The impact of interconnectors on decarbonisation

Prepared for the Department for Business, Energy and Industrial Strategy (BEIS)

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Context

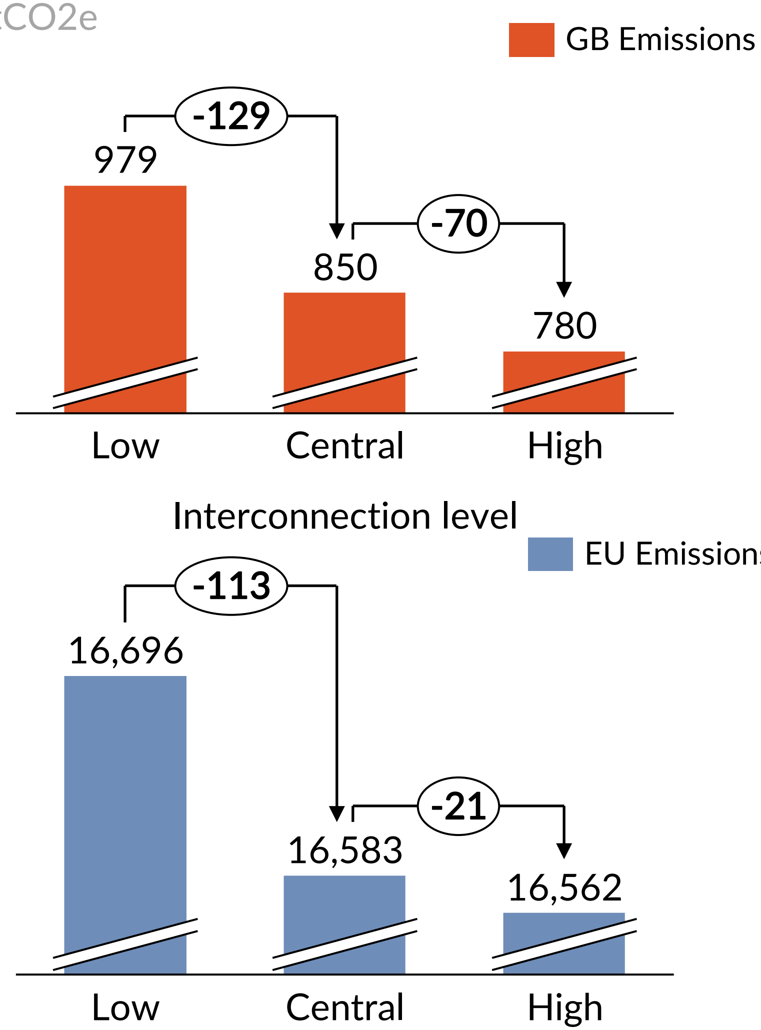
- The UK Government has recently legislated to achieve net-zero emissions by 2050, and other European countries are also adopting ambitious carbon reduction targets for the middle of this century.
- Interconnection has the potential to provide transmission-level flexibility which can help integrate low-carbon generation at a regional level. It allows all markets to maintain high-levels of generation from intermittent renewables rather than curtailing generation when it is not required to meet domestic demand.
- It is generally understood that increased flexibility, including interconnection, will be important to help integrate renewable energy across the region, and to contribute towards decarbonisation targets, however this has not been accurately quantified to date.
- Several previous studies have attempted to delve into the decarbonisation benefits of interconnection, but they have taken simplified metrics such as the average carbon intensity of the generation mix in the market to which we are connected rather than the marginal generation which may be higher carbon than the average.
- Where studies have attempted to look at the marginal generation, they have limited the analysis to the short-term impacts, rather than considering how this would change as connected markets also decarbonise.
- This study explores the impact of interconnection and associated cross border trading on carbon emissions at a regional level, considering different levels of interconnection and different decarbonisation pathways for Europe and GB.

Executive summary 1/2

- Energy modelling suggests, an increase in interconnector capacity between GB and EU would likely lead to:
  - a **decrease in emissions in GB and EU**
  - a **reduction in total power market cost in GB**, as baseload prices in GB decrease
  - **less thermal generation in GB**, with little change in thermal generation in the EU
  - **less curtailment of renewable energy sources (RES) technologies**
- In a Net Zero scenario for GB, GB becomes a net exporter by 2050 irrespective of interconnector capacity
- A shift towards a more decarbonised EU increases the rate of decrease in carbon emissions in GB but reduces the impact that increased interconnector capacity has on emissions

Total cumulative[1] CO_2 emission[2] in GB and EU

MtCO2e

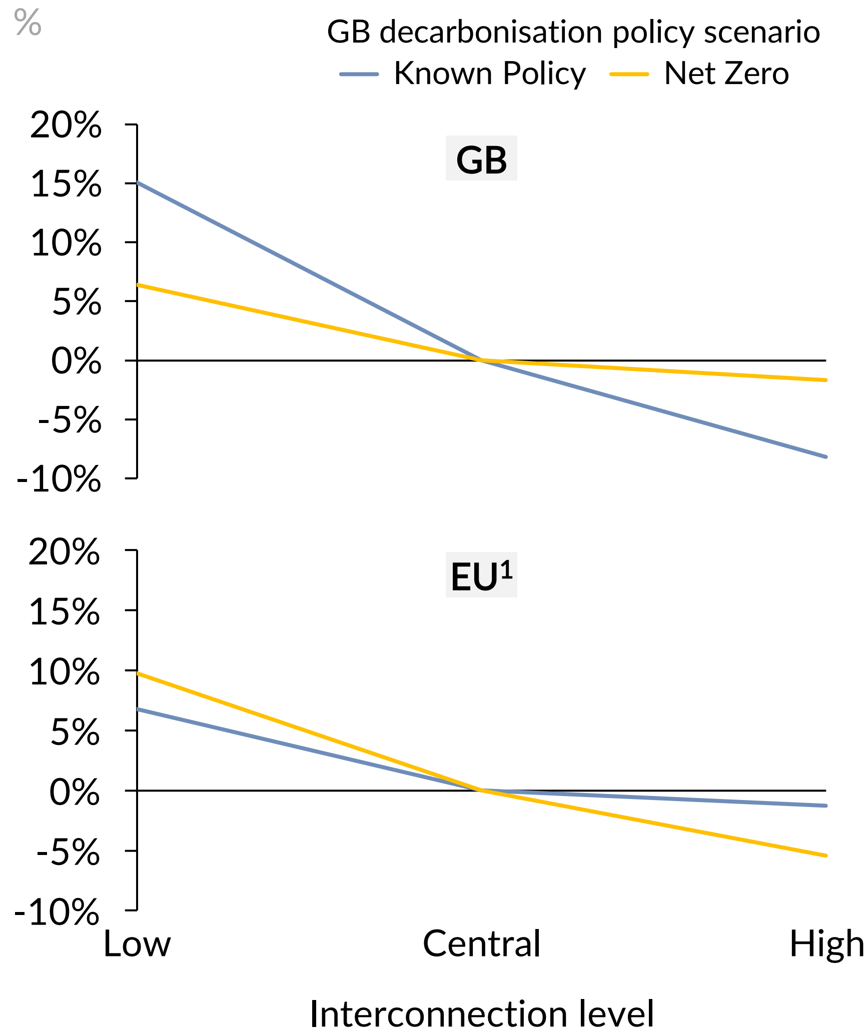


1) Cumulative emission refers to the total emissions across 30 years from 2020 to 2050. 2) The results are based on the Known Policy scenario in GB, and Existing Policy scenario in EU

