hydro capacity (+650MW), additional batteries (+3GW) and additional seasonal storage (+830MW).
- Along the transition, the **updated *IAS* is projected to rely longer on lignite through to early 2030s** with partial CCS retrofit (520MW) and partial conversion to biomass (60MW) instead of new gas investments as in the original *IAS.*
- In addition, by not developing new nuclear capacities from 2040 onwards, the **updated *IAS* illustrates the narrow window of opportunity to commission new nuclear projects in the mid 30s**; if commissioned too late, new nuclear projects would have a limited value to the system as other low carbon capacities would have pre-empted market opportunities.

Carbon emission reduction and power system cost outlook

- With the increasing role of lignite generation in the transition, **the updated *IAS* shows higher emission compared to the original IAS to 2030, but achieve 80% of CO_2 emission reduction in the energy sector by 2030**.
- However, the **updated *IAS* leads to significant reduction in LCOEs over the next decade compared to the original *IAS***, providing a hedge against rising commodity prices.
- In addition, the **reduction of LCOEs could lead to an additional 1bn€/year saving** without the 40% emission reduction constraint in 2025.
- Similarly, the **reduction of LCOEs could lead to an additional 560m€/year saving** without an early lignite phase-out in 2030.
- In the long-term, the **updated *IAS* shows an increase of LCOEs compared to the original *IAS*** as a result of the further development of variable RES and storage instead of new nuclear, further illustrating the narrow window of opportunity of such projects.

Source: Compass Lexecon

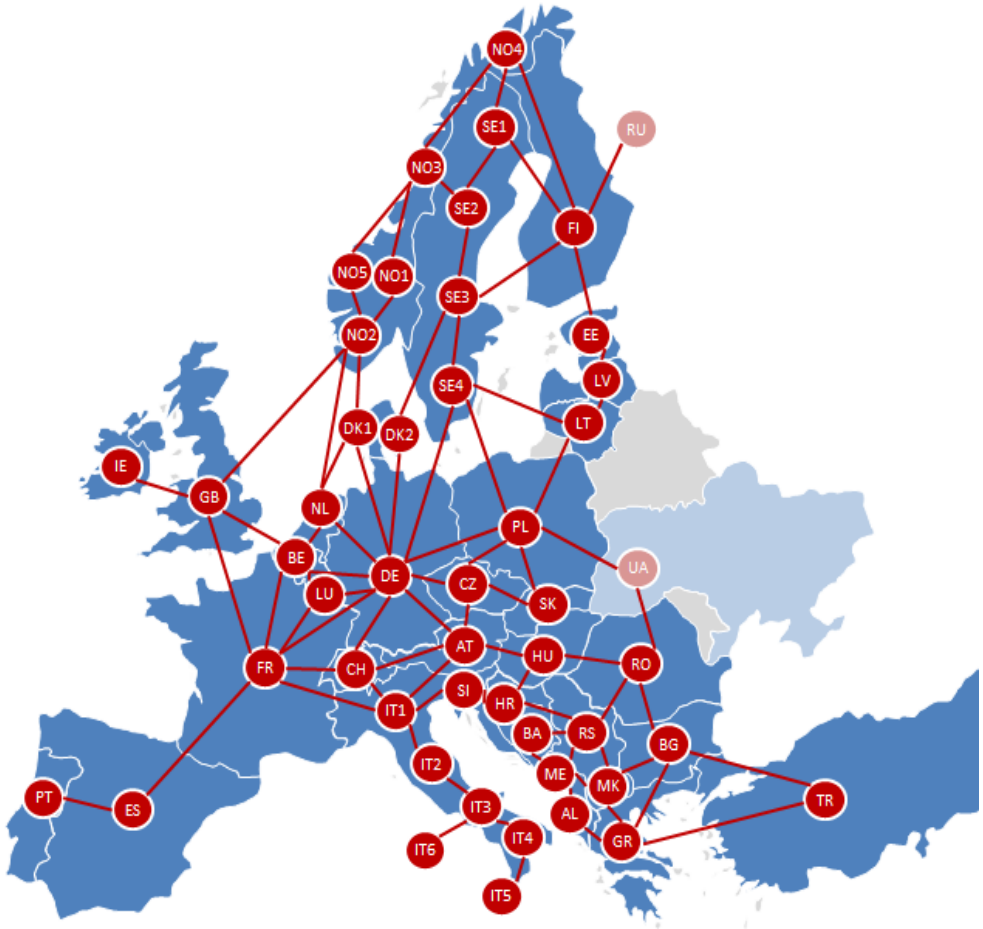
2 - Modelling of decarbonisation options for the Bulgarian power sector

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**

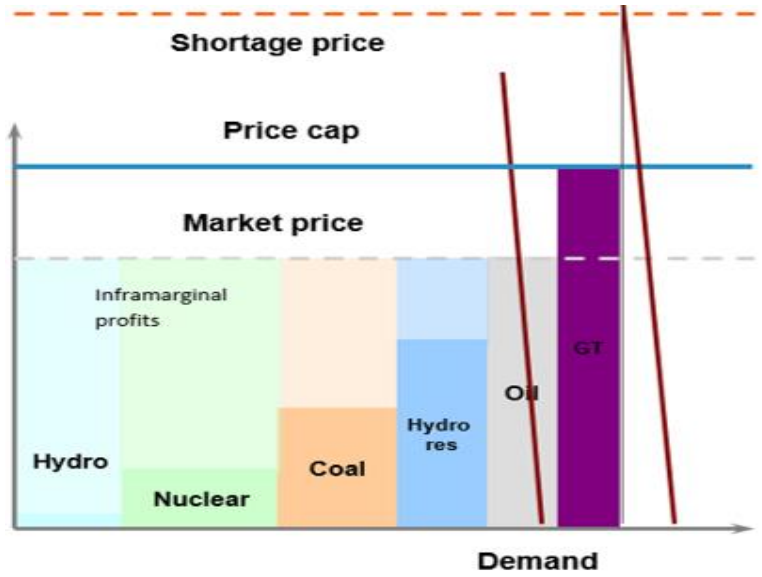
- **NECP renewable development** until 2030
- **Coal phase-down and nuclear plans** through 2050
- **European emission reduction** to net zero by 2050
- **CAPEX cost reduction** through 2050

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

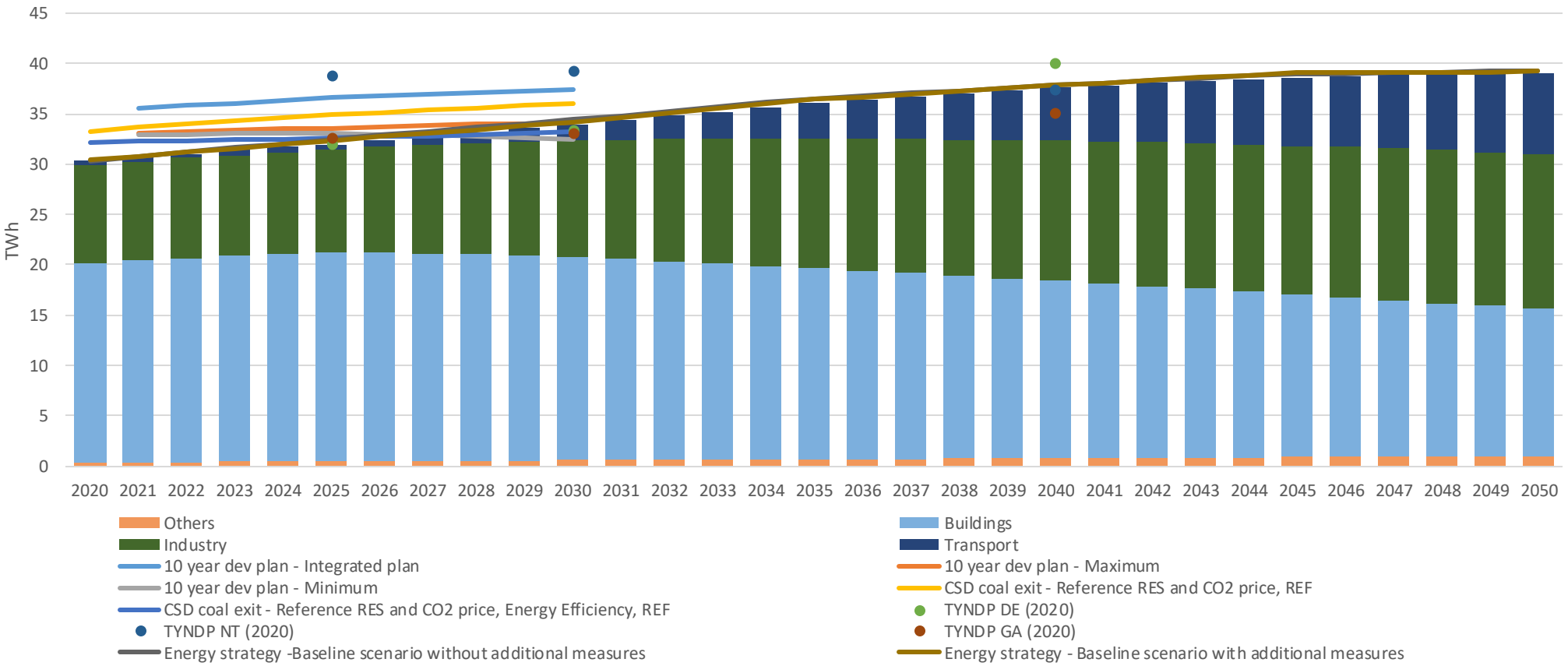
Key power price driver	Sources	Optimisation
Demand		
Power demand	■ Long term electrification based on BG Energy Strategy and EU decarbonisation scenario	■ Set as demand to be met
Supply		
RES capacity	■ Minimum set at NECPs and potential to reach EU-wide 60-65% RES-E penetration share by 2030 in line 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
Storage technologies	■ CAPEX and OPEX outlook based on latest data from EC Reference 2020 (July 2021) and BNEF 2020 for batteries	■ Dispatch optimised by hourly dispatch model
Commodity prices		
Gas	■ Forwards until 2025, convergence to 60€/MWh in 2030, and US HH + 5$/mmBTU in 2040 to reflect increasing long term gas supply cost	■ Set as an input (see annex)
CO_2 EUA	■ Forwards until 2025, convergence to 250€/tCO2 in 2050 (lower band of EC quoted carbon price necessary to decarbonise the EU by 2050)	■ 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.

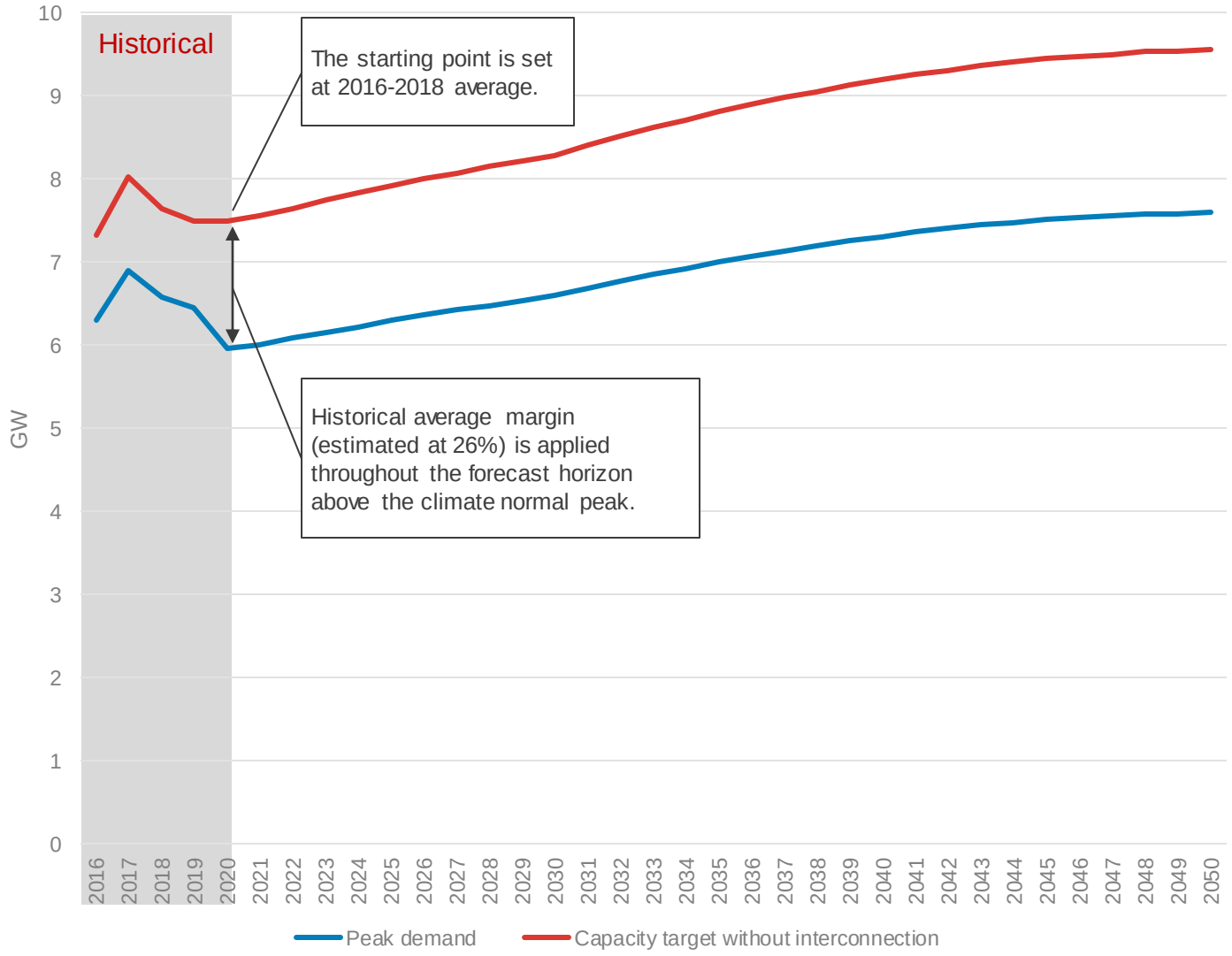
Benchmark of final electricity consumption (net) forecast in Bulgaria



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)

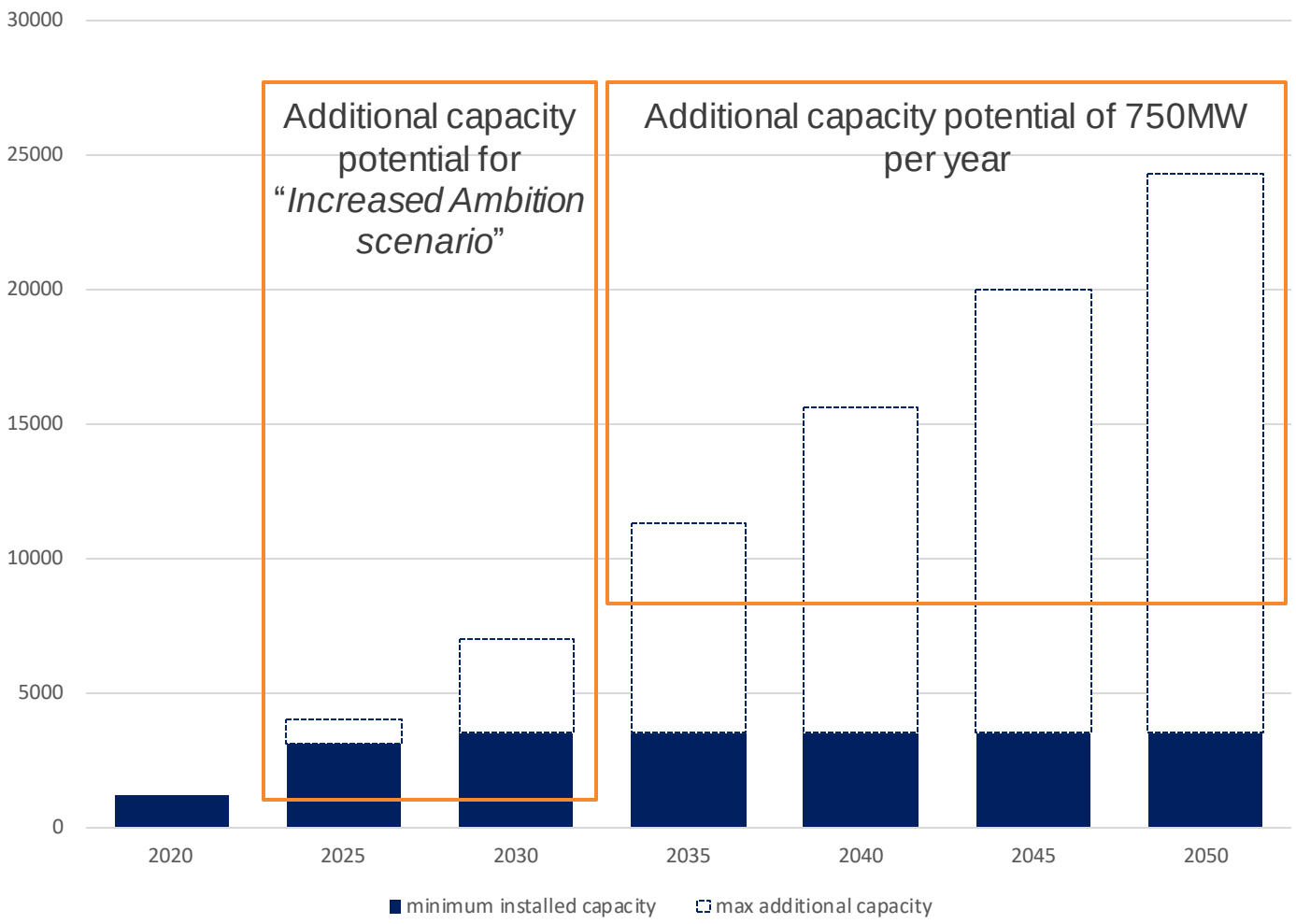


- To ensure security of supply, the modelling considers a minimum capacity margin to be maintained throughout the horizon set at historic average level.
- The capacity margin is assessed to equate 26% on top of climate normal peak demand. This corresponds to maintaining system services requirements and 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)

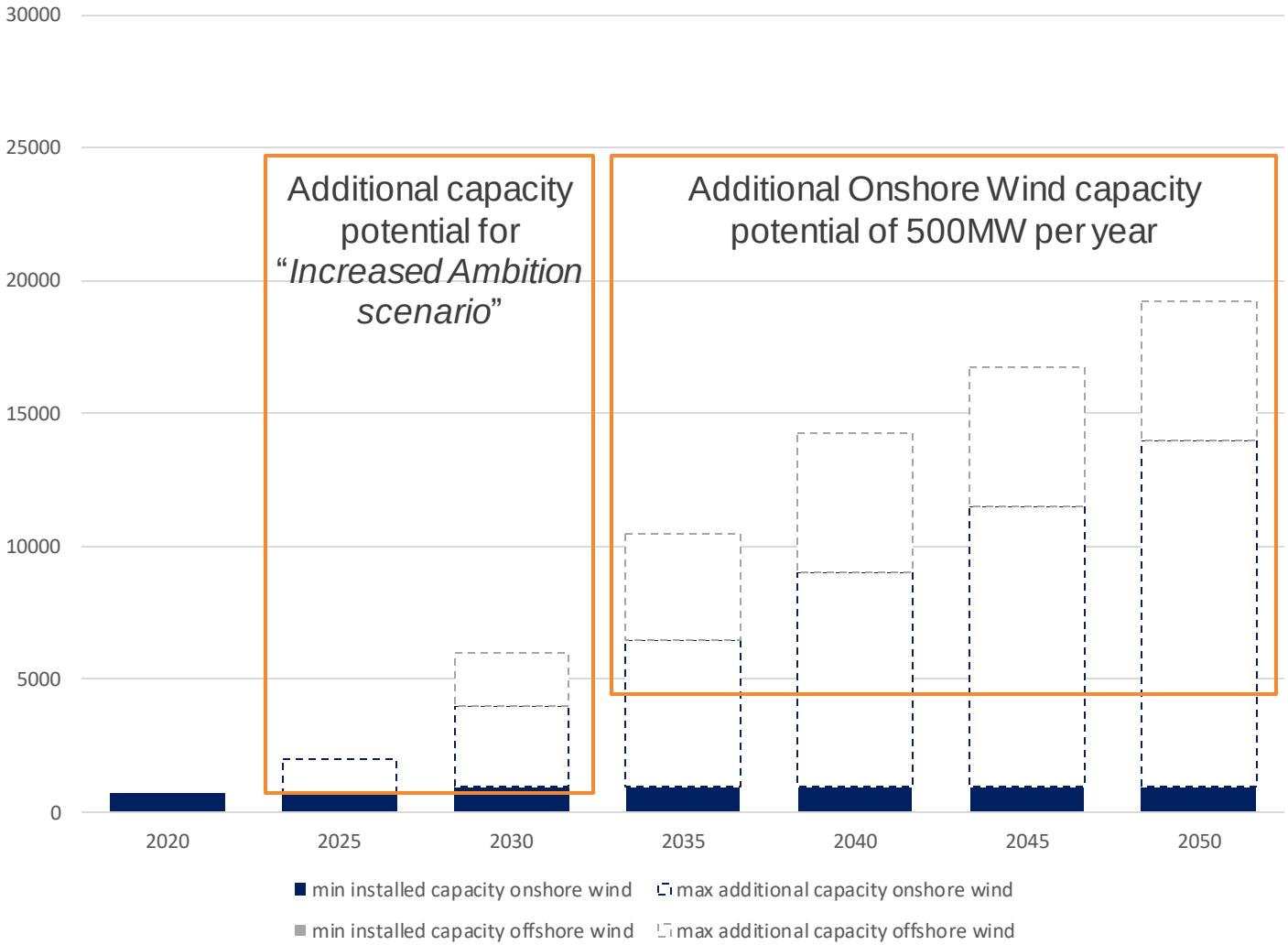


- Solar PV installed capacity is optimised from 2025 onwards, **given a minimum installed capacity reaching the NECP target by 2030**, and minimum rooftop PV increase to 2050.
- While in the "*2020 Commitment scenario*", no additional capacity potential is assumed before 2030, in the "*EU Increased Ambition 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)

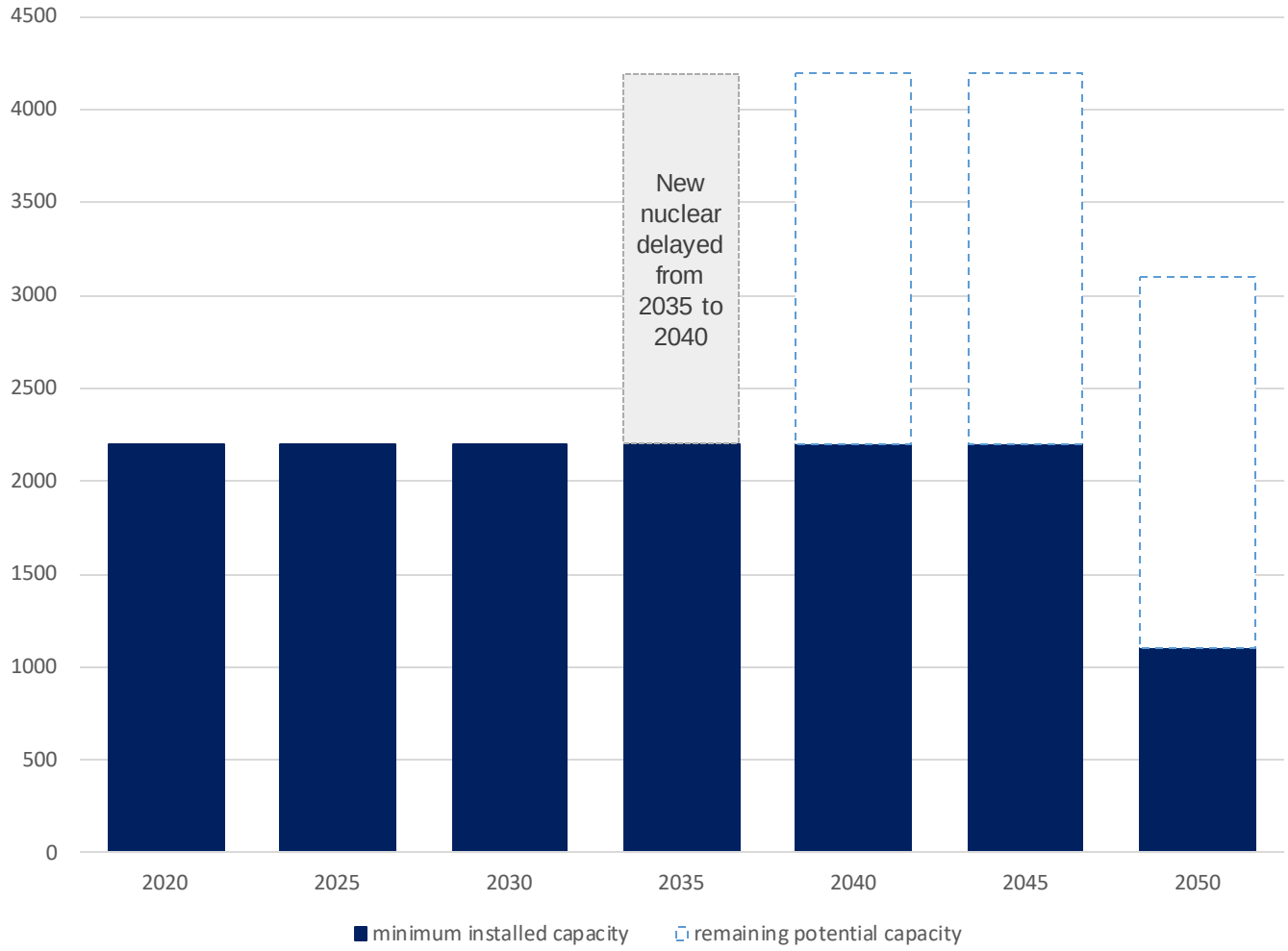


- Wind installed capacity is optimised from 2025 onwards, **given a minimum installed capacity reaching the NECP target by 2030**.
- While in the "*2020 Commitment scenario*", no additional capacity potential is assumed before 2030, in the "*EU Increased Ambition scenario*", **additional capacity potential 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)

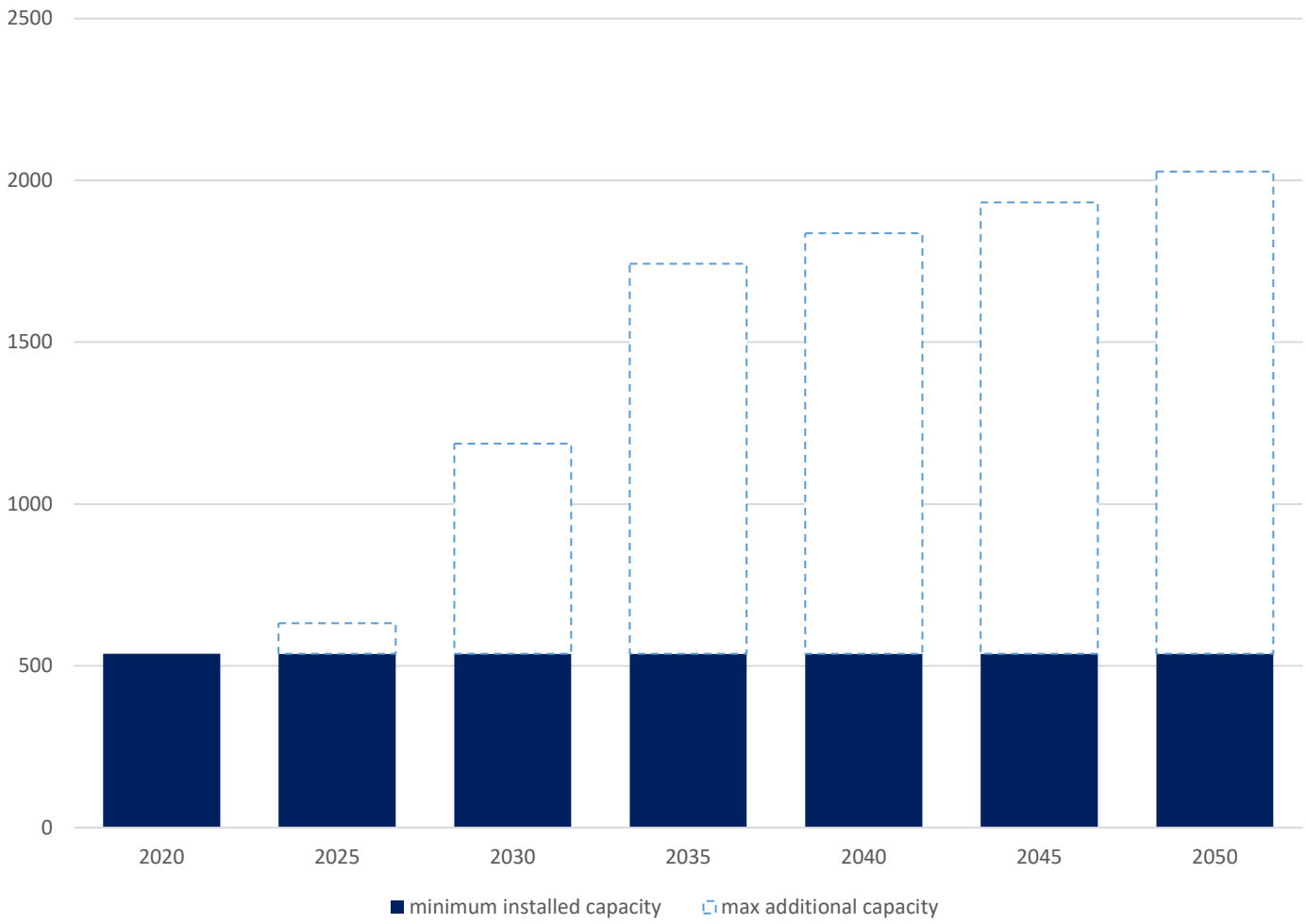


- **Existing nuclear units** assumed to be extended to 60 years:
  - Kozloduy 5 (1100MW) would be decommisionned in 2047
  - Kozloduy 6 (1100MW) would be decommisionned after 2050
- **New nuclear** is modelled endogenously after 2040 for up to 2GW assuming an investment cost projection based on EU reference 2020 Technology pathways.

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)

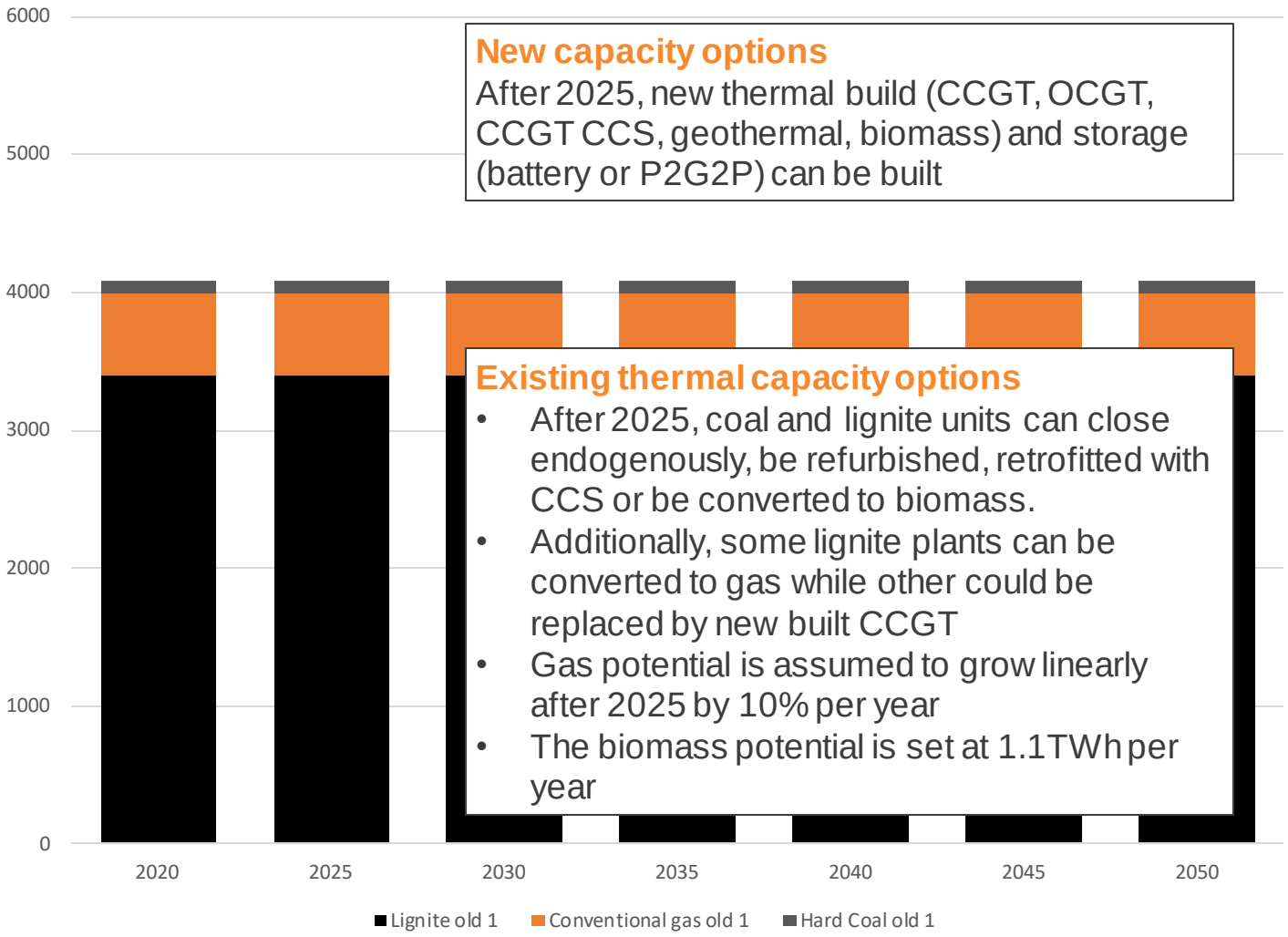


- **Existing run-of-river currently stands at c. 500MW**
- **New run-of-river capacity** is modelled endogenously after 2025 for up to 1.5GW additional run-of-river capacity by 2050.
- **Pumped storage energy storage capacity expansion** (from 8 to 24 hours) is also included in the modelling and **appears 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.

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 - EU Increased Ambition scenario results - 2021

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

The original 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.

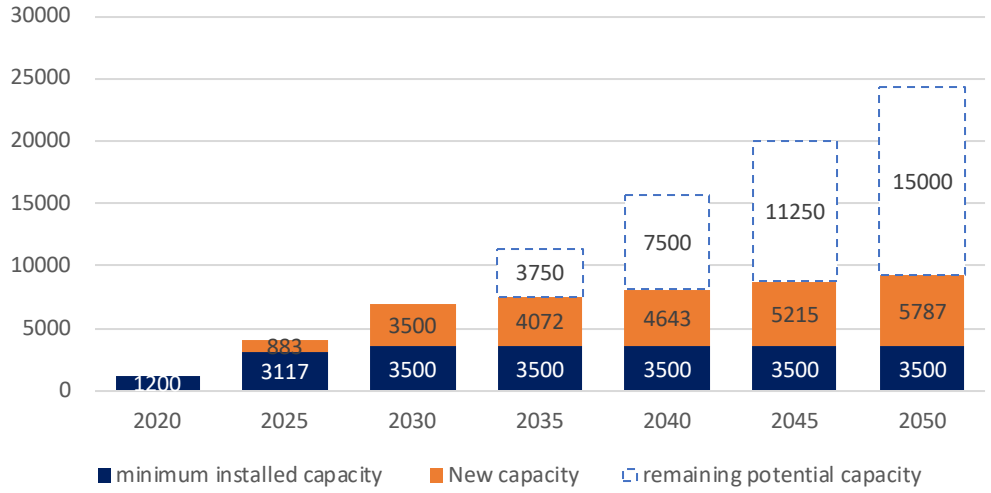
A EU Increased Ambition scenario - 2021

- EU IAS 21 -

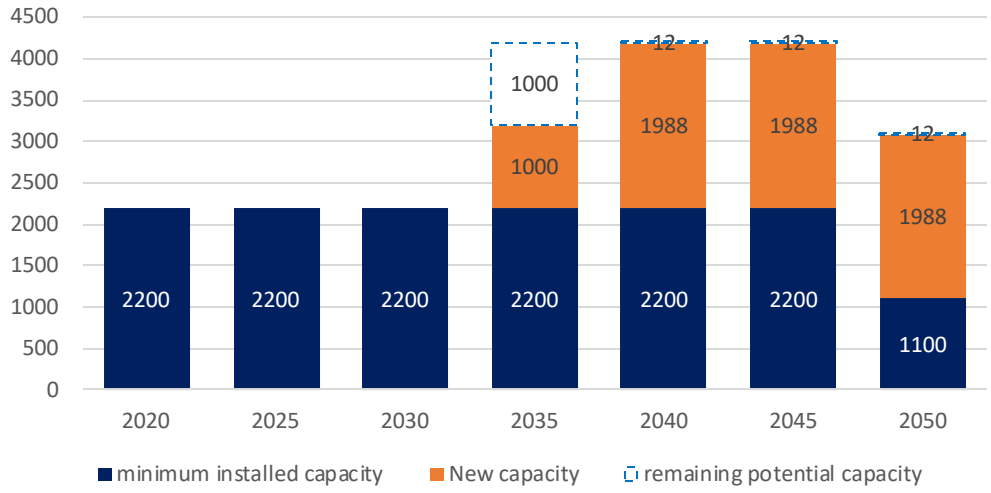
- **Cost-efficient development** of generation capacity with limited technical constraints, with additional renewable potential buildout relative to NECP target.
- **Upscaled EU target to reach 55%** of emission reduction by 2030 compared to 1990
- **Full decarbonisation for the power sector by 2050**
- **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

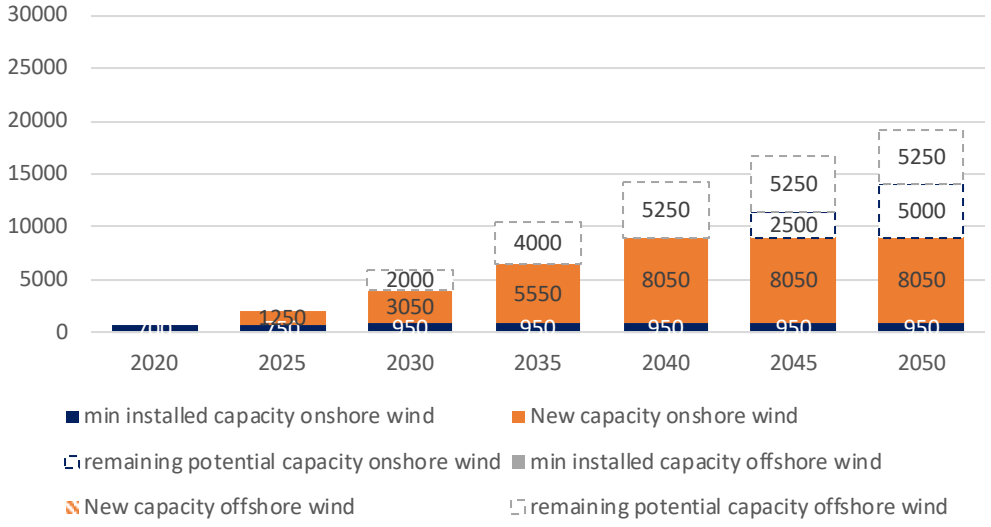
Solar PV – min cap. built, newbuild and remaining potential (MW)



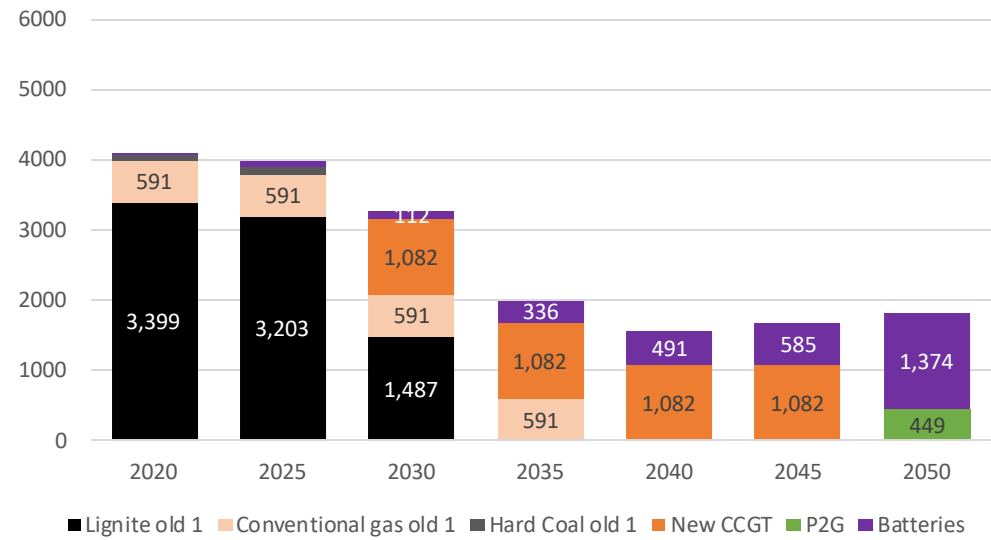
Nuclear – min cap. built, newbuild and remaining potential (MW)



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



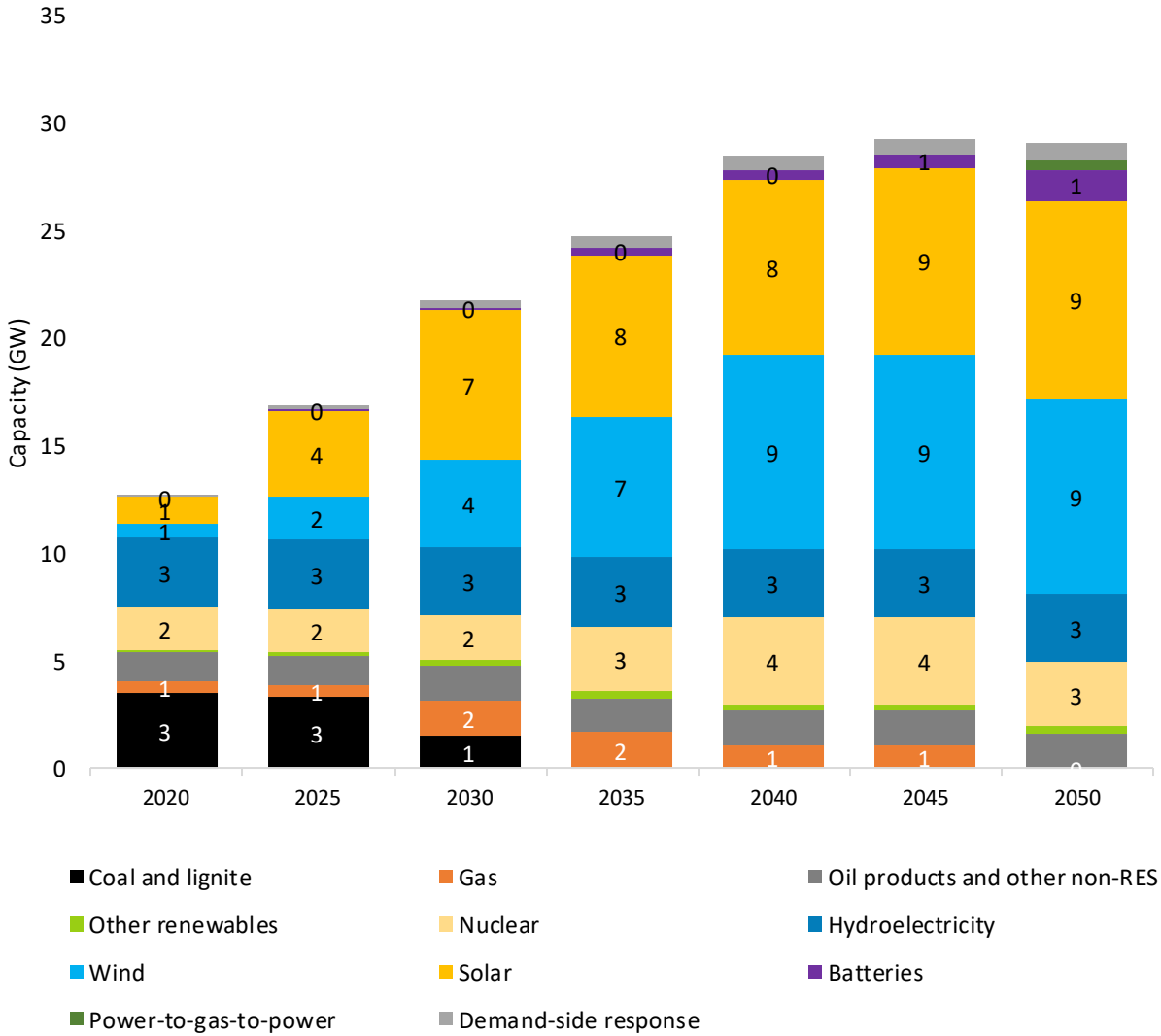
Thermal capacity outlook (MW)



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)