Source: Aurora Energy Research

- In a highly decarbonised EU, and Net Zero GB, **GB will be a net exporter** due to lower prices in GB compared to France as a result of a high level of renewables on the system.
- In a Net Zero scenario in GB, **baseload prices are expected to decrease** as more RES comes onto the system. On average, more interconnectors decreases the negative pricing due to RES curtailment which might suggest a higher average baseload price
- **Total system costs decrease marginally with higher interconnection levels, as wholesale prices in GB decrease.** A more decarbonised EU leads to lower total system costs in GB

Percent difference in cumulative[1] CO_2 emissions from 2020 to 2050 compared to central case



1) Includes all EU with GB.

Source: Aurora Energy Research

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Understanding the impact of interconnectors on carbon emissions requires detailed modelling of various scenarios in GB and EU

Interconnection	Decarbonisation
	

- The purpose of this report is to understand the impact of interconnectors on carbon emissions both at a GB and regional EU level
- It is essential to look at various parameters from policies to costs and discuss the shortcomings related to measuring emissions
- 18 scenarios were considered by varying multiple parameters related to decarbonisation policies and interconnector capacity
- Results are presented for GB and EU based on the various scenarios

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Carbon emissions are calculated based on average CO_2 intensity of generation, not accounting for CO_2 emissions of imports

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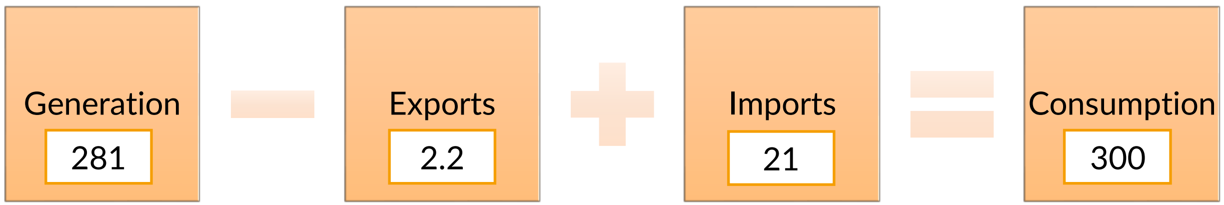
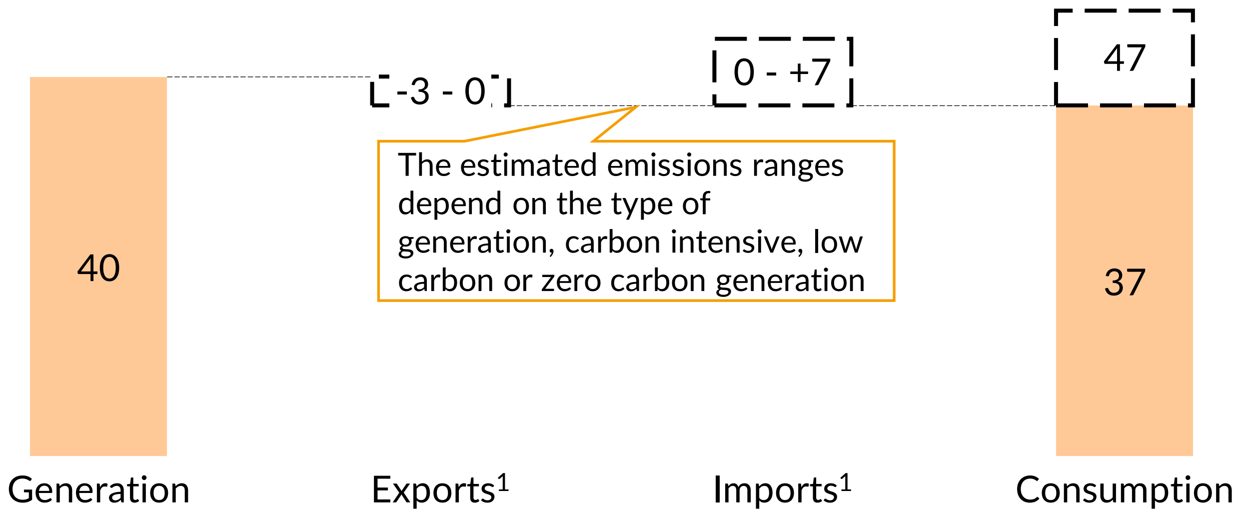
GB Electricity generation and consumption in 2018

TWh



Estimated GB Emissions[1] from generation and consumption in 2018

$MtCO2_e$



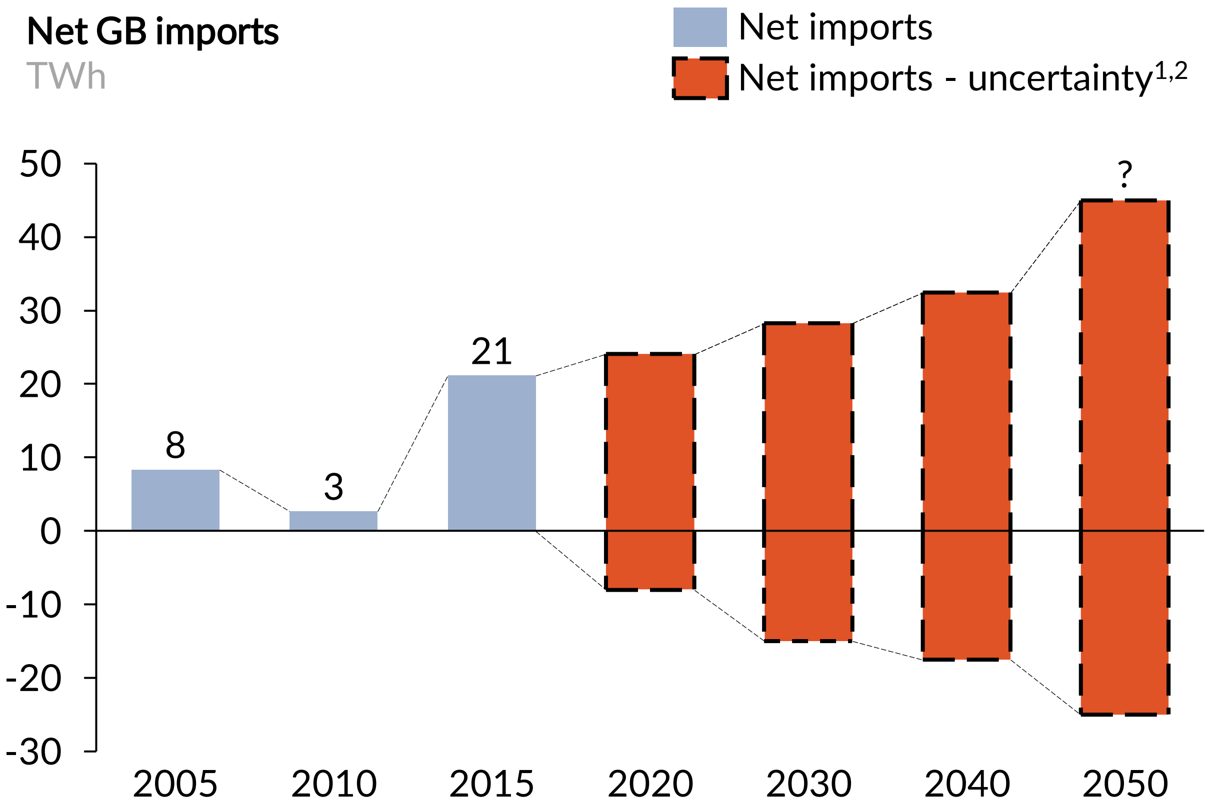
- Country-wide electricity emissions, are calculated by applying a grid average emission factor to the quantity of electricity **generated**
- However, the electricity consumed in a country is not always equal to the electricity generated. **Imported electricity does not contribute** to carbon emission calculations in the destination country, regardless of how it is generated
- The difference in emissions between generation and consumption can be attributed to emissions estimated via imported and exported electricity