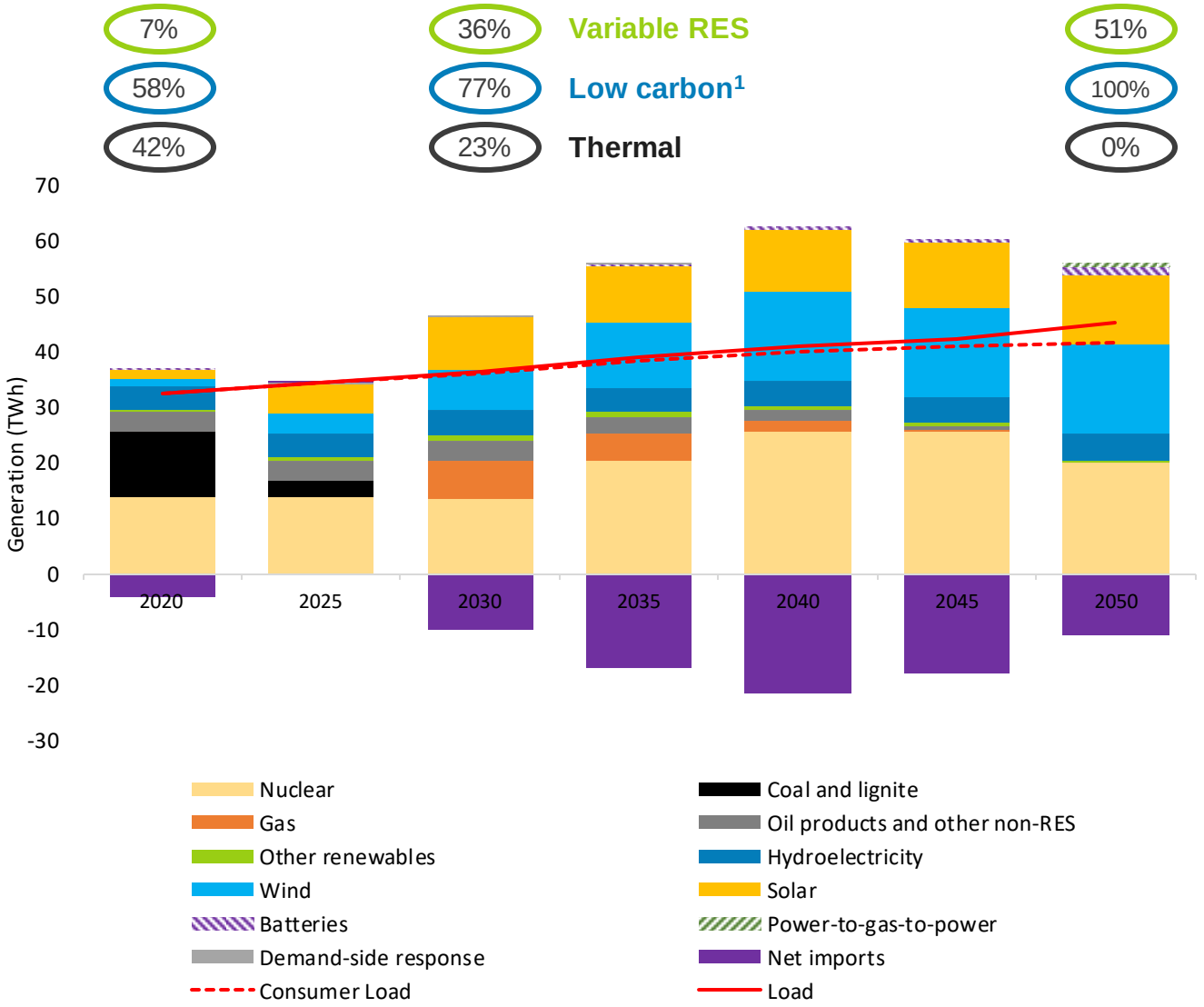


- Lignite plants are replaced from 2025 onwards by new gas capacity which allows to ensure security of supply in the medium term.
- From 2035 onwards new nuclear reactors come online for a total capacity of 2 GW, providing both low carbon electricity and ensuring security of supply.
- Overall, installed 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)

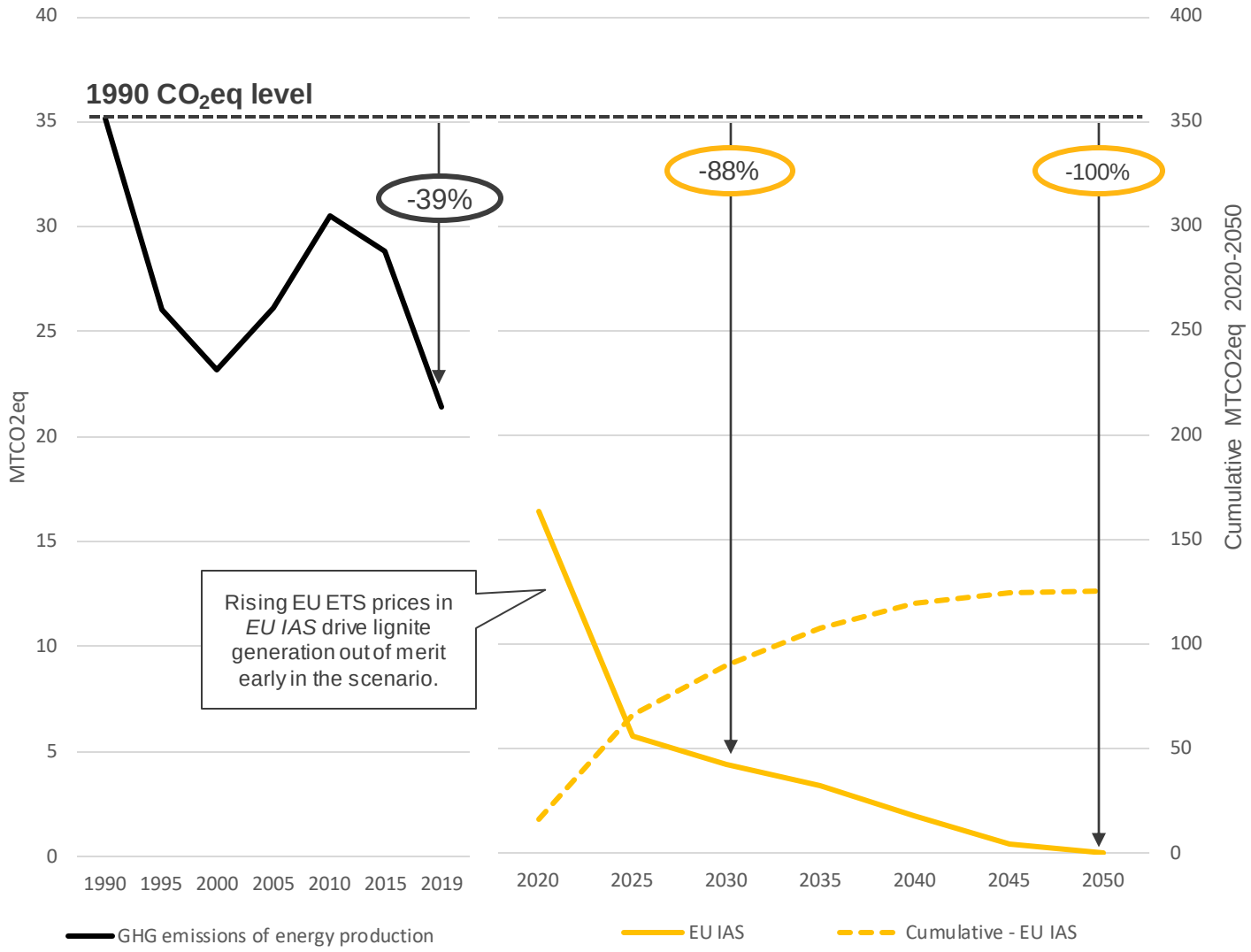


- Bulgaria still strongly relies on lignite generation up until 2025, before switching to gas in the medium term, and to nuclear and renewables in the 2040s.
- Overall, the Bulgarian export balance remains positive throughout most of the forecast horizon.
- Variable renewable generation grows substantially 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 99% 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

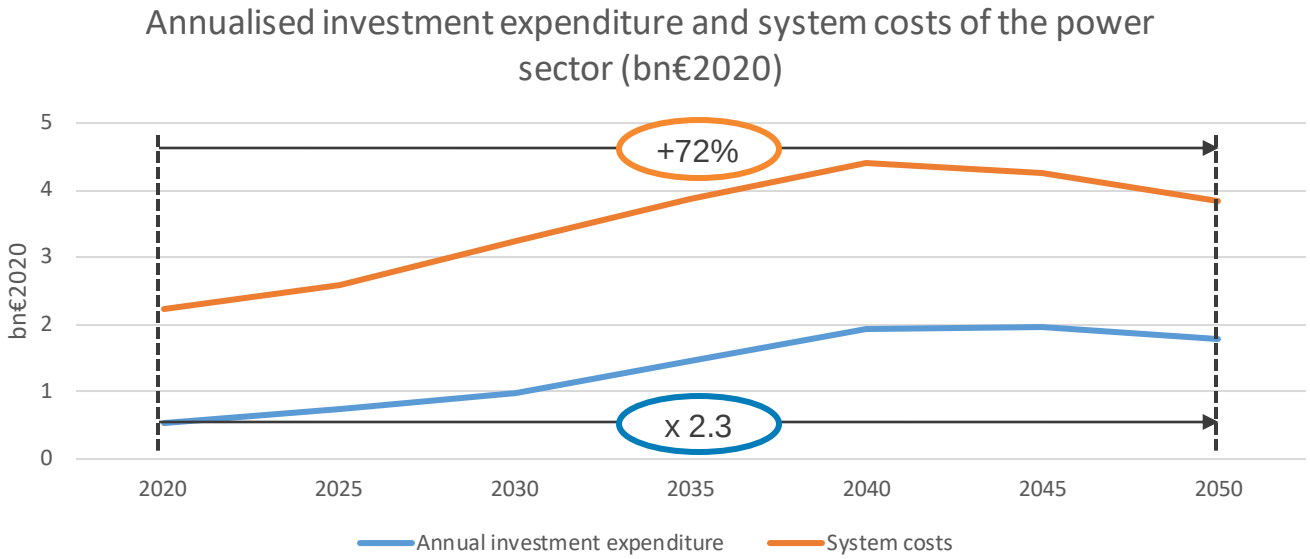
GHG emissions of the energy sector

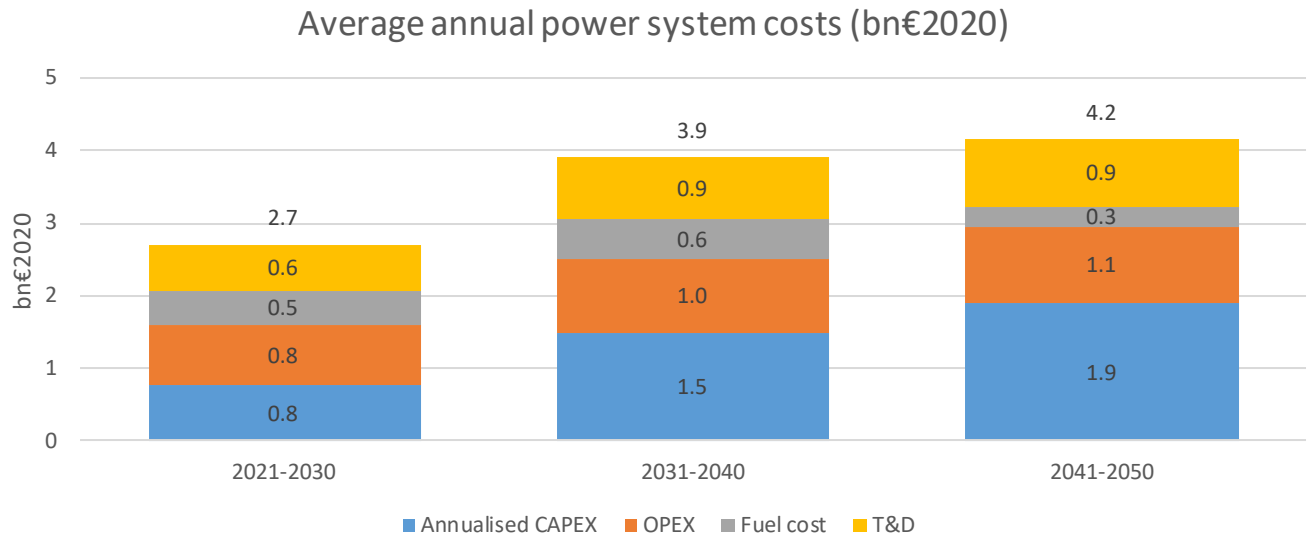


- In line with the decrease of thermal generation in the first decade, driven by the increase of carbon prices with the EU ETS Reform as part of the European "Fit for 55 package", energy sector emissions drop by 88% by 2030, which is equivalent to an overall c70% emission reduction for Bulgaria.
- Thus, 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.

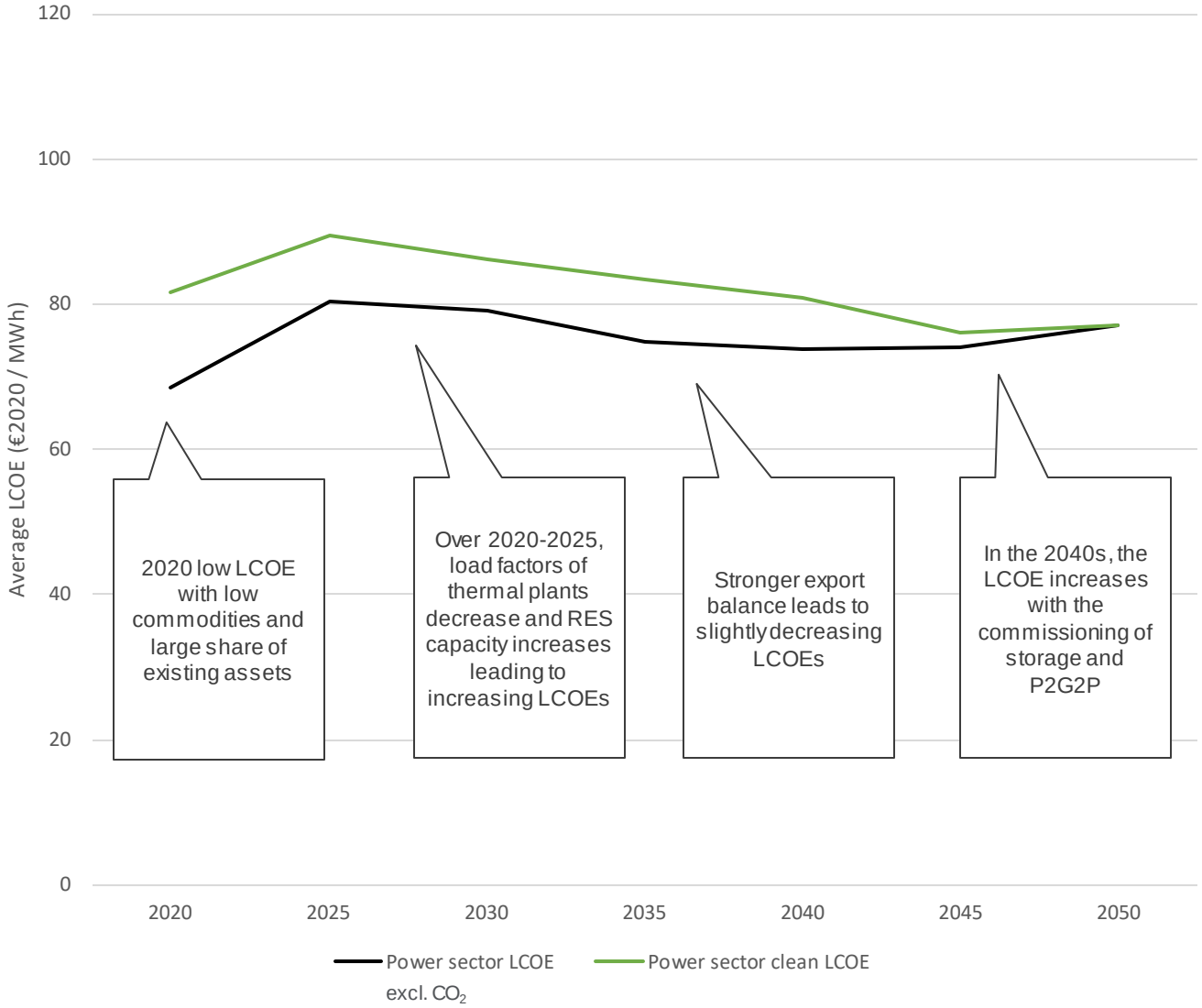
- Power system costs increase by c75% in *EU IAS* between 2020 and 2050, mainly due to the capital cost of new installations.
- Annual investments costs increase 2.3x between 2020 and 2050, partially offset by a reduction in fuel costs.

- 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 (€2020/MWh)



- 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

2.3 - EU Increased Ambition scenario results – 2022 Update

The updated "***EU Increased Ambition scenario***" explores the set of options to meet full decarbonisation by 2050 accounting for recent market evolutions

The updated 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 accounting for recent market evolutions.

- This scenario uses commodity prices accounting for recent market evolutions 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 updated EU ETS price projections reflecting current price levels, 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

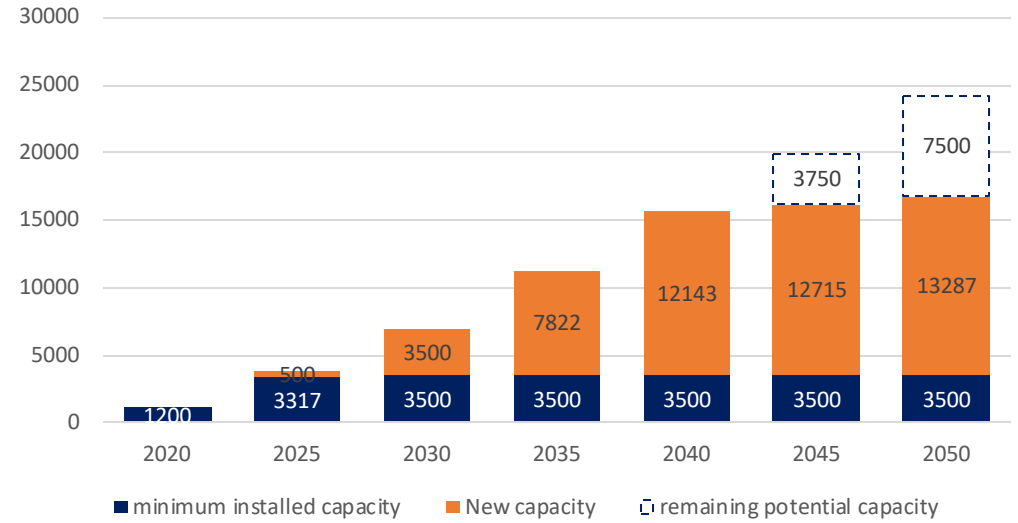
EU Increased Ambition scenario - 2022

- EU IAS 22 -

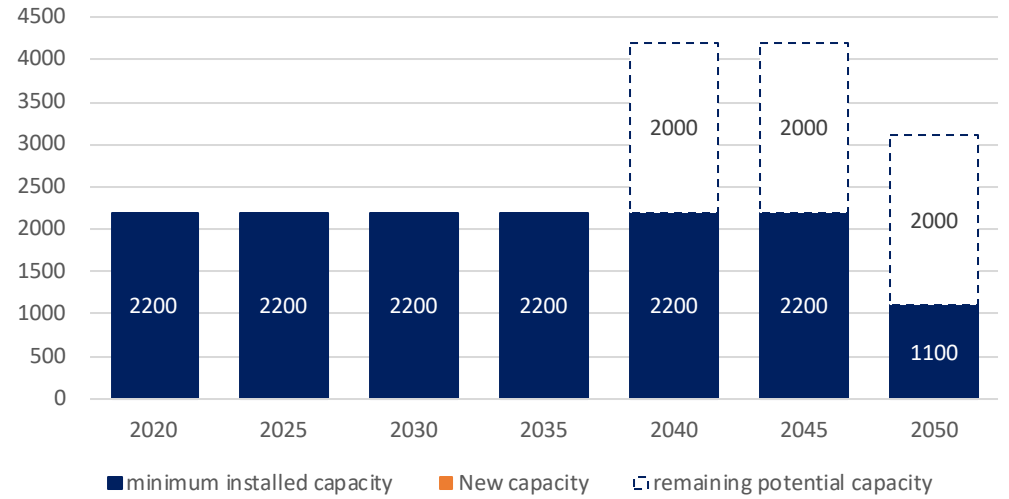
- **Cost-efficient development** of generation capacity with limited technical constraints, with additional renewable potential buildout relative to NECP and RRP target.
- **Upscaled EU target to reach 55%** of emission reduction by 2030 compared to 1990
- **Full decarbonisation for the power sector by 2050**
- **EU ETS price** in line with current price level reaching +100€/tCO_2 by 2030 and reaching 250€/tCO_2 by 2050 (lower band of EC 2050 Roadmap 2018)

The updated *IAS* projects a strong deployment of RES and batteries throughout to 2050 to maintain security of supply despite lignite phase-out

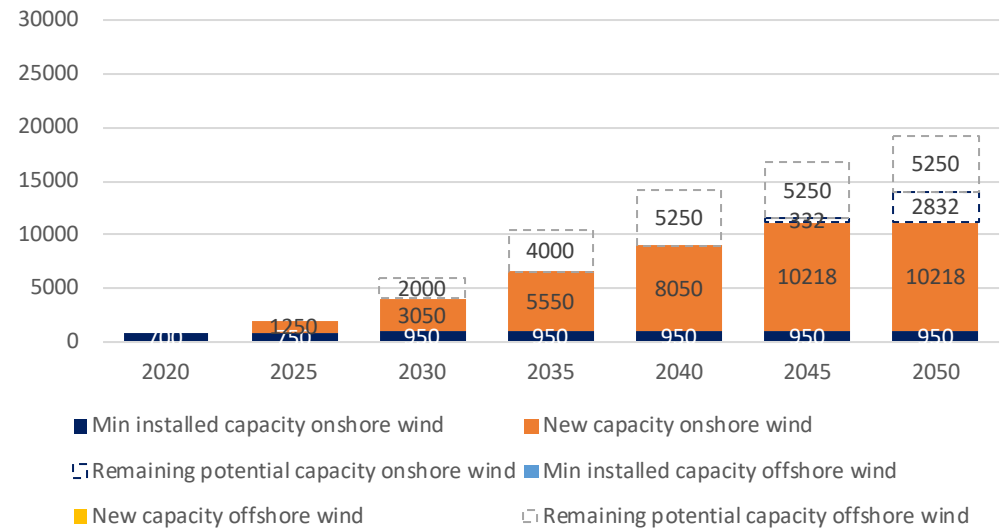
Solar PV – min cap. built, newbuild and remaining potential (MW)



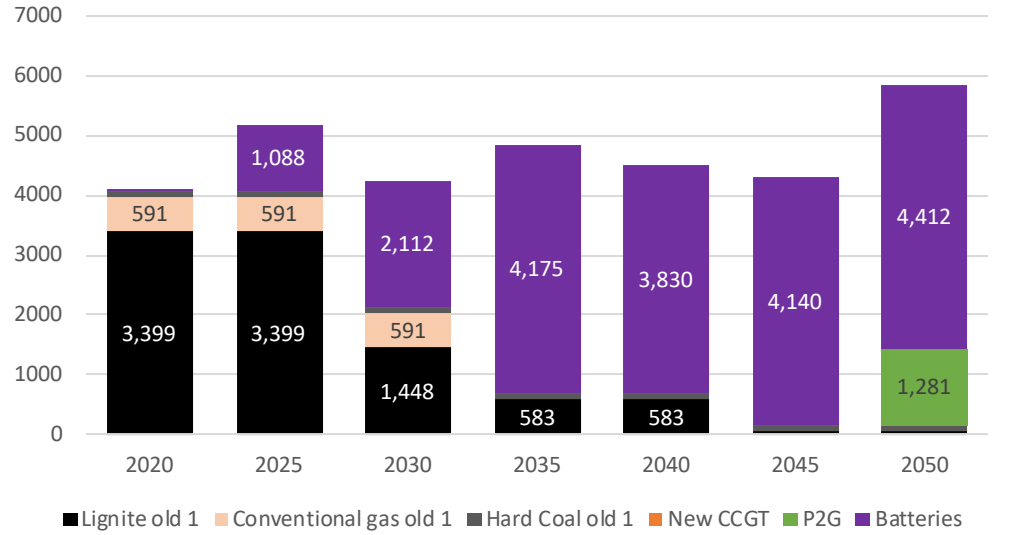
Nuclear – min cap. built, newbuild and remaining potential (MW)