1) Emissions of imports and exports are estimated based on the generation average CO_2 intensity factor in GB, in this example, 127gCO2/kWh

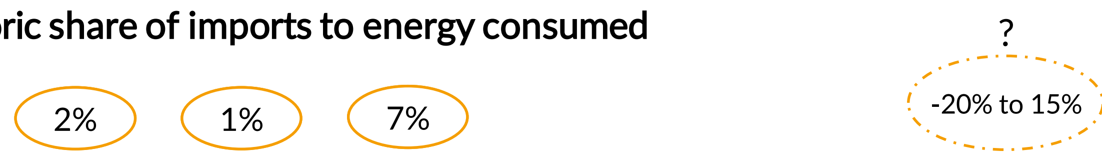
Source: Aurora Energy Research

GB has been consuming more than it generates with activity on interconnectors growing, as more capacity comes online

Net GB imports
TWh



Historic share of imports to energy consumed
%



- GB has consistently been a net importer of electricity
- Although activity on interconnectors is likely to increase as capacity increases, it is highly uncertain as what net imports to GB will be
- As more interconnector projects are expected to commission, it is likely that the share of imports to energy consumed will continue to rise
- Interconnector flows are determined by the relative power prices at both ends. How power prices and therefore interconnector flows will change over time. This is highly uncertain and influenced by a number of factors including decarbonisation in EU and GB, carbon prices, fossil fuel prices, interconnector capacity etc.

1) Dotted lines are a rough estimation that are tested throughout the report 2) A negative net imports refers to net exports

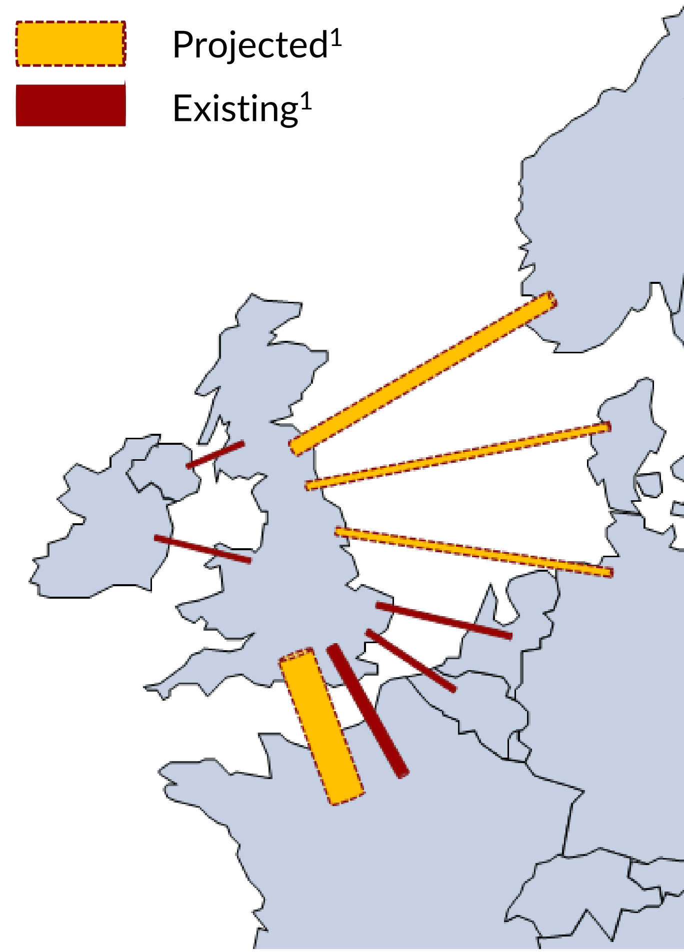
Source: Aurora Energy Research

Interconnector capacity between GB and the rest of Europe might increase between 8.4 – 23 GW by 2050

Estimated GB Interconnectors capacity by 2050

Country							
Capacity[2] [GW]	4.0 - 8.8	1.4 - 4.6	1.0 - 1.5	0.0 - 1.4	0.0 - 1.4	1.0 - 2.6	1.0 - 2.5

- The current interconnector capacity in GB is 5 GW, this could rise by between 8.4 to 23 GW by 2050, based on several scenarios discussed in this report
- Electricity imports are net-zero only when supplied by renewables and nuclear sources, or when the grid emission factor of the exporting country is near zero during the time of exports
- A closer look into the carbon intensity of the various interconnected countries can provide a better picture of the carbon emissions associated with interconnector imports



1) Interconnector thickness on the diagram represents the magnitude of capacity 2) The low end of the range is from existing capacities plus committed new projects, while the high end of the range represents a scenario where most known interconnection projects are commissioned

Source: Aurora Energy Research

The actual carbon emissions of imports vary significantly depending on their source

Low carbon power sources:

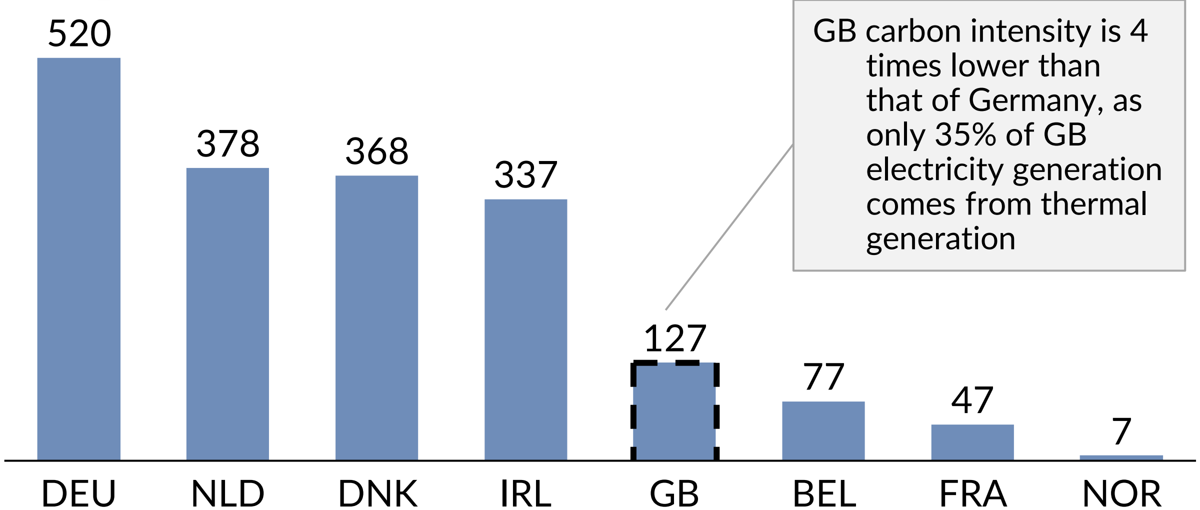
- Renewables: Solar, Wind, and EfW, Biomass, Hydro
- Nuclear, Gas CCS

Carbon intensive power sources:

- Thermal: CCGT, Coal, CHP, OCGT, Recips

CO_2 intensity across regions in 2020 based on modelled data,

kgCO_2e /MWh



GB carbon intensity is 4 times lower than that of Germany, as only 35% of GB electricity generation comes from thermal generation

- There can be a large discrepancy in the "imported" carbon emissions depending on the country and its generation mix at any given period
- For example, Germany's carbon intensity reaches around 520 kgCO_2e/MWh as carbon intensive technology accounts for more than 50% of generation, with coal a main source of energy
- In contrast, 96% of Norway's generation is hydroelectric, explaining the low carbon intensity there

Source: Aurora Energy Research

The role of interconnectors in supporting decarbonisation will likely increase, as interconnector capacity increases and emissions targets fall

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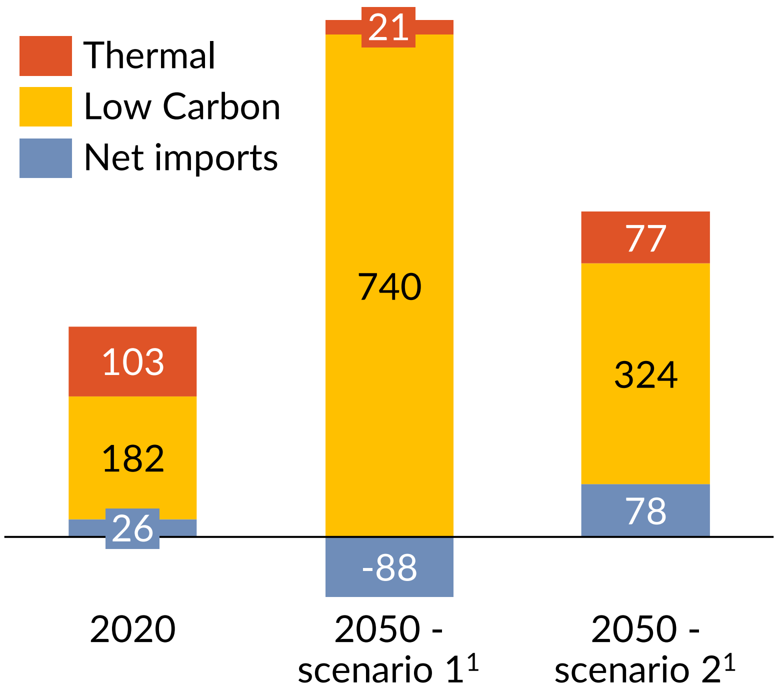
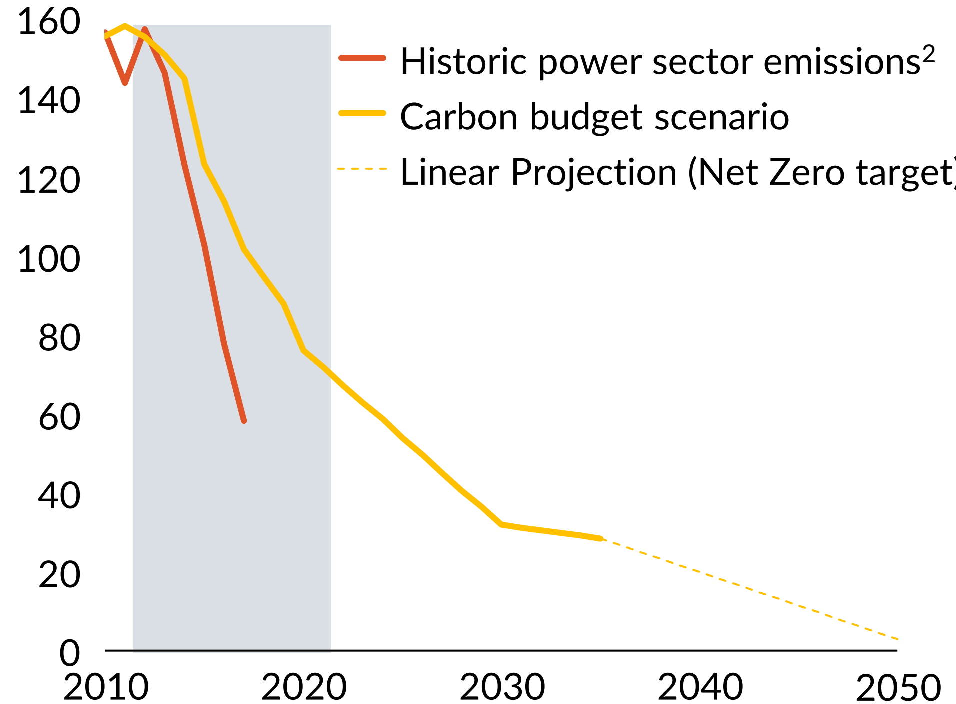
Total consumption in GB
TWh



Annual power sector emissions
$MtCO_2e$



- GB carbon emissions are expected to decrease due to legally binding targets
- Interconnection activity will be increasingly influential part of the total consumption in the UK, whether GB is a net importer or exporter
- Meeting carbon emission targets for the power sector will be increasingly influenced by interconnector activity

1) Scenarios 1 and 2 are hypothetical examples to demonstrate the range of possible outcomes. Detailed realistic simulations are presented in later sections. 2) Historic and carbon budget data are provided by Committee on Climate Change (CCC)