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



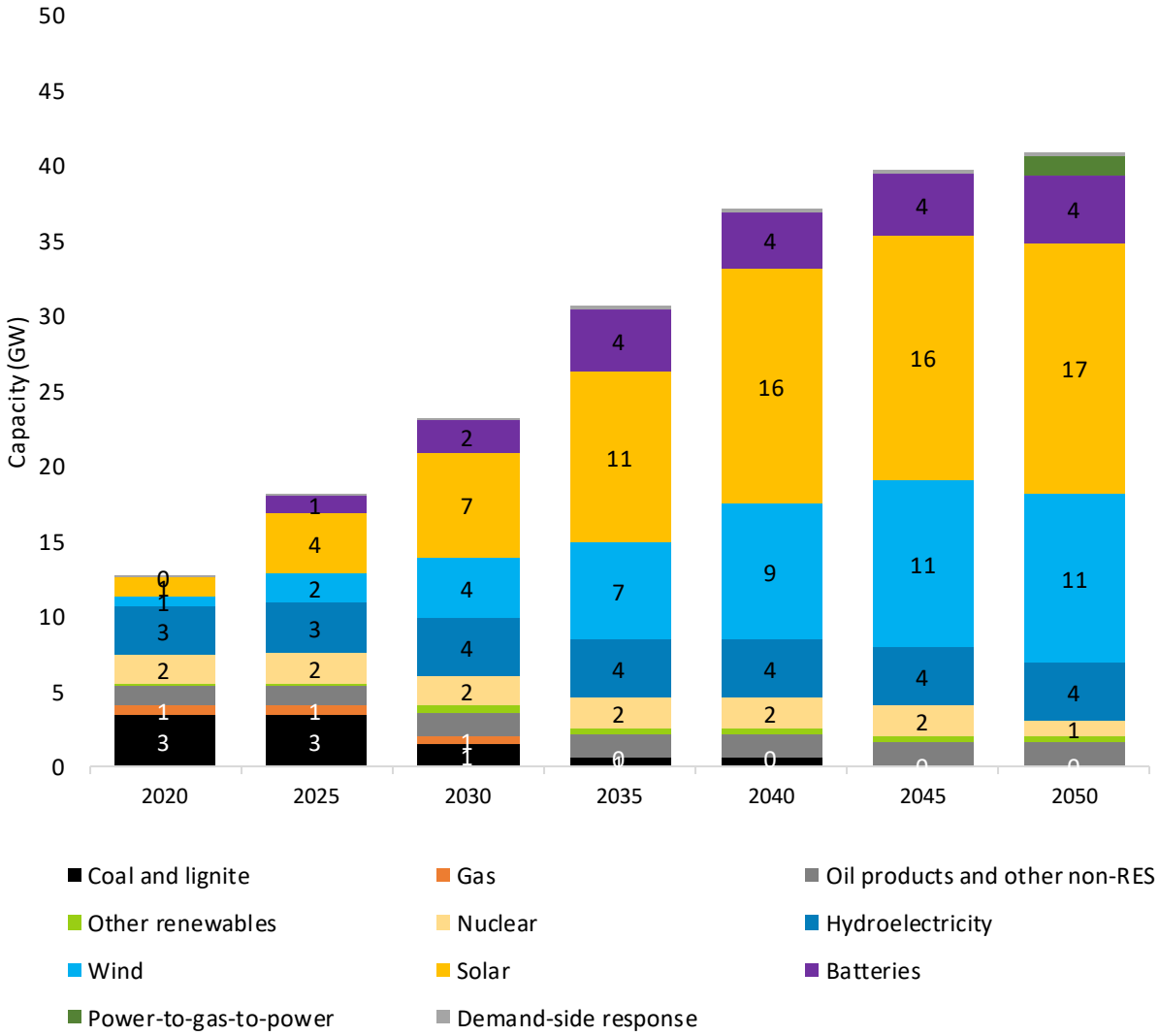
Thermal capacity outlook (MW)



Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River. In the thermal capacity outlook, lignite old 1 includes c520MW of lignite CCS capacity, and c63MW of other non-RES capacity from 2030 onward.

In the updated *IAS*, Bulgaria progressively transitions away from lignite by the 2040s, coupled with a strong growth of low carbon capacity from 2025 to 2050

Installed capacity (GW)

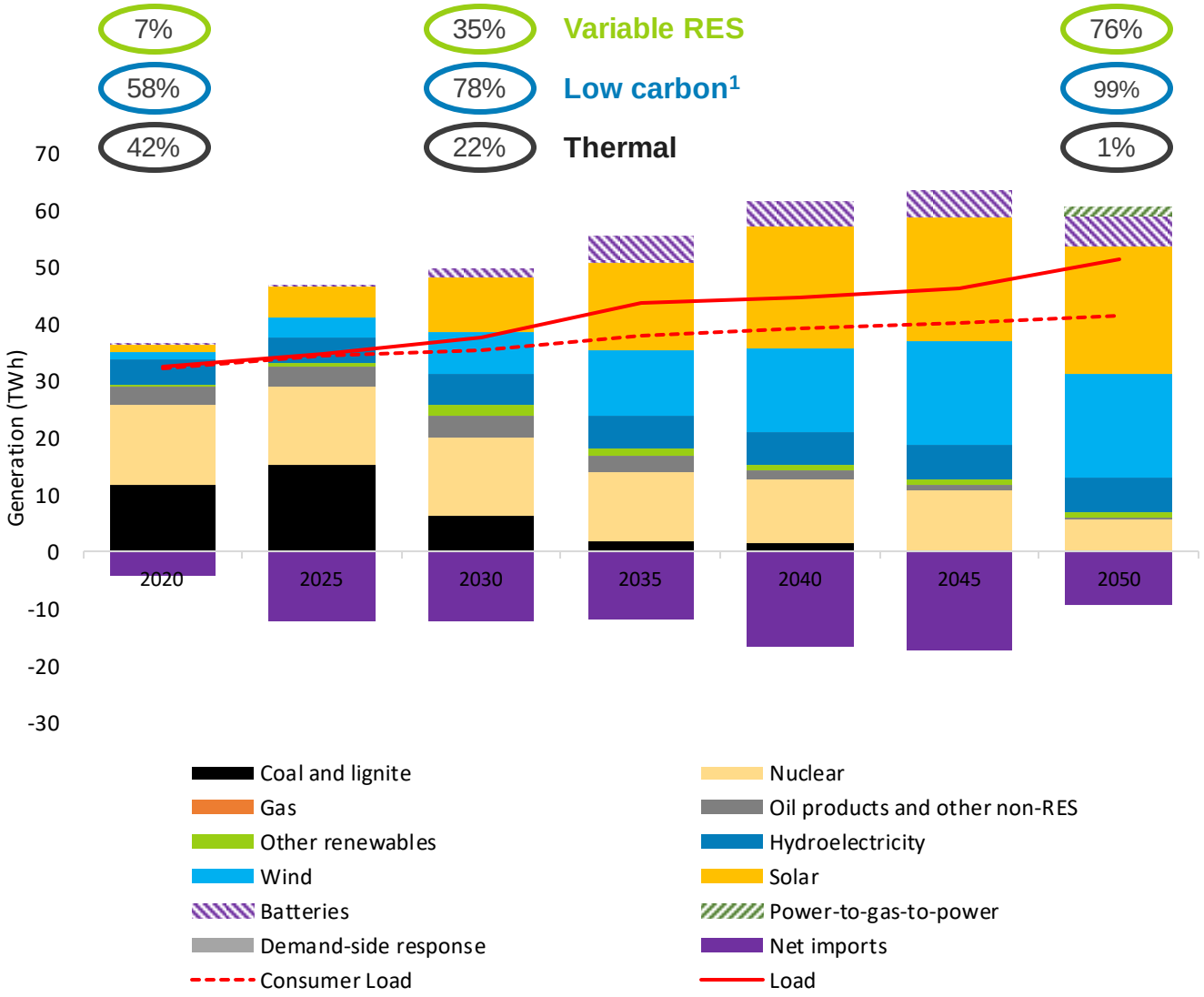


- Lignite plants are replaced from 2025 onwards by RES and batteries which allows to ensure security of supply in the medium term.
- Overall, installed capacity increases by 28.3 GW by 2050 relative to today. This increase is primarily driven by the growth of renewables, with both onshore wind and solar reaching 28 GW of installed capacity by 2050.
- The growth of renewables is also accompanied with a steady increase in battery capacity, with c. 4GW installed by 2050, as well as DSR and P2G2P.

Source: Compass Lexecon

In line with the capacity mix evolution, the updated *IAS* sees a strong growth of low carbon generation, with lignite production gradually phasing out by the 2040s

Generation (TWh)

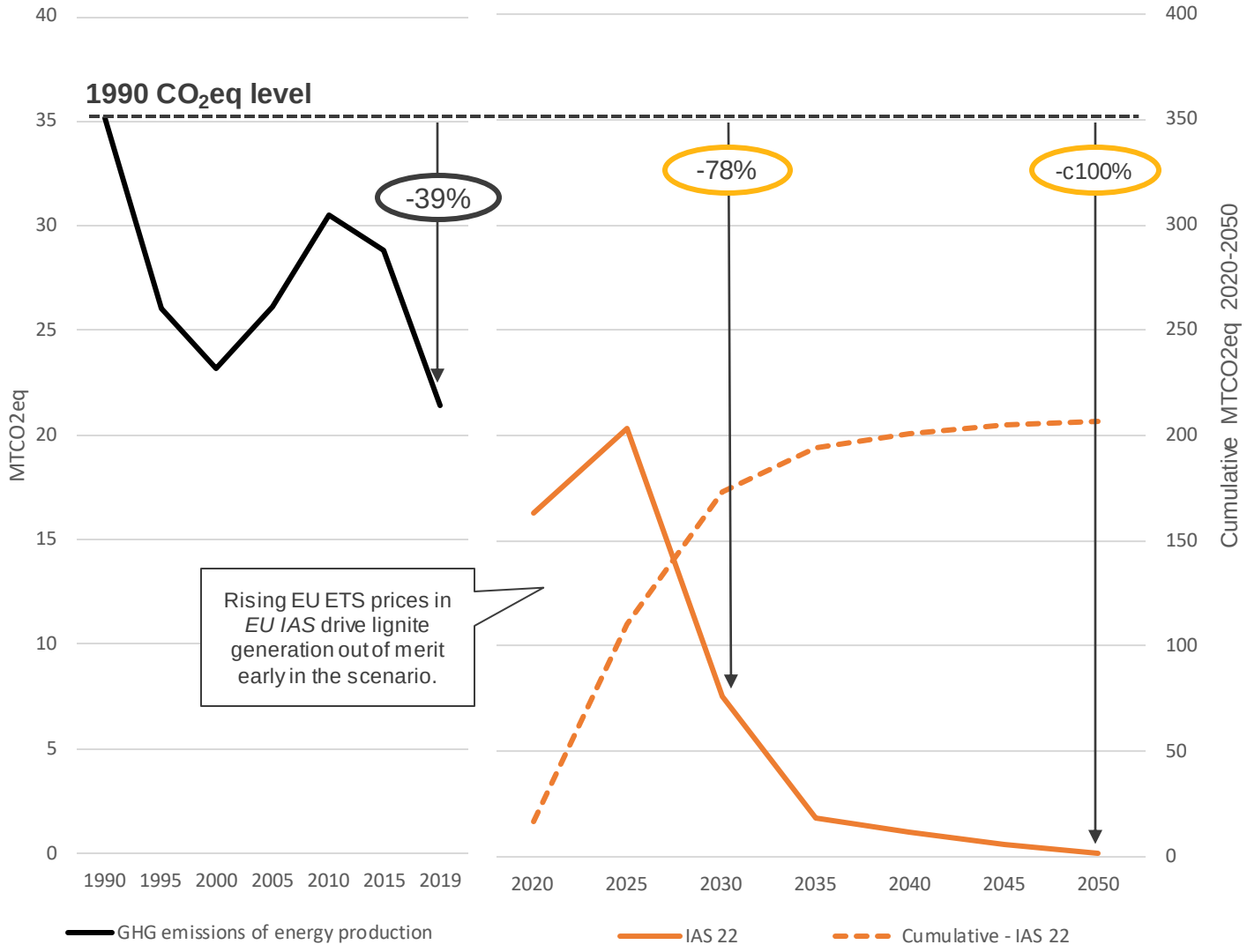


- Bulgaria still strongly relies on lignite generation up until 2025, before a progressive phase-out by the 2040s.
- Overall, the Bulgarian export balance remains positive throughout of the forecast horizon.
- Variable renewable generation grows substantially over the 2020-2050 period, reaching a share of 76% 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 78% by 2030 before further decreasing to full decarbonisation by 2050

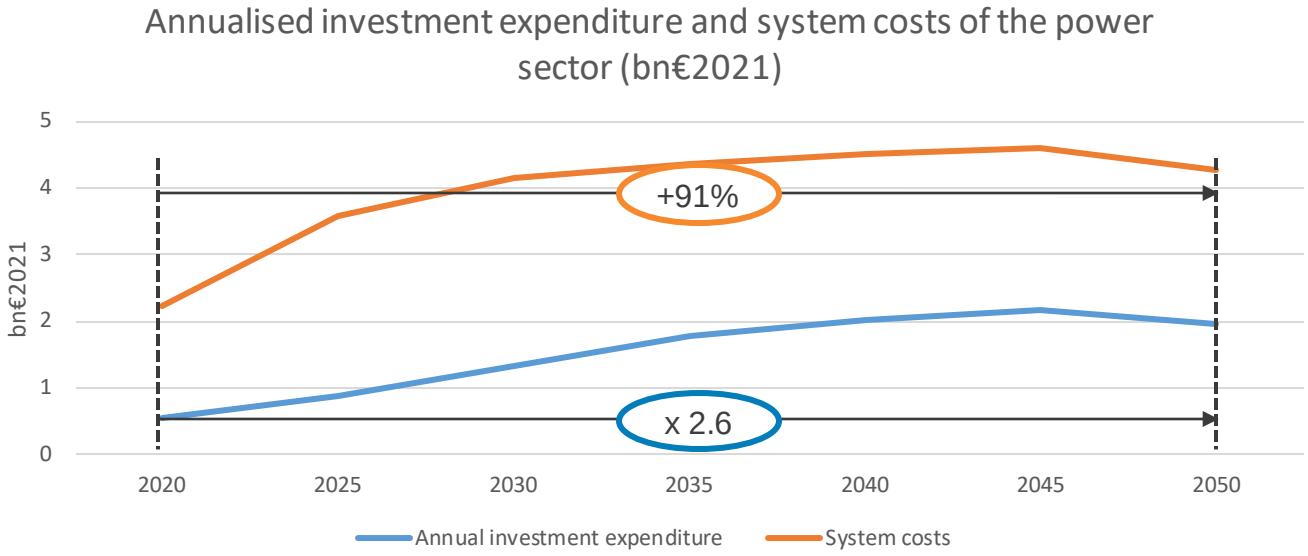
GHG emissions of the energy sector

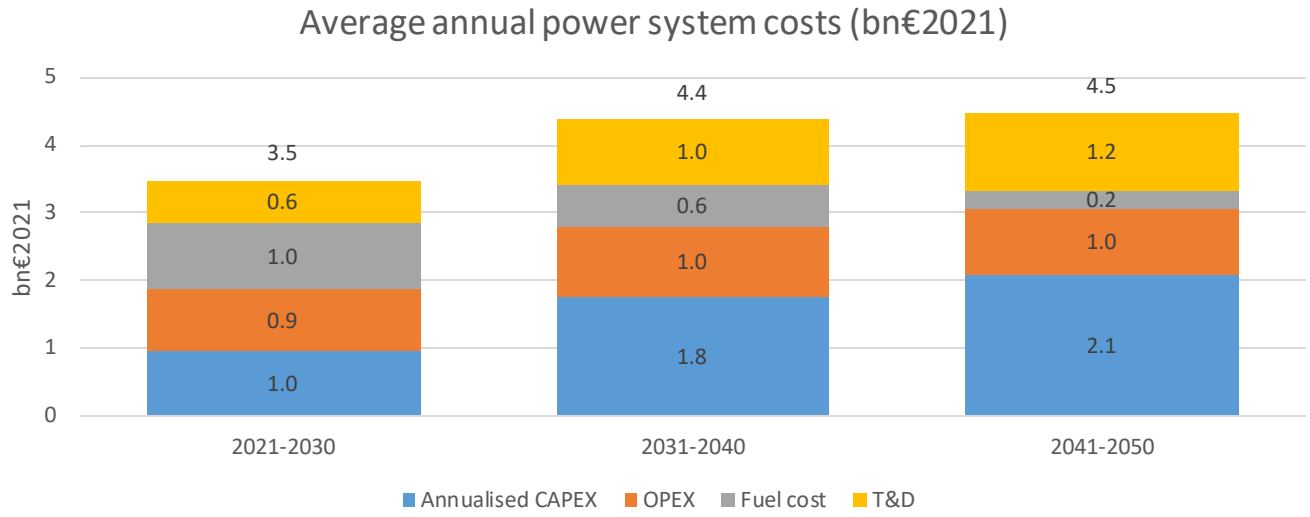


- In line with the decrease of thermal generation in the first decade, driven by the increase of carbon prices with the EU ETS Reform as part of the European "Fit for 55 package", energy sector emissions drop by 78% by 2030, which is equivalent to an overall c70% emission reduction for Bulgaria.
- Thus, 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 c90% over the forecast horizon in the updated *IAS*, and annual investment expenditures are multiplied by 2.6





- 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.

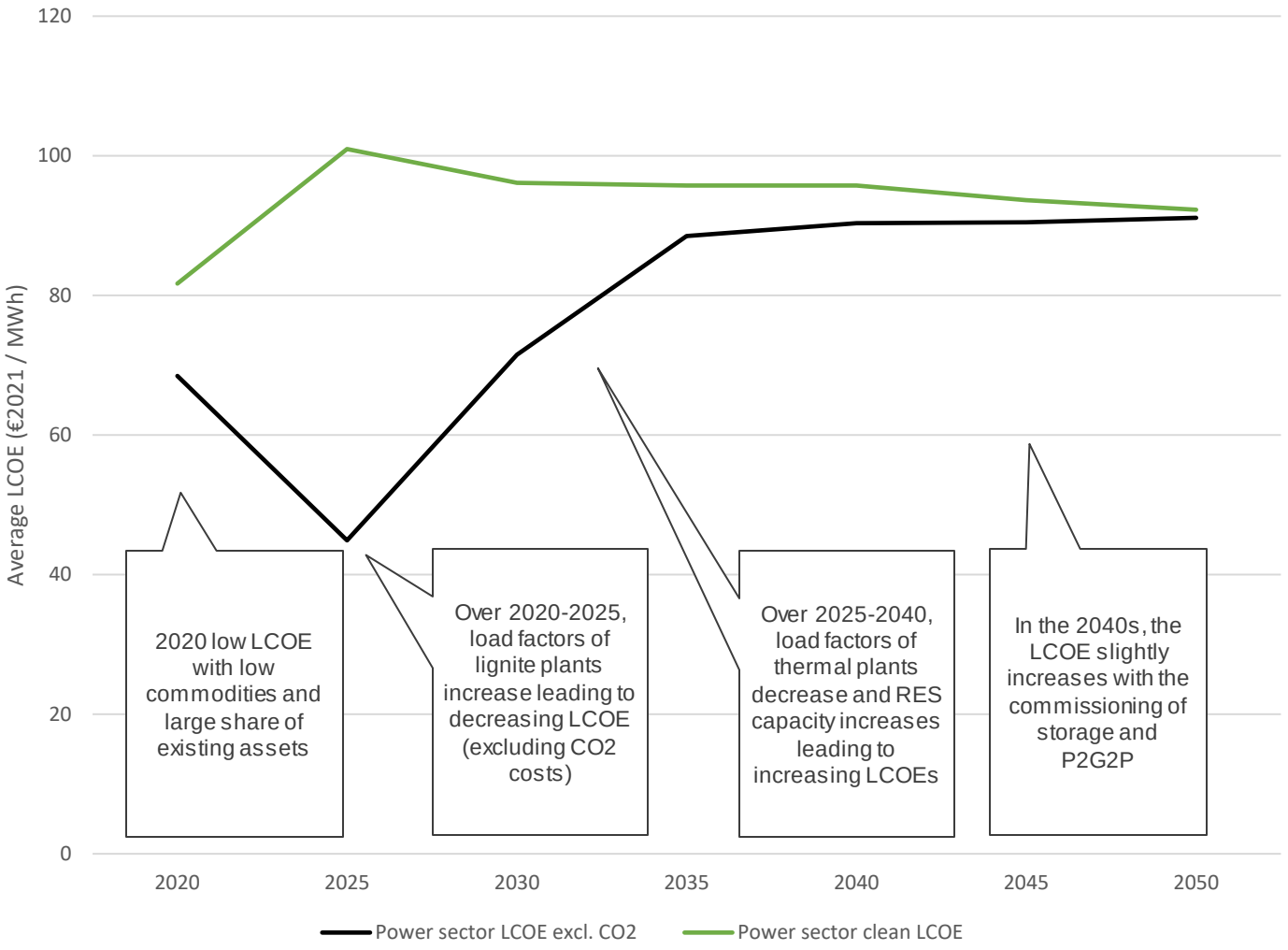
- Power system costs increase by c90% in the updated *IAS* between 2020 and 2050, mainly due to the capital cost of new installations.
- Annual investments costs increase 2.6x between 2020 and 2050, partially offset by a reduction in fuel costs.