Source: Aurora Energy Research

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Despite the recent rise in low carbon generation, Europe still has substantial carbon intensive generation

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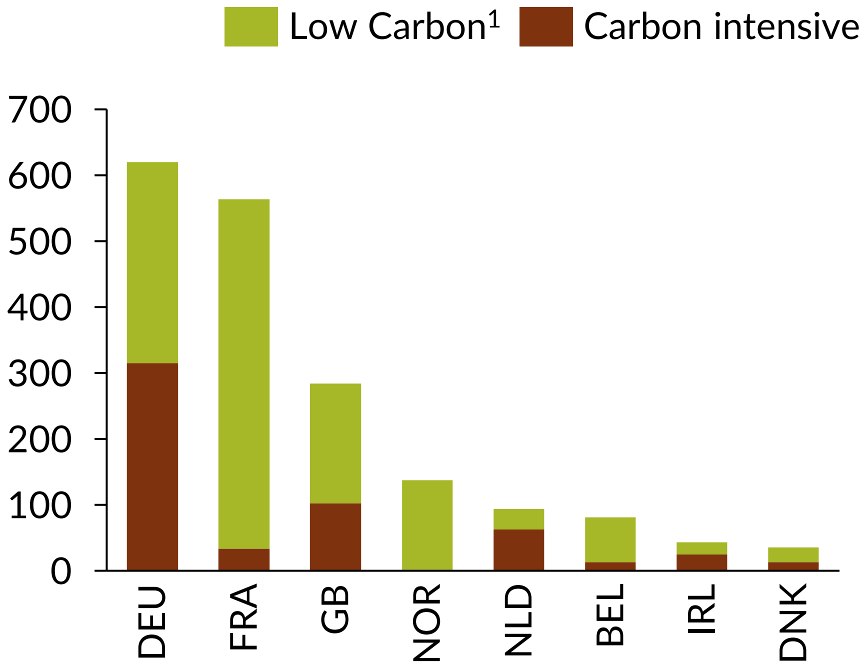
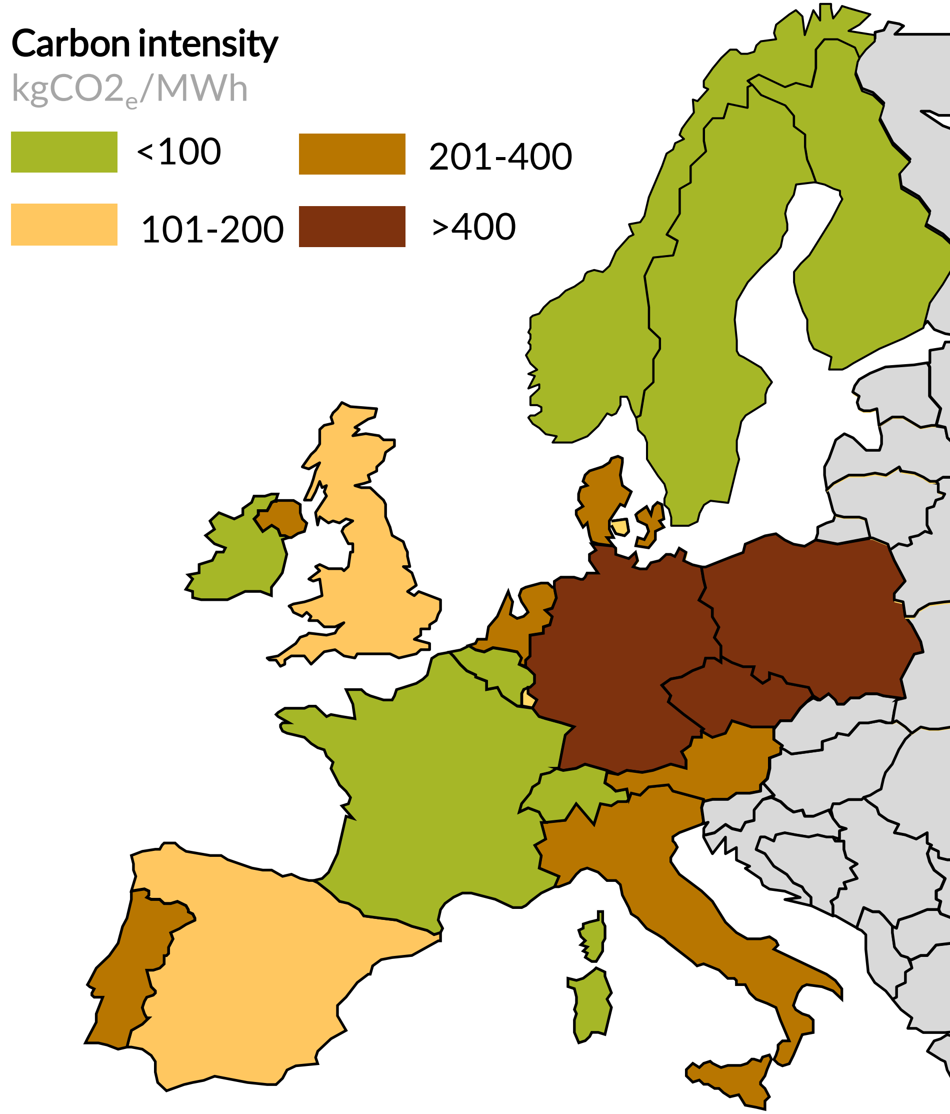
Generation across EU countries, 2020

TWh



Carbon intensity

$kgCO2_e/MWh$



- Germany accounts for 31% of power generation across the EU, with 51% of this generation coming from carbon intensive technologies such as coal and CCGT plants

1) Low-carbon generation includes solar, wind, biomass, hydro and nuclear energy.

Source: Aurora Energy Research

Tracking carbon emissions associated with interconnector flows is difficult; considering average intensity of the source is not exact

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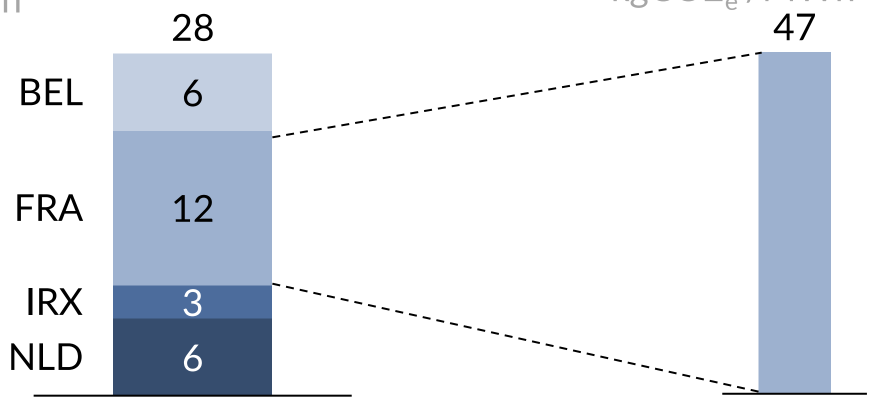
GB imports in 2020 by country

TWh

Average carbon intensity in FRA in 2020

$kgCO2_e$ /MWh



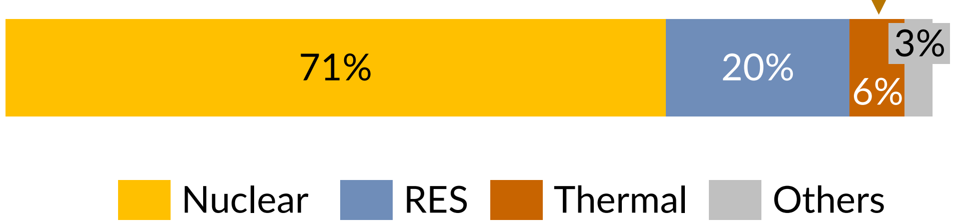
- To calculate the carbon emissions of imports to GB from EU, the average carbon intensity of the exporting country could be considered
- However, this method is limited as generation in a particular country varies from low to high carbon intensity across the year

Emissions from imports

Average CO_2 intensity in exporting country × Imported power = Imported CO_2 per region

Generation by source in FRA in 2020

%

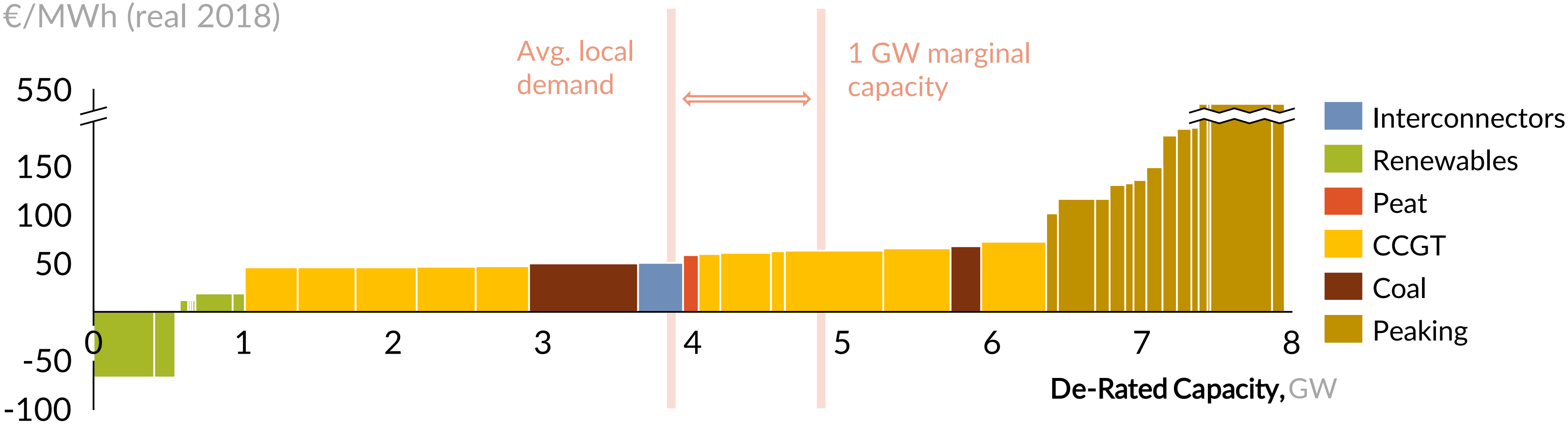


- The extra imported energy is not necessarily sourced from low carbon sources and it could be from thermal plants if these plants are responding to increased demand for export
- So the carbon intensity of imported power can range significantly depending on the generation technology

Source: Aurora Energy Research

An alternative approach is to focus on the "marginal plant" i.e. the source that produces an additional unit of power to export

Irish Merit Order, Short Run Marginal Cost
€/MWh (real 2018)