- 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 (€2021/MWh)



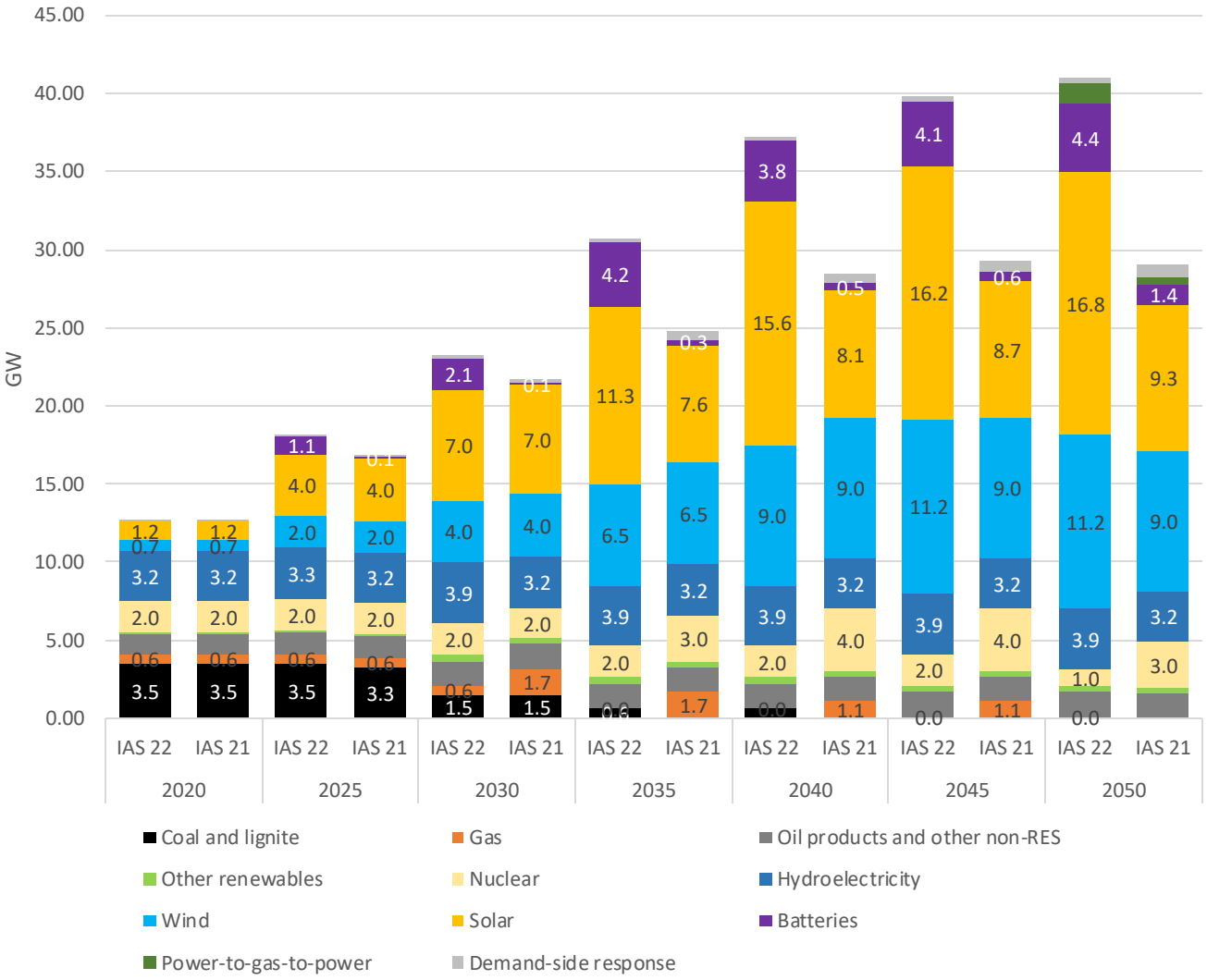
- LCOEs (excluding CO2 costs) drops by 2025, as lignite plants' load factors increase. LCOEs then increase, in line with the need for new greenfield investments to decarbonise Bulgaria, before stabilizing with the increase of net export balance in the 2030s.
- However, when looking at clean LCOEs which 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 Comparison of the updated IAS and original IAS

The updated *IAS* shows a stronger development of RES and batteries throughout to 2050

Capacity comparison between scenarios



The updated *IAS* shows a stronger development of RES and batteries throughout to 2050

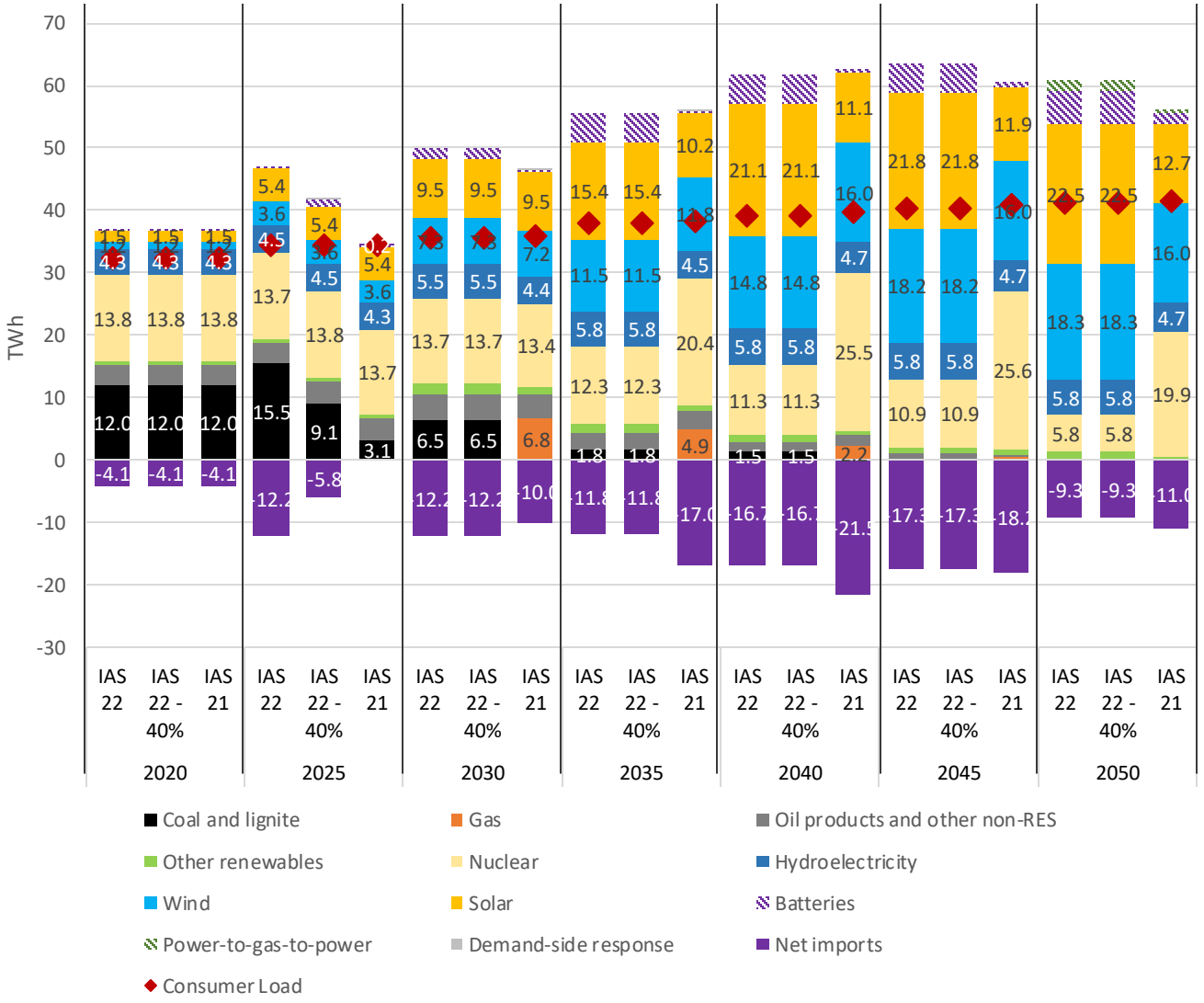
- In line with the RRP, battery development materializes from 2025 onwards enabling to further develop variable renewable capacity in the 2030s
- The accelerated development of RES in the 2030s (incl. new RoR and partial conversion to biomass) and the delay of possible commissioning of new nuclear in the late 2030s push new nuclear outside of the equation due to limited additional export opportunities.

- Regarding thermal capacities, the updated *IAS* features a prolonged utilisation of lignite through CCS retrofit in the 30s and partial conversion to biomass, instead of commissioning new gas plants.
- Total thermal capacity reduces in the updated *IAS* as battery provides a larger share of the firm capacity necessary to ensure security of supply throughout to 2050.

Source: Compass Lexecon

While the updated *IAS* shows a stronger development of RES and batteries throughout to 2050, the updated *IAS* shows a stronger role of lignite in 2025-30

Generation comparison between scenarios



While the updated *IAS* shows a stronger development of RES and batteries throughout to 2050, the updated *IAS* shows a stronger role of lignite in 2025-30

- In line with the evolution of the capacity mix, the updated *IAS* show a stronger share of RES and batteries throughout to 2050.
- The increase in both solar and wind generation combined with increased battery generation in the long term offset the generation of new nuclear from the original *IAS.*

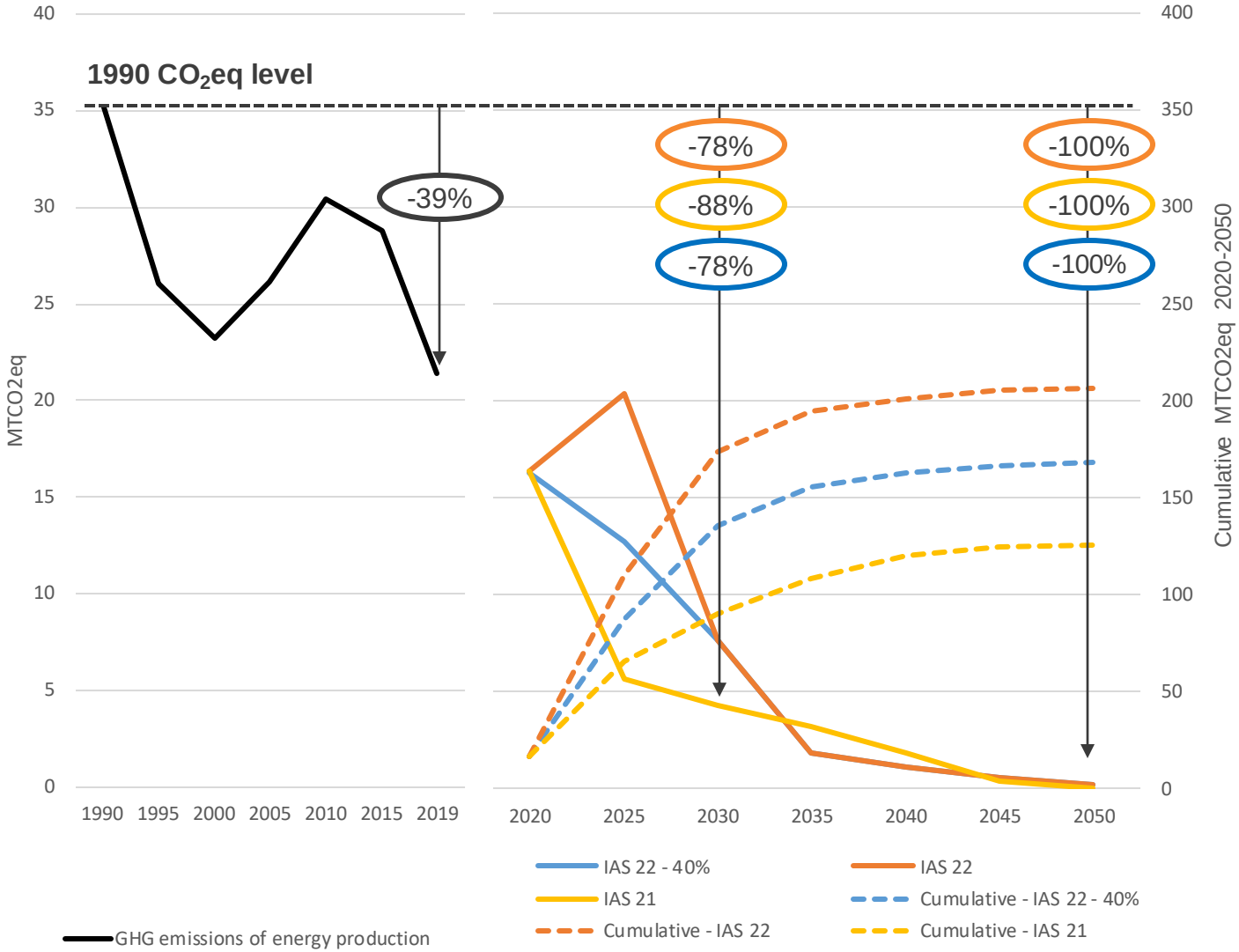
In the short to medium term, the updated *IAS* shows a stronger role of lignite generation.

- In 2025, the updated *IAS* reflecting recent commodity market changes (increase of gas and CO2 price) makes greater use of lignite due to its cost competitiveness. This remains with the 40% emission reduction constraint proposed in the RRP.
- In 2030, the updated *IAS* features a prolonged role of lignite with partial CCS retrofit on 1/3 of the generation instead of transition gas generation in the original *IAS*.

Source: Compass Lexecon

Across the three *IAS* emission are projected to drop by at least c80% by 2030 before fully decarbonising by 2050

GHG emissions of the energy sector

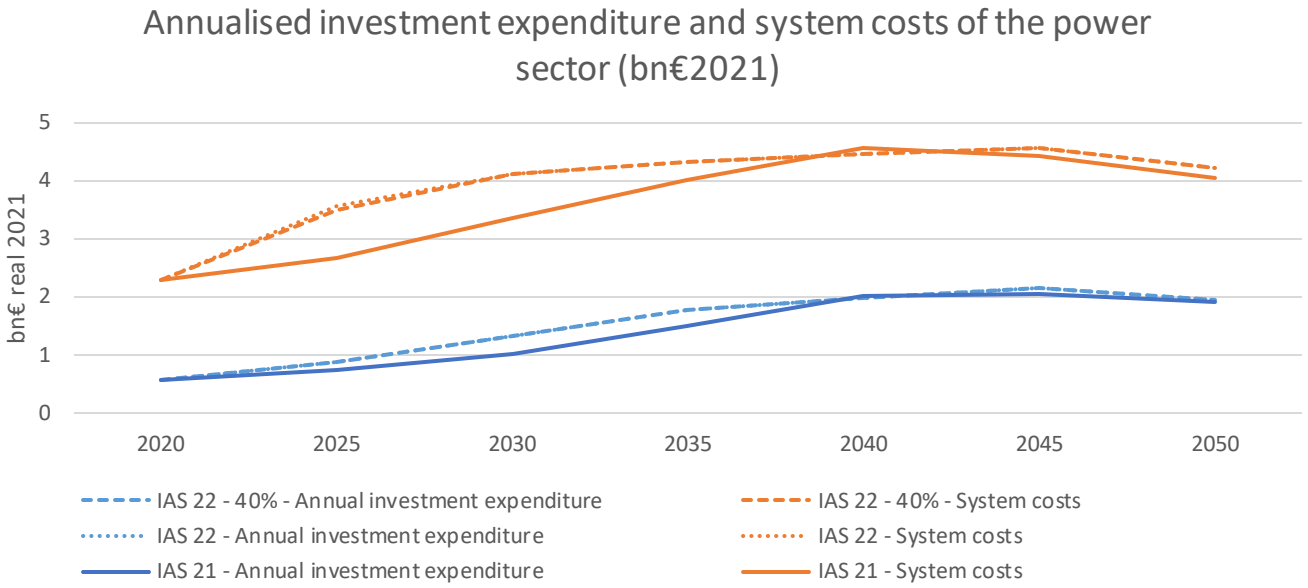


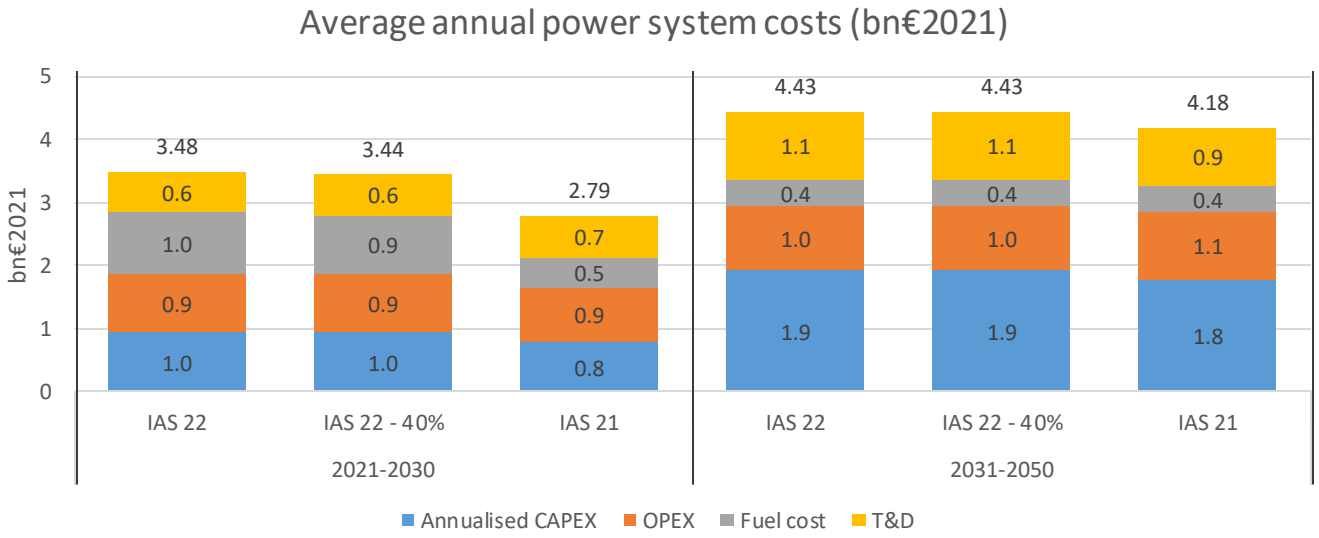
In line with the decrease of thermal generation in the first decade, energy sector emissions drop by at least c80% by 2030.

- The updated *IAS* shows higher emission in the first decade compared to the original *IAS*. This directly reflects the increased role of lignite in the short term.
- However, the implementation of the 40% emission reduction constraint in the updated *IAS* enables to mitigate the emission increase in the first decade.
- Around 2030, the partial CCS retrofit of lignite generation enables to mitigate the increase of emission compared to the original IAS and further reduce them by avoiding the use of gas in the transition.
- 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.

While CAPEX expenditures increase in all scenarios, updated *IAS* shows higher system costs in the first decade with increased commodities



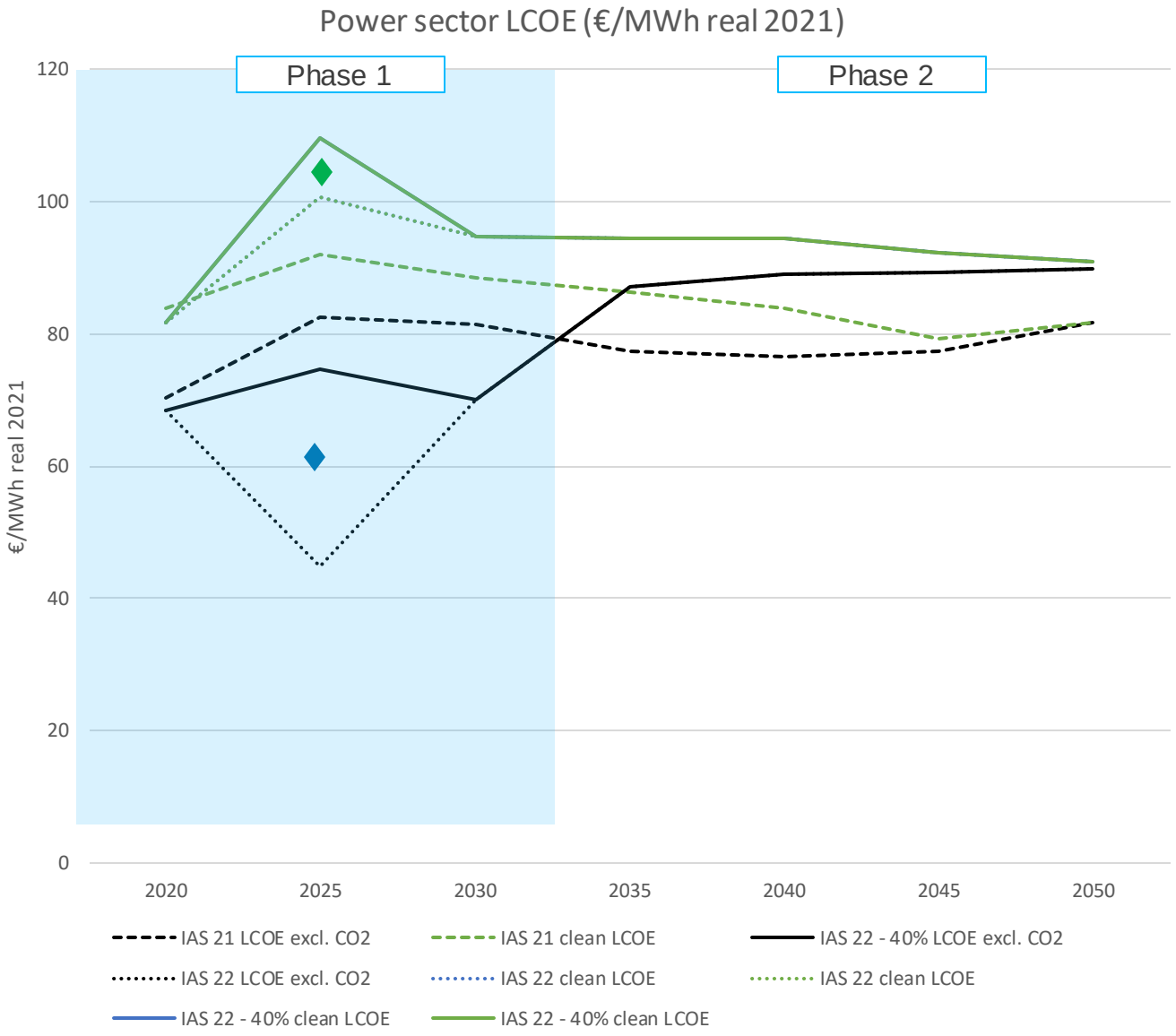


- All scenarios' power system costs becomes increasingly CAPEX intensive over time.
- In line with the increase of commodity prices, the updated IAS shows higher power system costs compared to original *IAS*.
- In the long term, the shift to more renewable in the updated *IAS* translates into high T&D cost compared to the original *IAS*.

- 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 updated *IAS* shows mitigated cost in the first decade and increased cost in the long term, the 40% emission reduction could lead to 1bn€ cost increase in 2025.



- **Phase 1:** Up until 2035, the updated *IAS* results in lower LCOEs than original *IAS*, as the greater role of lignite generation enable to reduce the unitary cost of Bulgarian power generation.
- In addition, the implementation of the 40% emission reduction constraint would materially increase power system cost in 2025 (♦) by around 30€/MWh or 1bn€/year.
  - This remains even when accounting CO2 in the LCOE (♦).
- **Phase 2**: Post 2035, the updated *IAS* shows higher LCOEs than original *IAS*, as a results of the delay of possible commissioning of new nuclear and increased T&D cost to integrate additional RES generation.
- Overall, the updated *IAS* LCOEs stabilise at around 90€/MWh, or 10€/MWh higher than the original *IAS*.

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.

The updated modelling of the *IAS* provides a detailed assessment of the power sector demand, capacity, emissions and costs

Capacity and generation outlook

- **Across both the original and updated *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 11GW wind and solar capacity being developed by 2030.
- This translates into an **increasing share of variable RES generation** in both scenario from 7% in 2020 to 35% (resp. 36%) in 2030 in updated *IAS* (resp. original *IAS*) and 76% (resp. 53%) in 2050 in updated *IAS* (resp. original *IAS*).
- Besides, the **updated *IAS* projects increasing low carbon capacity by 2050** compared to the original *IAS* in the form of additional hydro capacity (+650MW), additional batteries (+3GW) and additional seasonal storage (+830MW).
- Along the transition, the **updated *IAS* is projected to rely longer on lignite through to early 2030s** with partial CCS retrofit (520MW) and partial conversion to biomass (60MW) instead of new gas investments as in the original *IAS.*
- In addition, by not developing new nuclear capacities from 2040 onwards, the **updated *IAS* illustrates the narrow window of opportunity to commission new nuclear projects in the mid 30s**; if commissioned too late, new nuclear projects would have a limited value to the system as other low carbon capacities would have pre-empted market opportunities.

Carbon emission reduction and power system cost outlook

- With the increasing role of lignite generation in the transition, **the updated IAS shows higher emission compared to the original IAS to 2030, but achieve 80% of CO_2 emission reduction in the energy sector by 2030**.
- However, the **updated *IAS* leads to significant reduction in LCOEs over the next decade compared to the original *IAS***, providing a hedge against rising commodity prices.
- In addition, the **reduction of LCOEs could lead to an additional 1bn€/year saving** without the 40% emission reduction constraint in 2025.
- In the long-term, the **updated *IAS* shows an increase of LCOEs compared to the original *IAS*** as a result of the further development of variable RES and storage instead of new nuclear, further illustrating the narrow window of opportunity of such projects.
- Overall, the updated and original *IAS* **show how Bulgaria can put in place an ambitious decarbonisation strategy with rapid and deep emission reductions in the power sector** thanks to new technologies.

Source: Compass Lexecon

2.5 Comparison of the updated IAS sensitivities

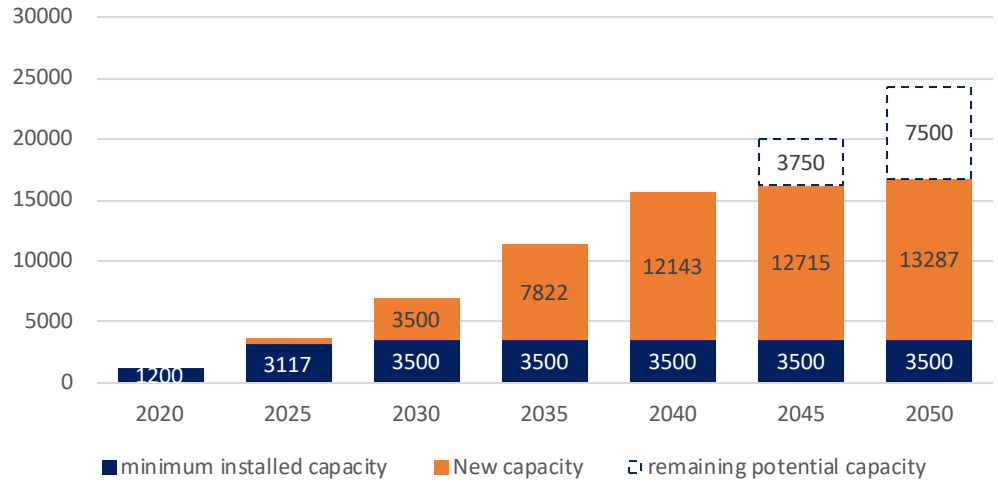
In addition to the updated central scenario, two sensitivities of *IAS 2022* were analysed to assess key decarbonisation options uncertainties

The updated "***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.

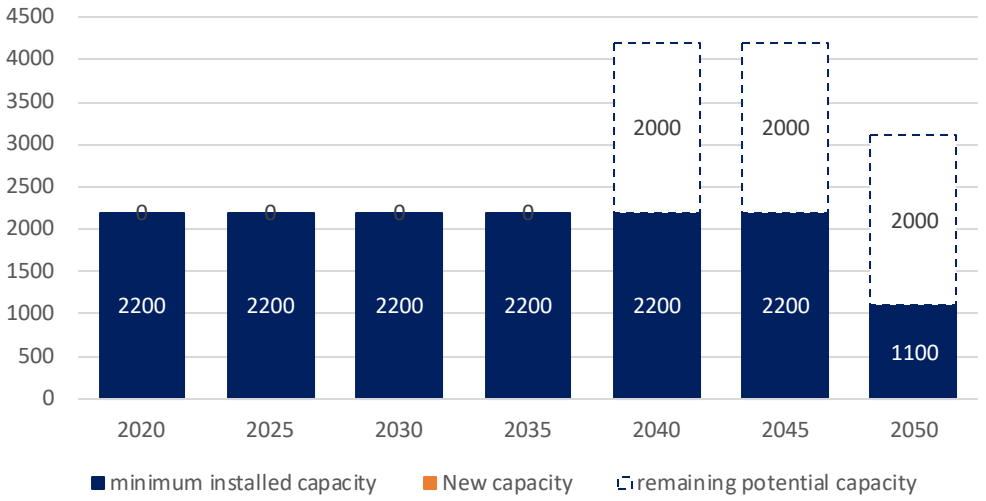
Ff55		Nuclear	Renewables	CO_2 price	Dispatch
B	EU IAS - 2022	Investment framework in place to support nuclear buildout from 2040	Central buildout potential (11 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch
1	EU IAS – 2022 – Lignite closure 2030	Investment framework in place to support nuclear buildout from 2040	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 – 2022 – Nuclear new build from 2035	Investment framework in place to support nuclear buildout from 2035	Central buildout potential (11 GW by 2030, +750MW/year deployment potential for solar, 500 MW/year for onshore wind)	High	Based on SRMC dispatch

In a scenario with lignite closure in 2030, the system relies more heavily on renewables and batteries throughout the horizon

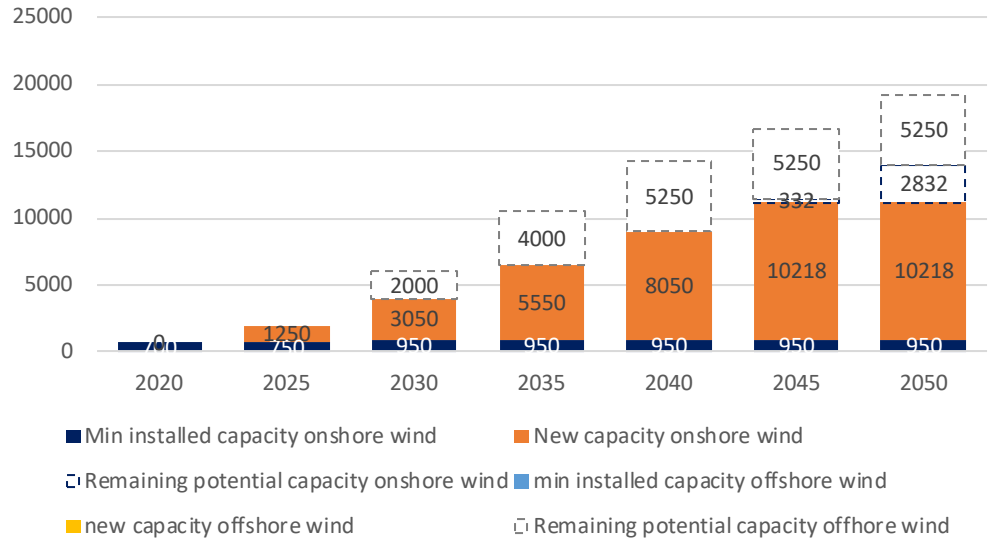
Solar PV – min cap. built, newbuild and remaining potential (MW)



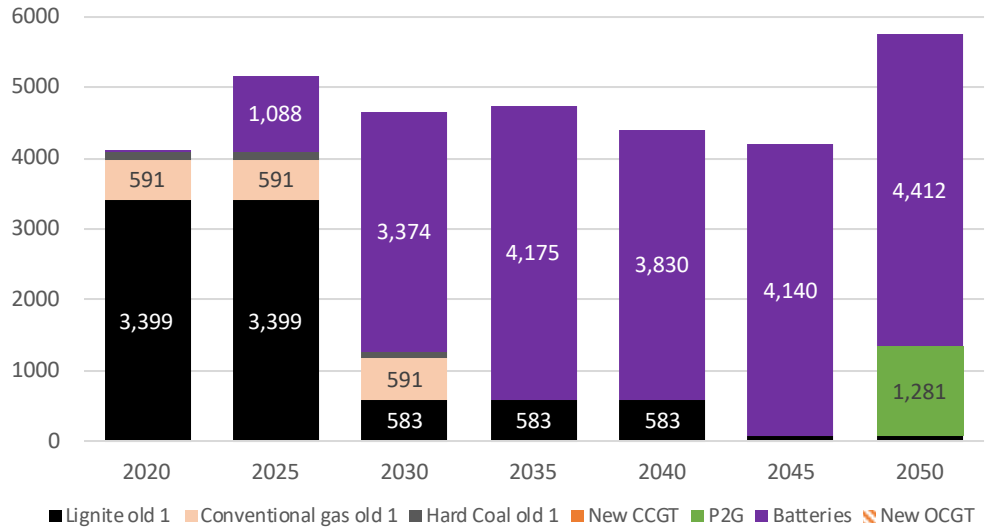
Nuclear – min cap. built, newbuild and remaining potential (MW)



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



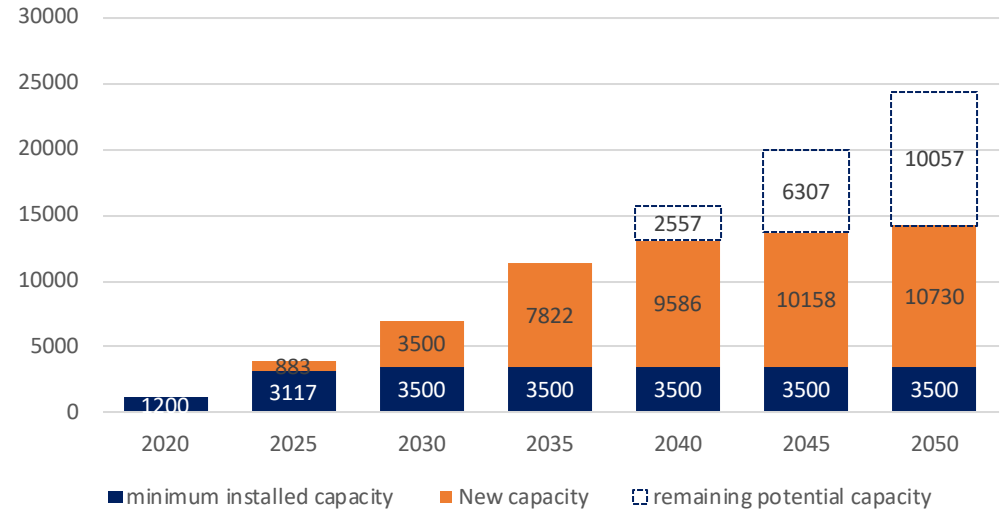
Thermal capacity outlook (MW)



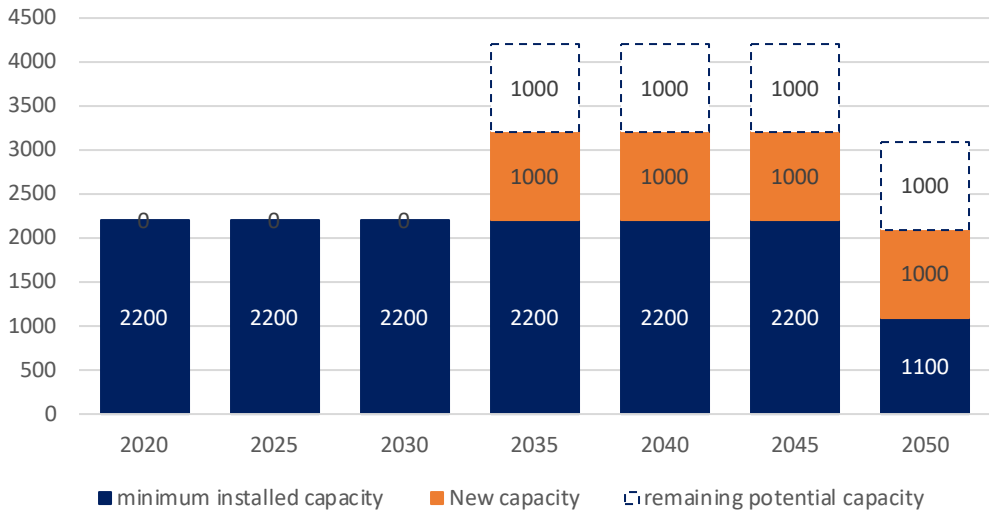
Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River. In the thermal capacity outlook, lignite old 1 includes c520MW of lignite CCS capacity, and c63MW of other non-RES capacity from 2030 onward.

With new nuclear power build from 2035, the need for RES and batteries to decarbonise Bulgaria by 2050 decreases

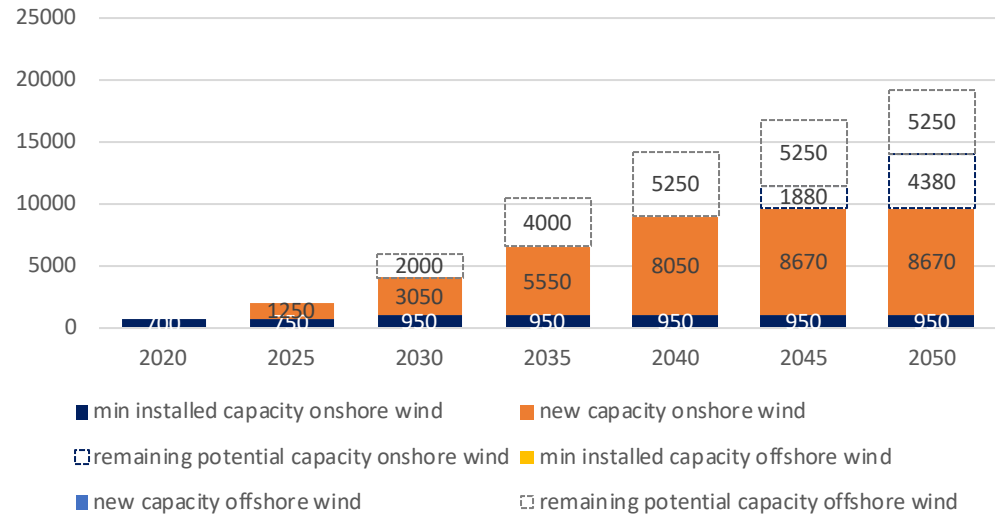
Solar PV – min cap. built, newbuild and remaining potential (MW)



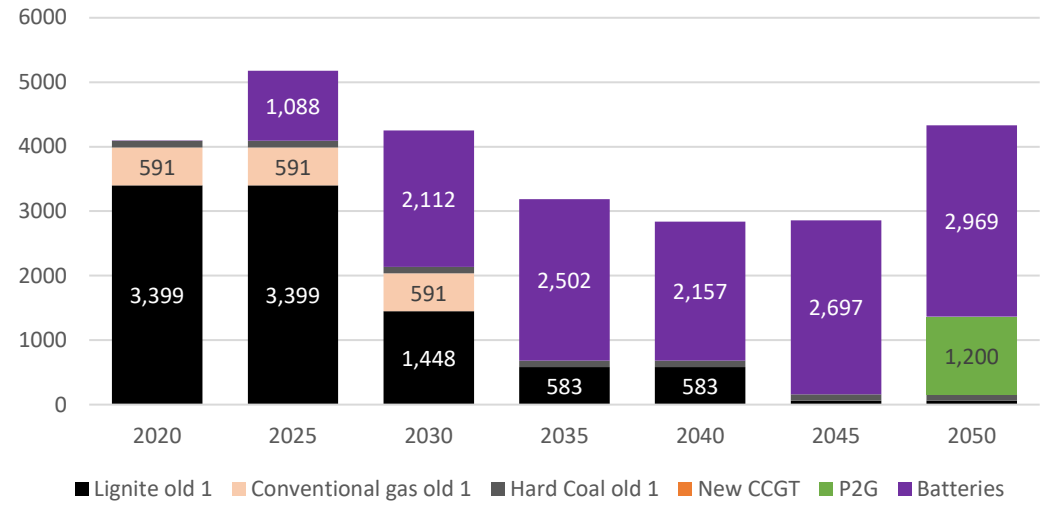
Nuclear – min cap. built, newbuild and remaining potential (MW)



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



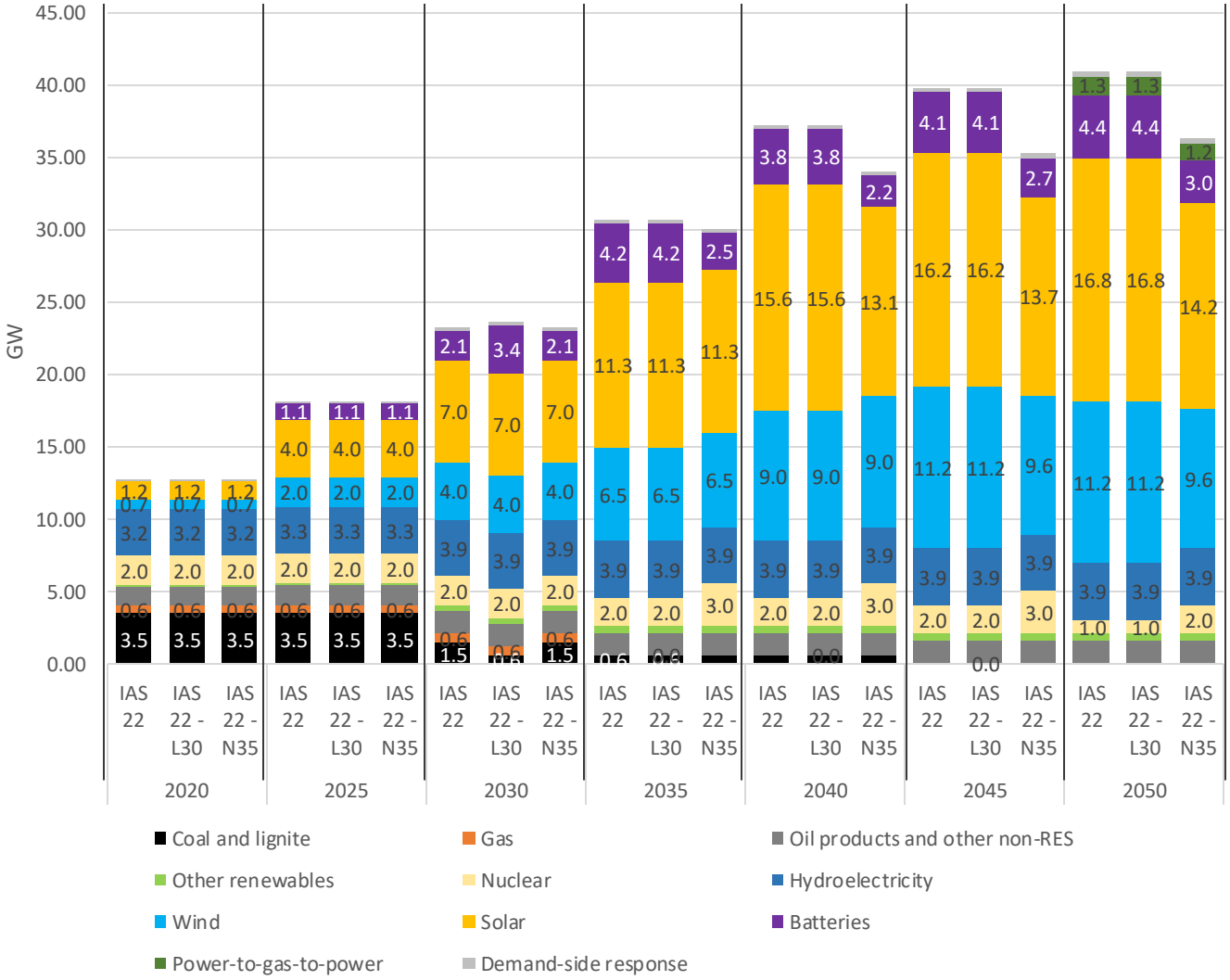
Thermal capacity outlook (MW)



Source: Compass Lexecon
Note: In addition the modelling develop the extension of the Pumped Storage but not the Run of River. In the thermal capacity outlook, lignite old 1 includes c520MW of lignite CCS capacity, and c63MW of other non-RES capacity from 2030 onward.

The updated *IAS* sensitivities show the impact of phase out of lignite in 2030 and earlier new nuclear commissioning and RES and batteries development

Capacity comparison between sensitivities



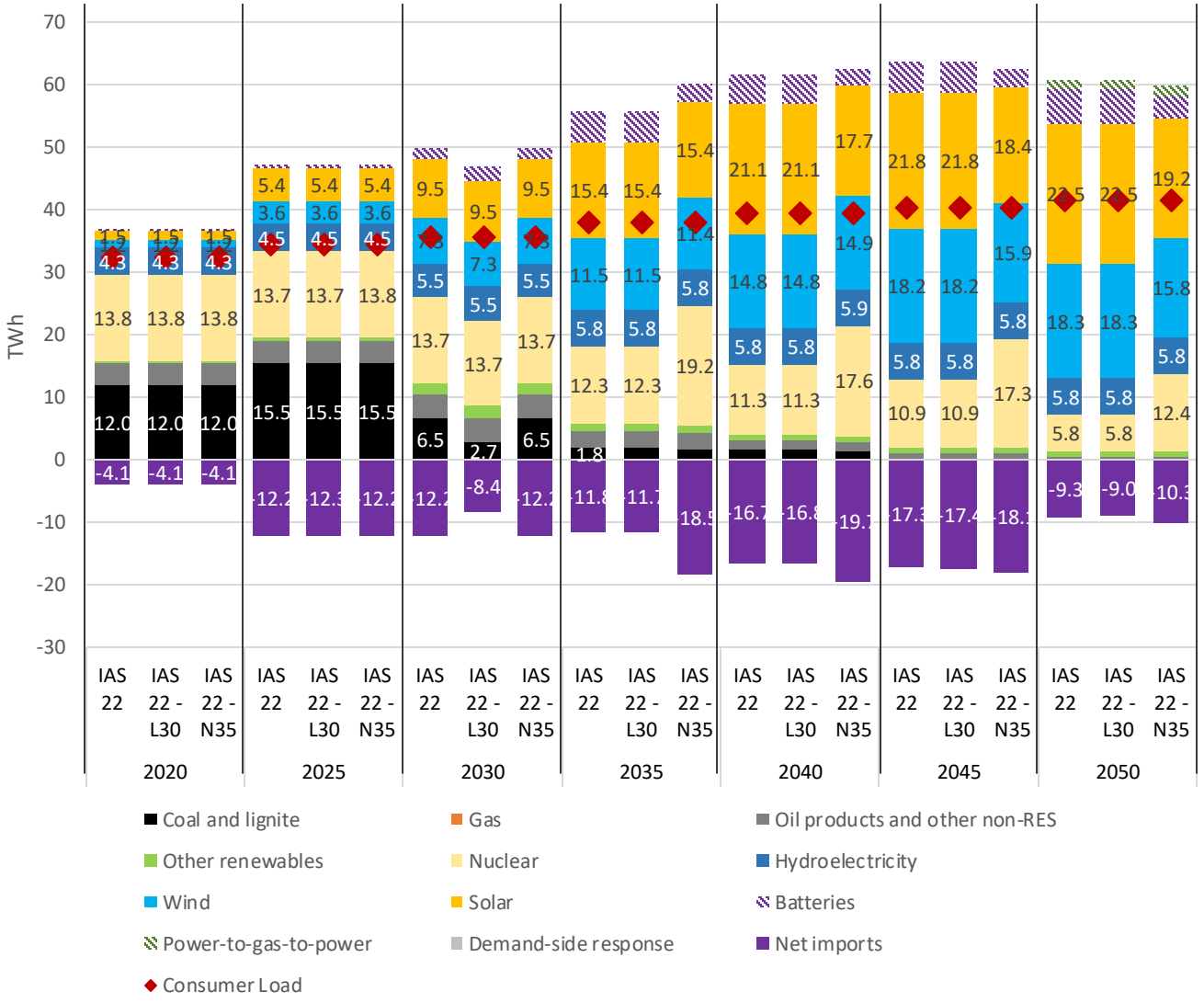
The updated *IAS* sensitivities show the impact of phase out of lignite in 2030 and earlier new nuclear commissioning and RES and batteries development

- The lignite phase out by 2030 would imply commissioning additional battery capacity in 2030 (+1.3GW) to maintain security of supply.
- Earlier new nuclear commissioning by 2035 would allow to reduce the necessary RES and battery additional capacity to decarbonise the Bulgarian power system.
- However compared to the original IAS, only 1GW of new nuclear is commissioned as earlier battery and solar development reduced the market opportunities for new nuclear.