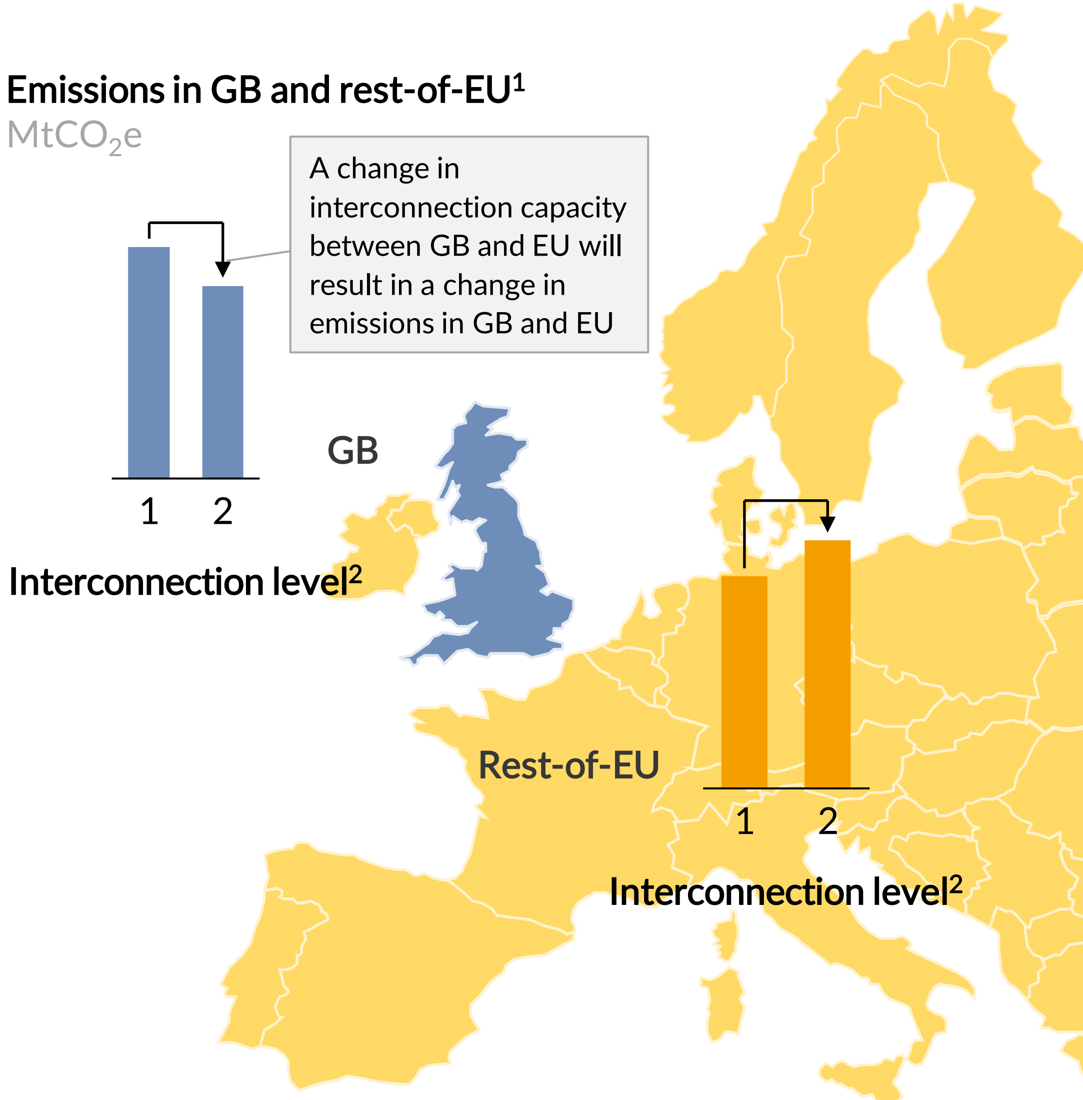


- The marginal production in Ireland refers to the additional unit (1 GW) of power produced, once average domestic demand is satisfied and this is determined based on the merit order in Ireland
- The marginal production varies with demand but in 2020 it is mainly through Coal or CCGT plants
- Tracking the marginal plants at every half hour could indicate which sources are used to generate the additional power for export
- However, such an approach could only measure the intensity of imports in one specific interconnector and not the effect of interconnector flows within a larger region of different countries, a region similar to the EU
- Thus, it would not reflect a true approximation to the emissions from interconnectors and accordingly a more thorough approach was implemented

Source: Aurora Energy Research

Impact of interconnectors on decarbonisation is best measured by the incremental change of CO_2 emissions across EU

- Flexing interconnection capacity between GB and EU causes a change in emissions in both GB and EU
- The impact of interconnection capacity on carbon emissions can be measured via the incremental change of emissions across EU
- Considering total EU eliminates the carbon accounting dilemma, as generation and consumption matches
- This approach represents the best measure to emissions via interconnectors as it considers all interconnection lines between GB and EU, and takes into account the various generation technologies within EU
- Thus, the incremental carbon emissions that will result from the increase in interconnection capacities between GB and EU will be considered as imported or exported carbon emissions depending on the countries under study.
- This is the method we have used in later sections to measure the impact that changes in interconnection has on emissions in GB and EU.



1) Includes all EU countries except GB. 2) 1 and 2 refer to different interconnection capacity between GB and EU

Source: Aurora Energy Research

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Aurora's pan-European electricity market model is used to simulate the impact of interconnectors on carbon emissions

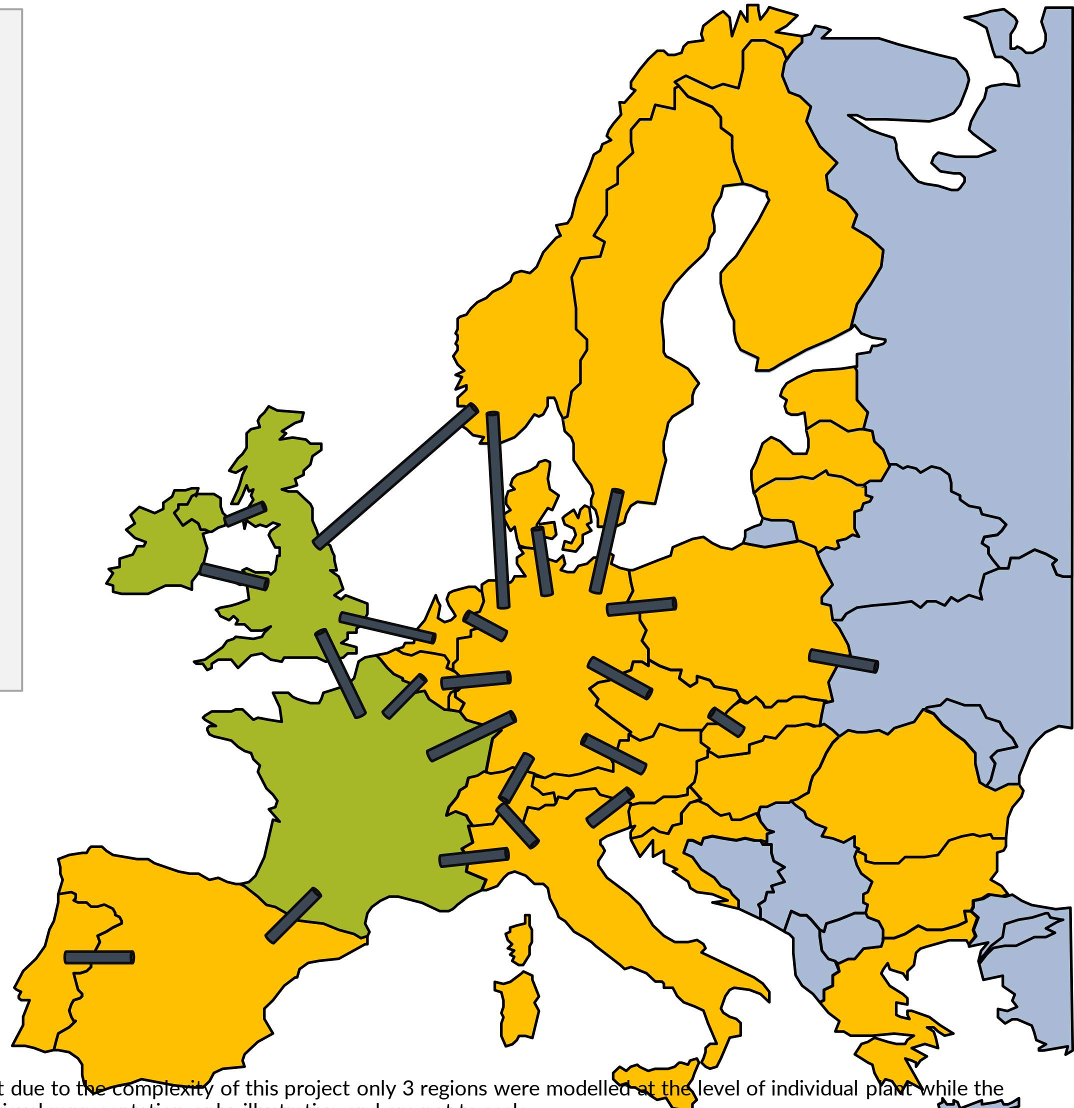
- Aurora's EU model currently covers 15 regions
  - 3 regions[1] are modelled at the level of individual plants
  - 12 regions aggregate plants into technology classes
- Even in aggregated regions, a single technology class may contain several discrete technologies (e.g. high/mid/low merits CCGT)
- Bi-directional interconnector flows are determined by power price differentials between countries accounting for ramping restrictions, imperfect market integration and flow rate change costs
- GB and interconnected markets are modelled simultaneously for consistent import/export flows

Key

- Individual plant
- Plant aggregation
- Higher aggregation

Modelling granularity

Interconnector[2]



1) Aurora models 10 regions at level of individual plant and 5 regions aggregated, but due to the complexity of this project only 3 regions were modelled at the level of individual plant while the rest of the regions were aggregated. 2) Sizes and lengths of interconnectors are for visual representation only, illustrative and are not to scale.