Source: Compass Lexecon

The updated *IAS* sensitivities show the impact of phase out of lignite in 2030 and earlier new nuclear commissioning and RES and batteries development

Generation comparison between scenarios



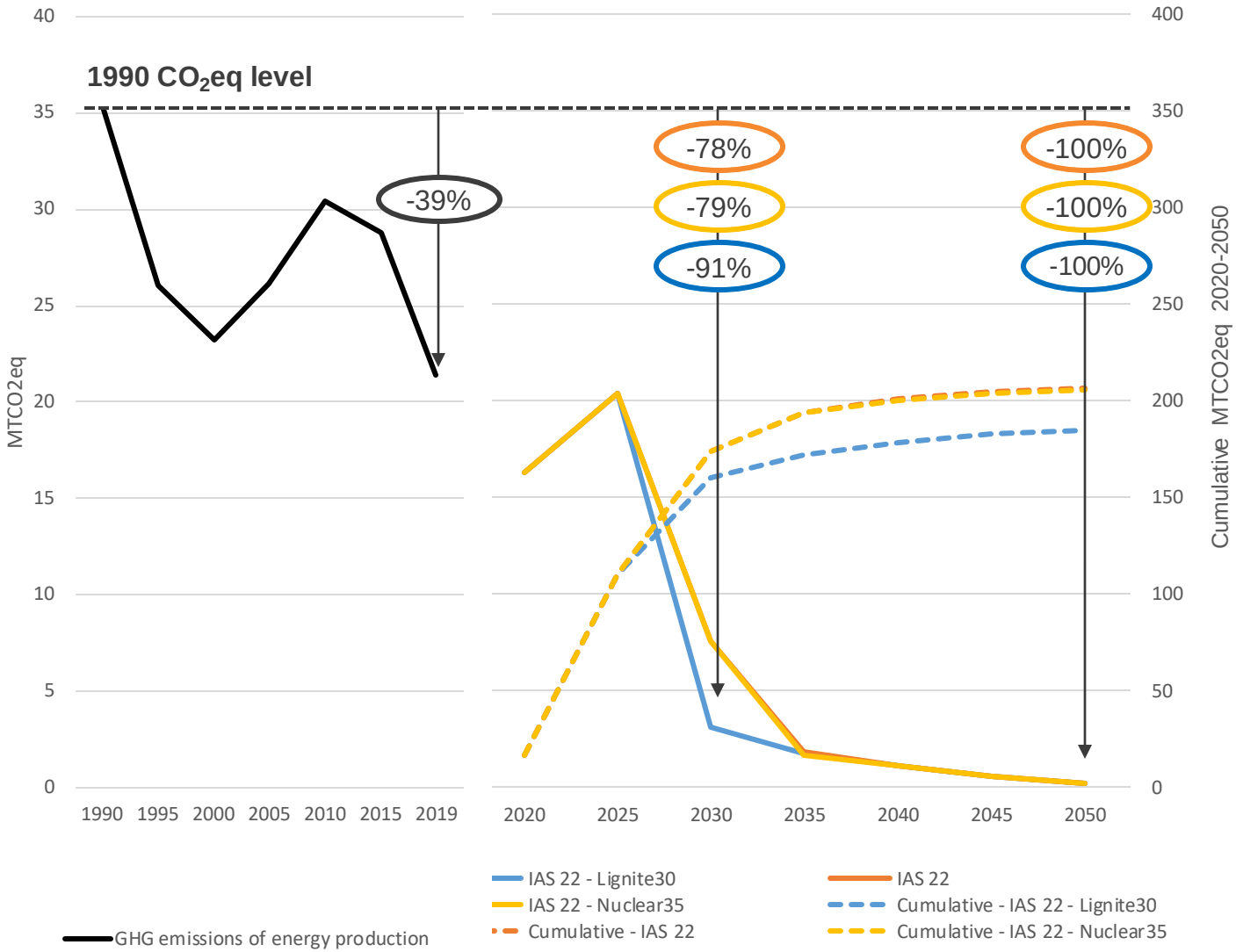
The updated *IAS* sensitivities show the impact of phase out of lignite in 2030 and earlier new nuclear commissioning and RES and batteries development

- The lignite phase out by 2030 would translate into a reduction of c4TWh of not CCS retrofitted lignite and a reduction of c4TWh of the net export balance.
- Earlier new nuclear commissioning by 2035 would allow to temporarily increase the net export balance of Bulgaria before new RES generation development is mitigated compared to the updated *IAS* and net export balance stabilizes at the same level than the updated *IAS* from 2045 onwards.

Source: Compass Lexecon

Across the three *IAS* sensitivities emission are projected to drop by at least c80% by 2030 before fully decarbonising by 2050

GHG emissions of the energy sector

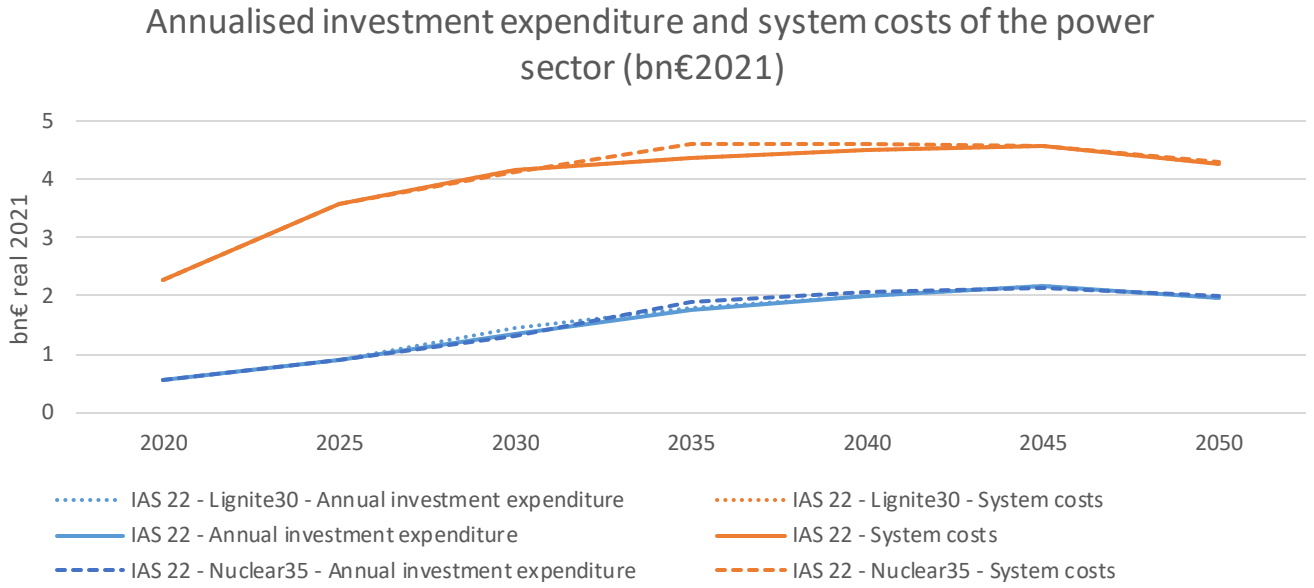


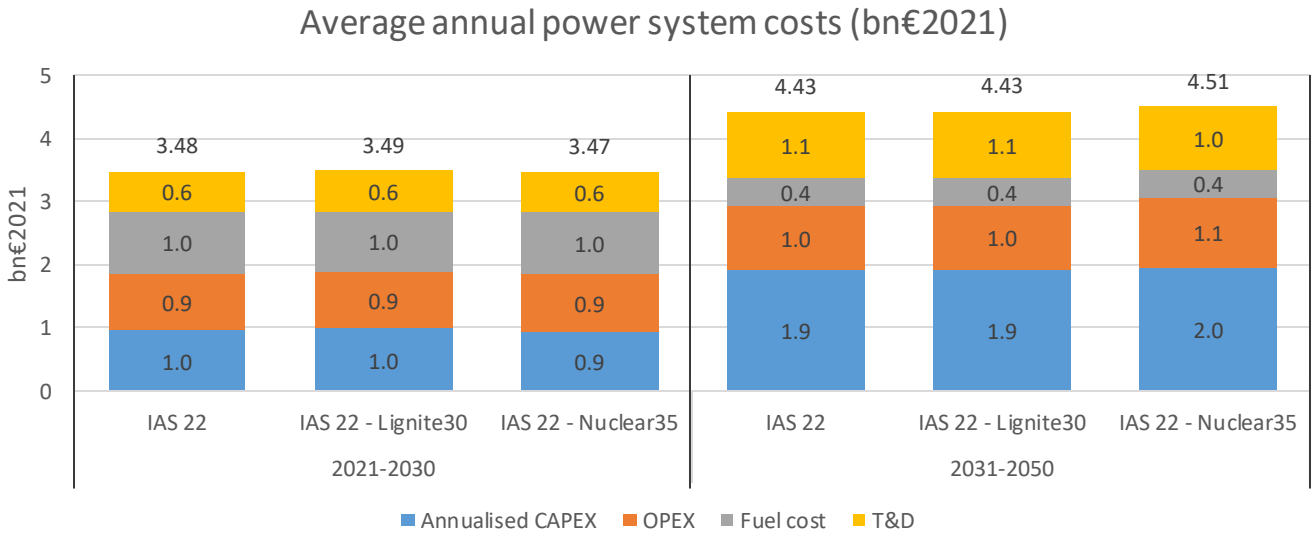
In line with the decrease of thermal generation in the first decade, energy sector emissions drop by at least c80% by 2030.

- The lignite phase out by 2030 allows to increase emission reduction by 2030 from c80% to above 90%.
- New nuclear project largely offsetting new RES development, the updated IAS and the Nuclear35 sensitivity features a similar emission reduction trajectory.
- 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.

While CAPEX expenditures increase in all sensitivities, updated *IAS* shows an intermediate system cost



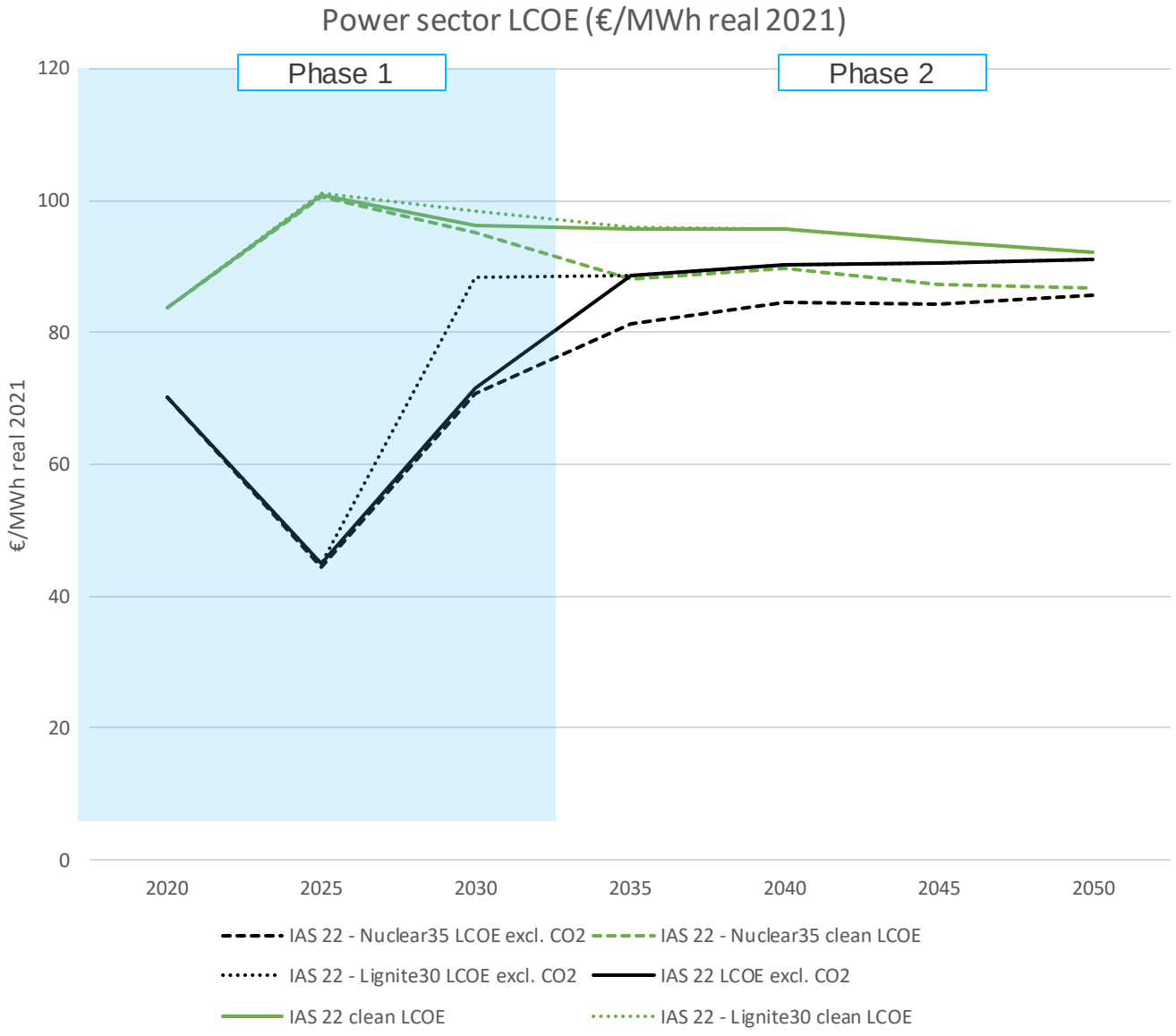


- All sensitivities' power system costs becomes increasingly CAPEX intensive over time.
- In the lignite30 sensitivity, while system cost are comparable to updated IAS throughout, annualised investment are higher in 2035 with the increase of battery capacity.
- In the nuclear35 sensitivity, system cost and annualised investment are higher in 2035 with the commissioning of 1GW of new nuclear.

- 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 earlier lignite phase-out would increase cost by +500m€/year in 2030, earlier commissioning of new nuclear would help mitigate long term cost increase

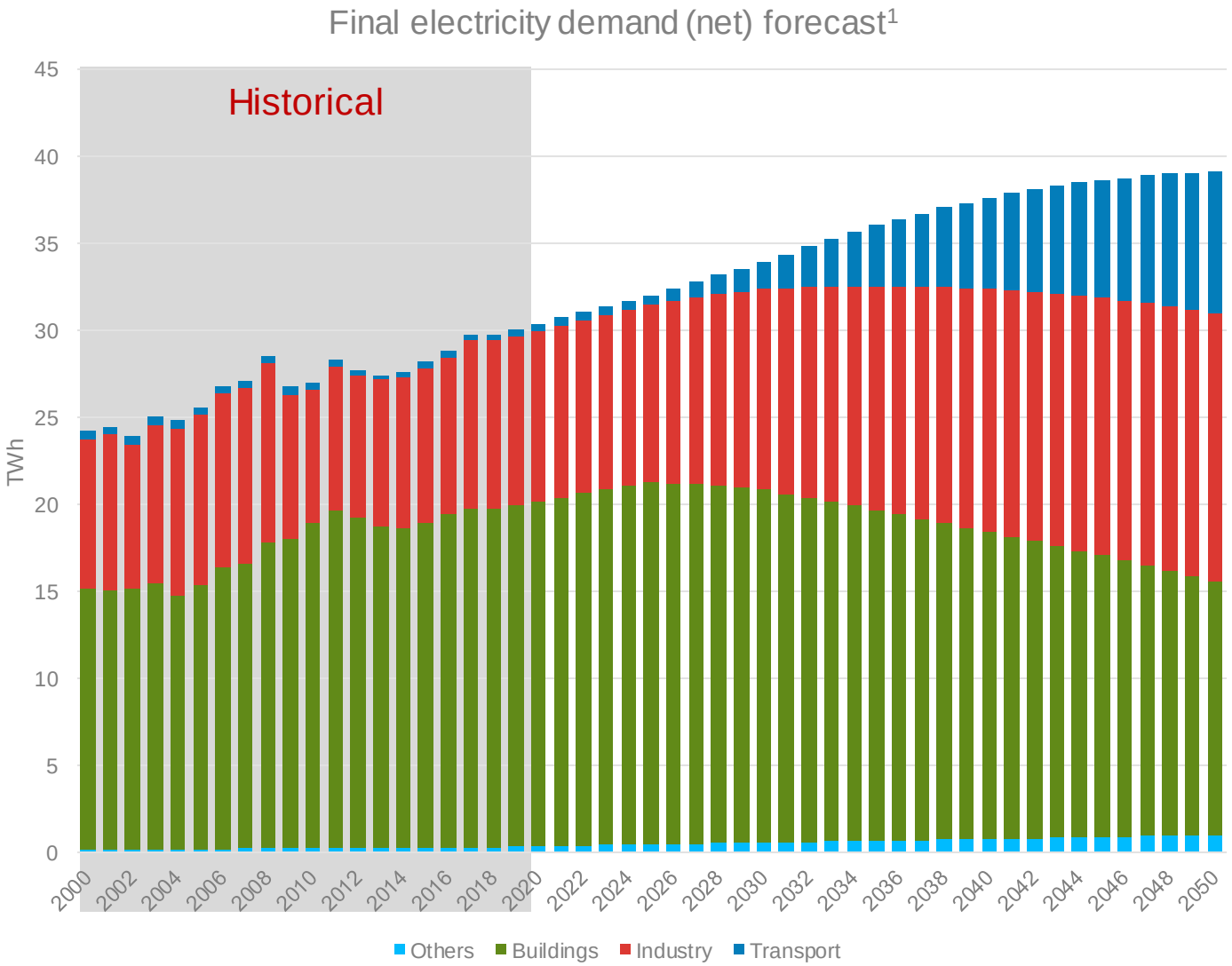


- **Phase 1:** Up until 2035, the Lignite phase out in 2030 results in higher LCOEs (+17€/MWh or 560€m€/year) than the updated *IAS*, as the reduced role of lignite generation increase the unitary cost of Bulgarian power generation.
- **Phase 2**: Post 2035, the Lignite phase out in 2030 and the updated *IAS* show comparable LCOEs as the reduction of lignite compensated by additional new batteries mainly impacts 2030.
- However post 2035, the Nuclear 2035 commissioning sensitivity results in lower LCOEs than the updated *IAS*, as a results of the higher commercial balance in this sensitivity.
- Overall, the while the updated *IAS* LCOEs stabilise at around 90€/MWh, the earlier commissioning of new nuclear LCOEs stabilise at around 85€/MWh, or 5€/MWh higher than the original *IAS*.

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.

Annex – Power market modelling detailed assumptions

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



- 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

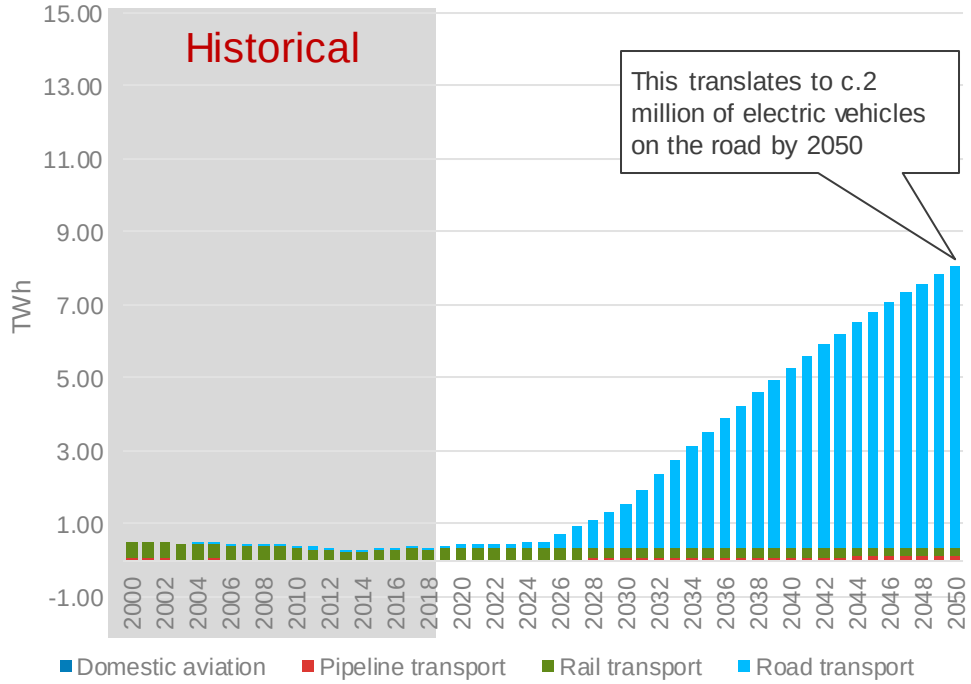
- Road transport electrification is expected to drive electricity demand from the transport sector.

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

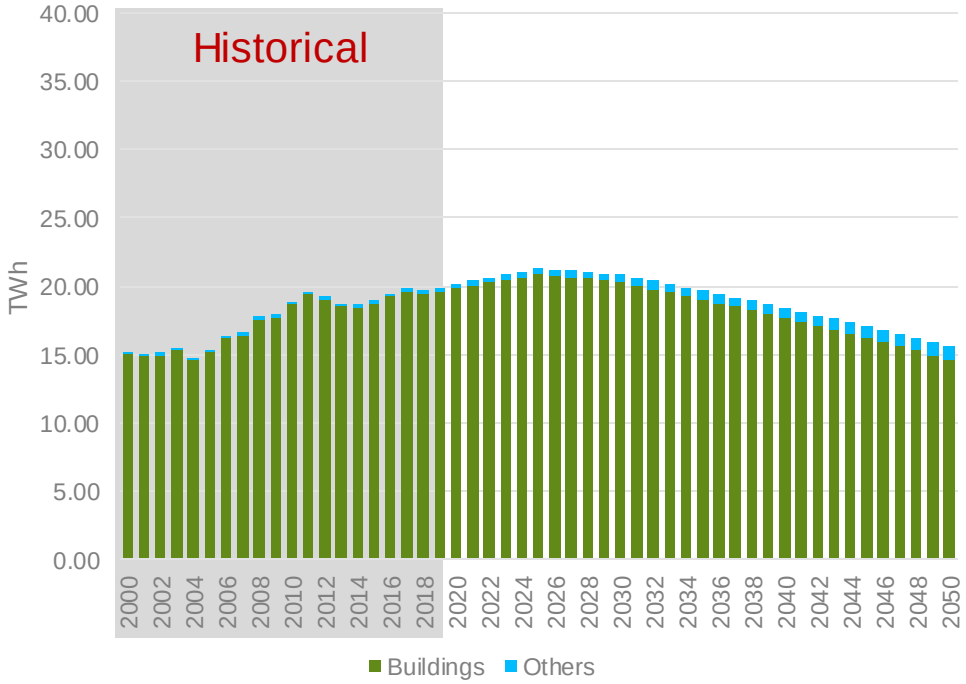
- Buildings energy efficiency is expected to improve materially over the forecast horizon, lowering overall energy needs. The yearly renovation rate of existing households required starts at 0.5% in 2025 and reaches 2.5% by 2050.

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

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



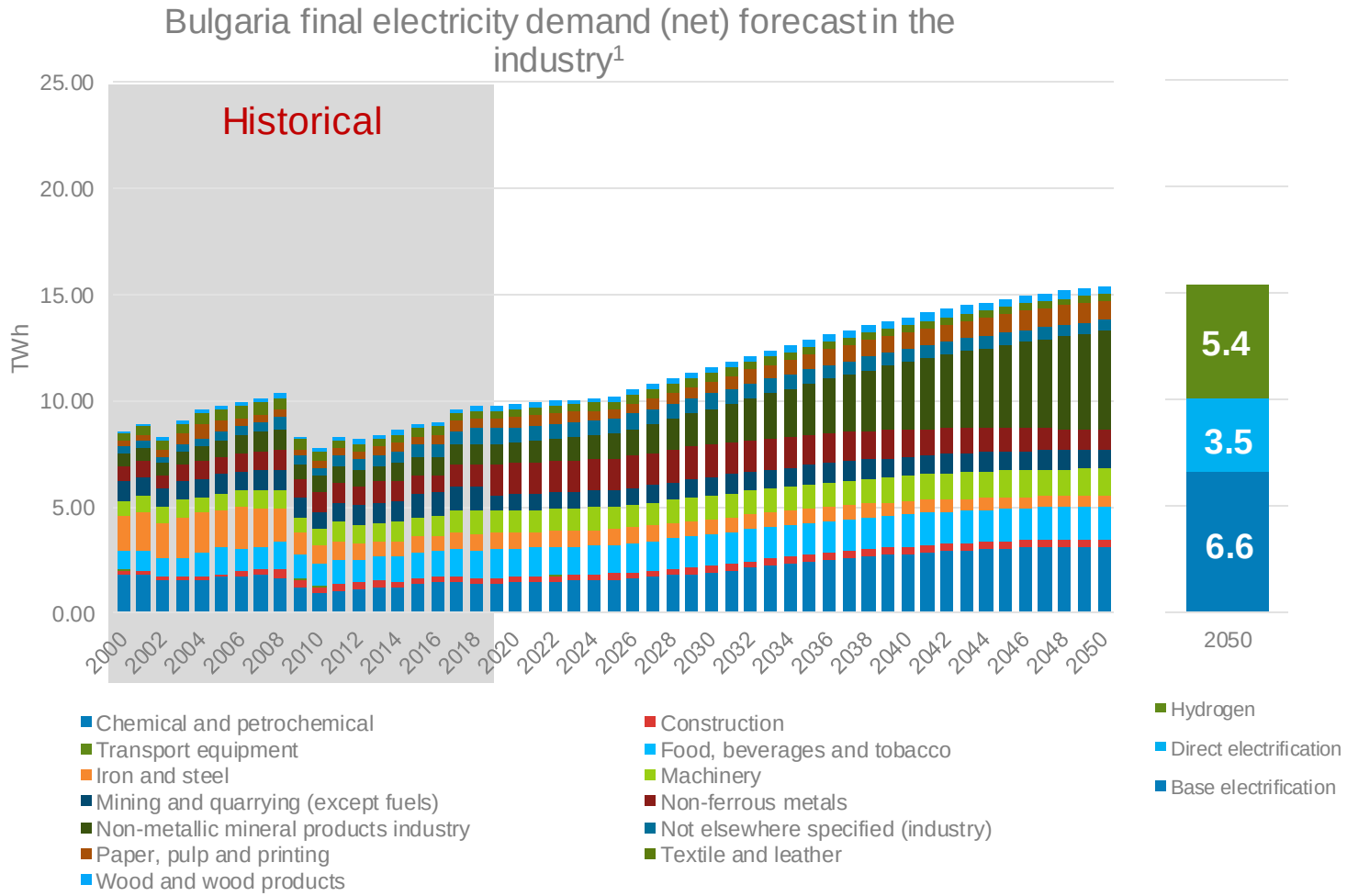
Bulgaria final electricity consumption (net) in Buildings and other sectors[2]



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

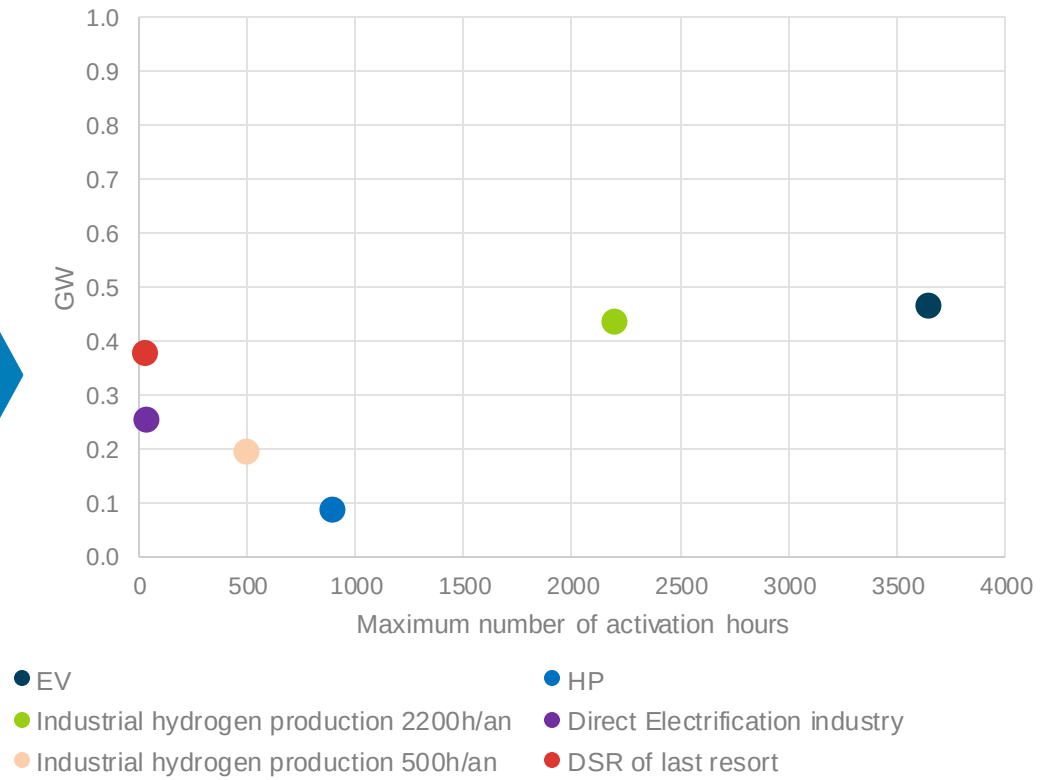
- New industrial electricity demand can be reduced 40 hours per year at 60% of its power

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)	3100	3000	2900	2850	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 (4h)	1310	870	790	710	EU REF 2020
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.

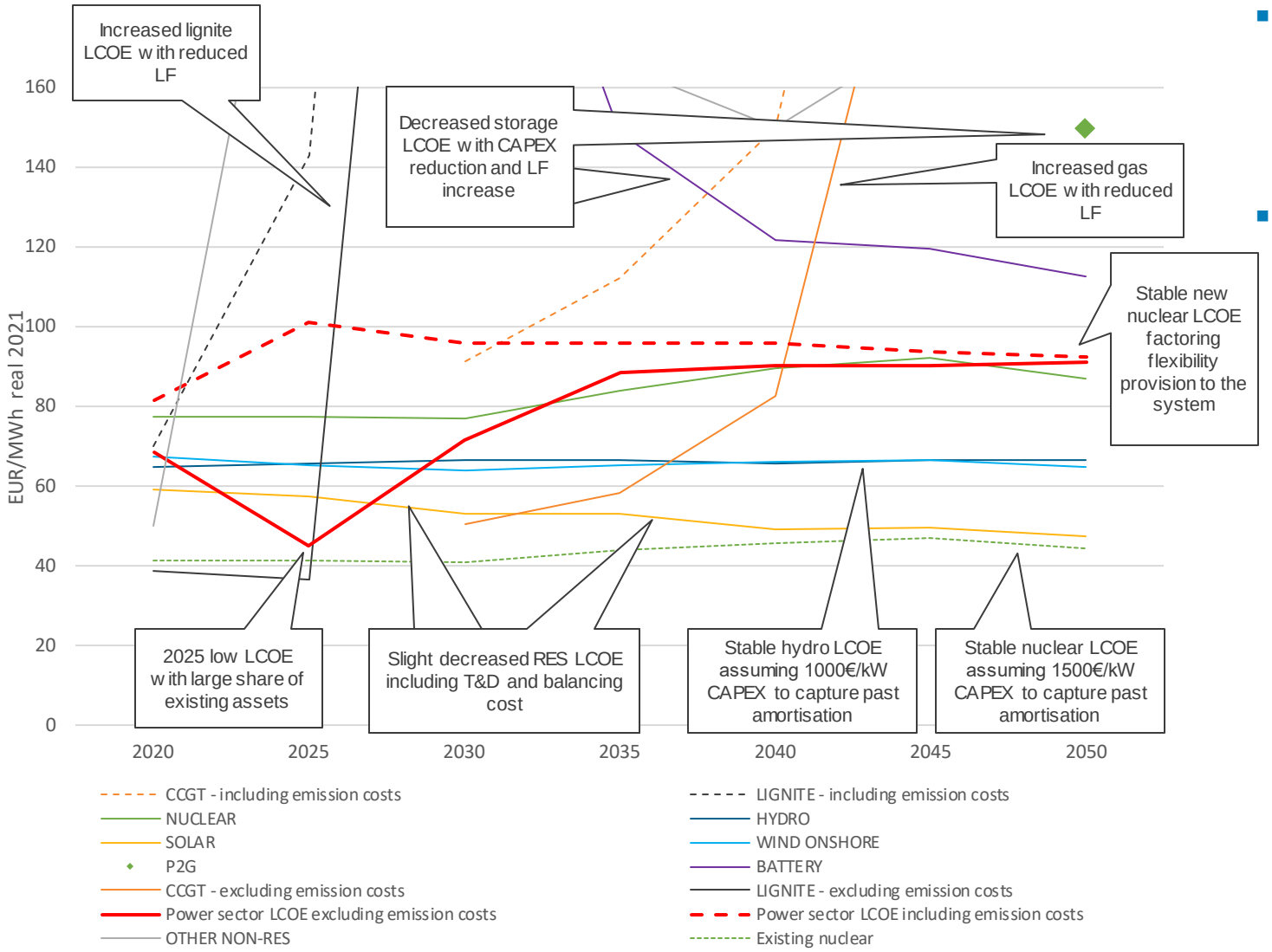
€/MWh	Transmission cost	Distribution cost	Connection cost	Total
Rooftop PV	1.5	2.5		4
Ground-mounted PV	1.5	6	12	19.5
Wind onshore	5	6	5.5	16.5
Wind offshore	5	n/a	30	35

- 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)

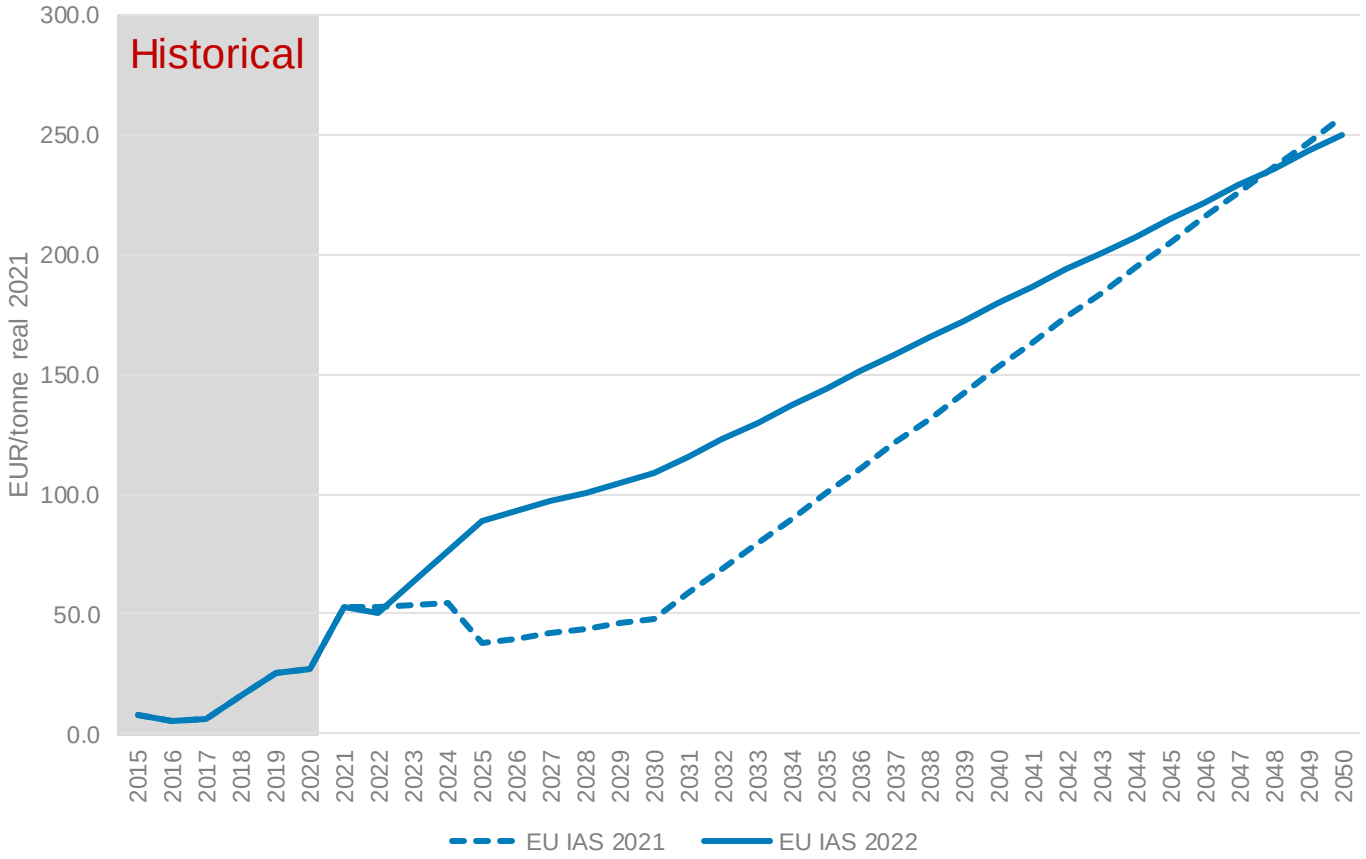
	2020	2025	2030	2035	2040	2045	2050
BG-GR	-400	-800	-800	-1800	-1800	-1800	-2550
BG-MK	-350	-400	-400	-400	-700	-700	-1200
RO-BG	-500	-2100	-2100	-2100	-2400	-2400	-2400
RS-BG	-400	-400	-400	-1300	-2100	-2100	-2100
BG-TR	-500	-500	-1200	-1200	-2400	-2400	-2400

- 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 slightly between both scenarios, reaching 250€/tonne in 2050

CO_2 price (€2021/tonne)

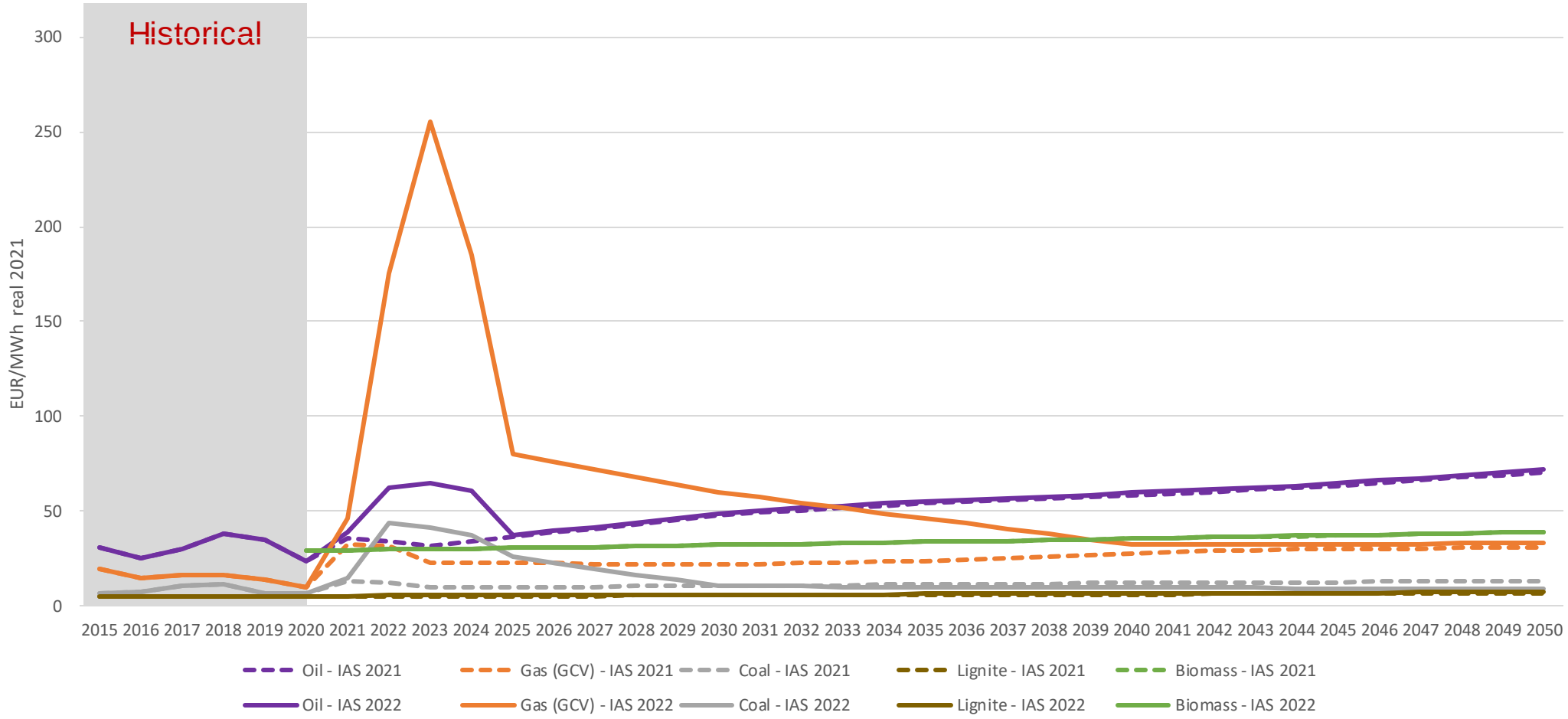


- CO_2 prices in the updated *EU IAS* scenairo are assumed to be in line with forward prices until 2030, and then to converge to EC 2018 Energy Roadmap lower range of decarbonisation scenarios in 2050 (250€/tonne)

Source: EU Reference scenario 2020, EU Ff55 Impact assessment, Forwards as of August 2022

Imported coal and gas prices are expected to reach c.8.9€/MWh and c.32.9€/MWh by 2050

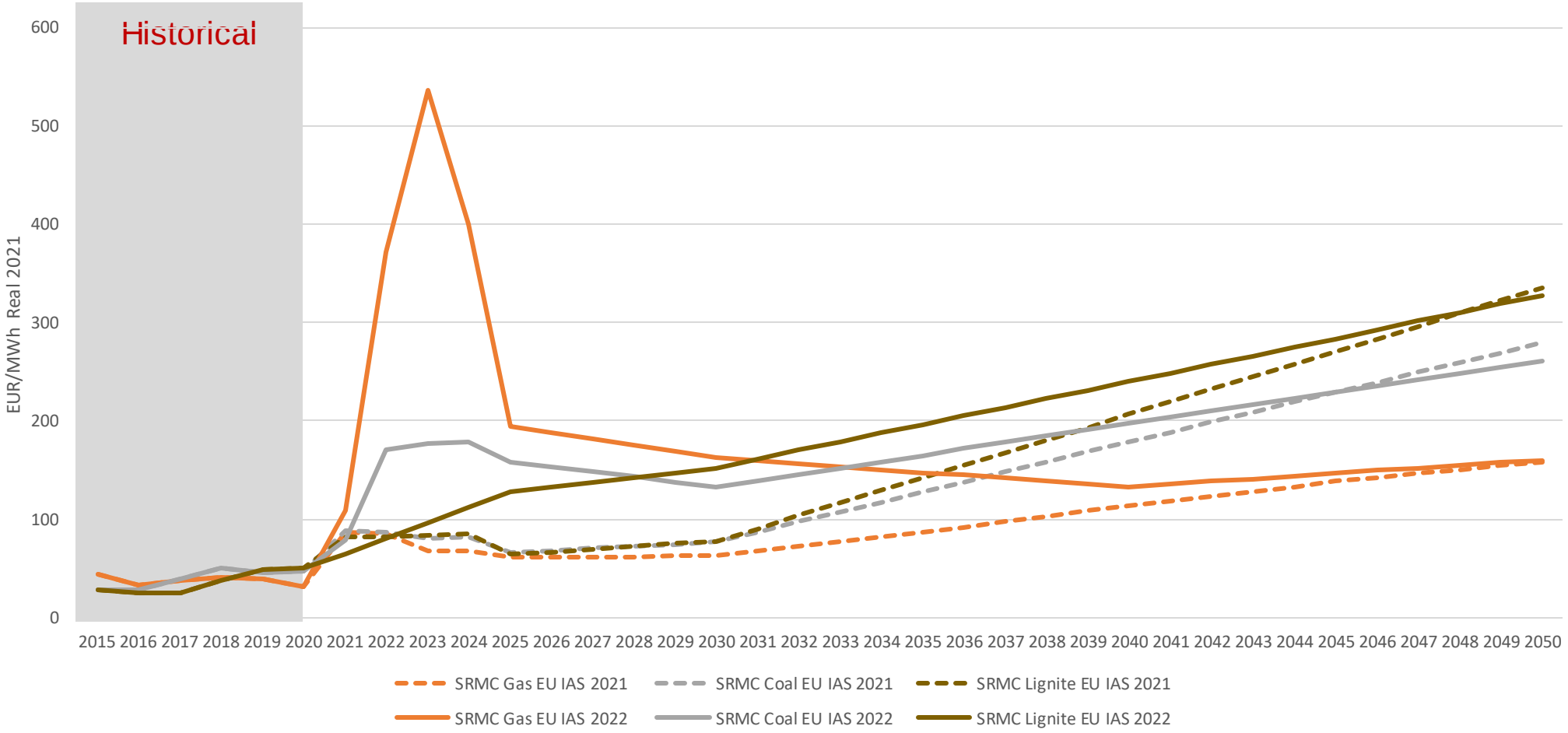
Commodity prices (€/MWh real 2021)



Source: EU Reference scenario 2020, ENTSOE TYNDP 2020, Forwards as of August 2022, 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 2021)



Source: EU Reference scenario 2020, ENTSOE TYNDP 2020, Forwards as of August 2022, Compass Lexecon analysis

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