Source: Aurora Energy Research

The model iterates between dispatch and investment decisions to find an equilibrium

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1 Input

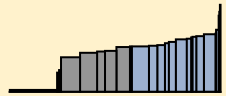
- **Technology** assumptions (plant parameters)
- **Policy** assumptions (e.g. renewables subsidies, CO_2 prices)
- **Demand** assumptions (based on in-house analysis on the effect of EVs)
- **Commodity price** assumptions (based on in-house AER-GLO model)

2

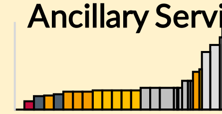
Time horizon: 2018 - 2065

Dispatch module (on an hourly/half-hourly basis)

Wholesale market



Balancing Mechanism/ Ancillary Services



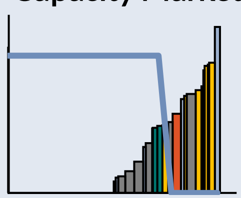
- **Dynamic dispatch** of plant, considering ramping costs and rate restrictions, and availability of plants and individual generators to form the supply stack
- **Endogenous interconnector flows** according to estimated gradient between domestic and foreign electricity spot prices
- **Iterative modelling** between wholesale and balancing markets

Iterations across modules to
- reach equilibrium solution
- ensure internal modelling consistency

3

Investment decision module (on an annual basis)

Capacity Market



- **Detailed modelling of the Capacity Market** mechanism and associated bid levels/clearing prices
- **Forecasts investor behaviour** for correct entry/exit of plants based on modelling of future cash flows
- **Entry and exit of technologies modelled endogenously**, not assumed

4 Output

- **Capacity mix** (New build entry and exit decisions)
- **Generation mix** (at technology/plant level)
- **Wholesale & imbalance prices** (half-hourly granularity)
- **Capacity Market prices**
- **Profit & loss and NPV for modelled technologies**

1) See Appendix 1 for further details of the modelling methodology

Source: Aurora Energy Research

The impact of interconnectors on emissions is assessed by varying EU & GB decarbonisation level and interconnection capacity

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This report presents the modelling results of 18 different scenarios, as shown in the adjacent matrices, based on three dimensions:

- **GB Decarbonisation Policy:** Aligns with BEIS power sector reference case (Known Policy) and Net Zero Higher Demand Scenario (Net Zero)
  - **Known Policy**: Scenario that only includes current, implemented and planned policy and is not net zero consistent. Assumptions here are aligned with what BEIS publish in the Energy and Emissions Projections publication 2019.
  - **Net Zero:** Scenario that contain assumptions[1] on demand, generation mix and carbon prices that are consistent with meeting Net Zero. This is an illustrative pathway that shows what a net zero consistent power sector in GB could look like. Assumptions are consistent with BEIS' Net Zero Higher Demand scenario.
- **EU Decarbonisation Policy:** refers to the changes in carbon price and renewable energy generation across the EU and is divided into three levels
  - **Low**: refers to a decrease in renewables energy generation across EU compared to existing
  - **Existing:** refers to the known policies in EU regarding decarbonisation
  - **High:** refers to the changes needed to carbon prices, demand, capacity[2] and generation technologies to reach a Net Zero scenario across several EU countries
- **Level of Interconnection between GB and EU:** refers to the interconnection capacity between GB and EU and is divided into three levels
  - **Low**: refers to the existing[3] interconnection capacity between GB and EU
  - **Central:** refers to the current pipeline of interconnector projects between GB and EU
  - **High:** refers to an increased interconnection capacity between GB and EU as per the input assumptions[4]

GB Known Policy		EU decarbonisation policy		
		Low	Existing	High
Level of inter-connection	Low			
	Central			
	High			

Results related to GB Known Policy will be coloured in Red

Results related to GB Net Zero will be coloured in Green

GB Net Zero		EU decarbonisation policy		
		Low	Existing	High
Level of inter-connection	Low			
	Central			
	High			

1) Input assumption changes are shown in slides 22 to 24. 2) Capacity assumptions include a 40% increase in renewable energy capacities across EU. 3) Existing interconnection capacity plus an additional 4GW of projects that are under construction. 4) Interconnection input assumptions are presented in slide 23.

Source: Aurora Energy Research

Demand and carbon price assumptions for GB Known Policy and GB Net Zero scenarios

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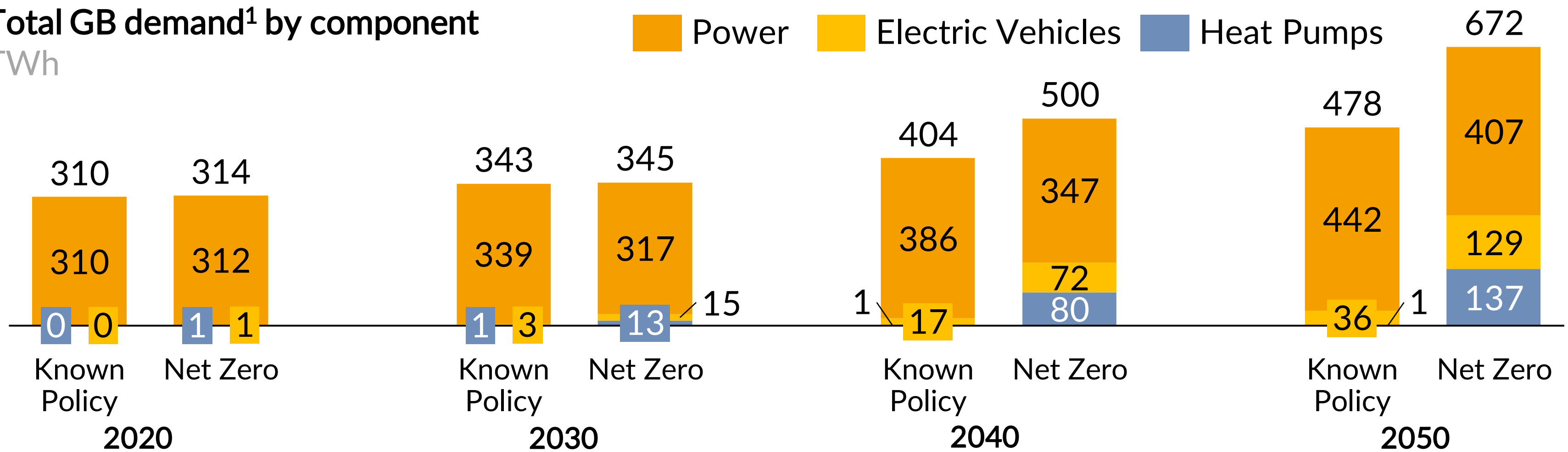
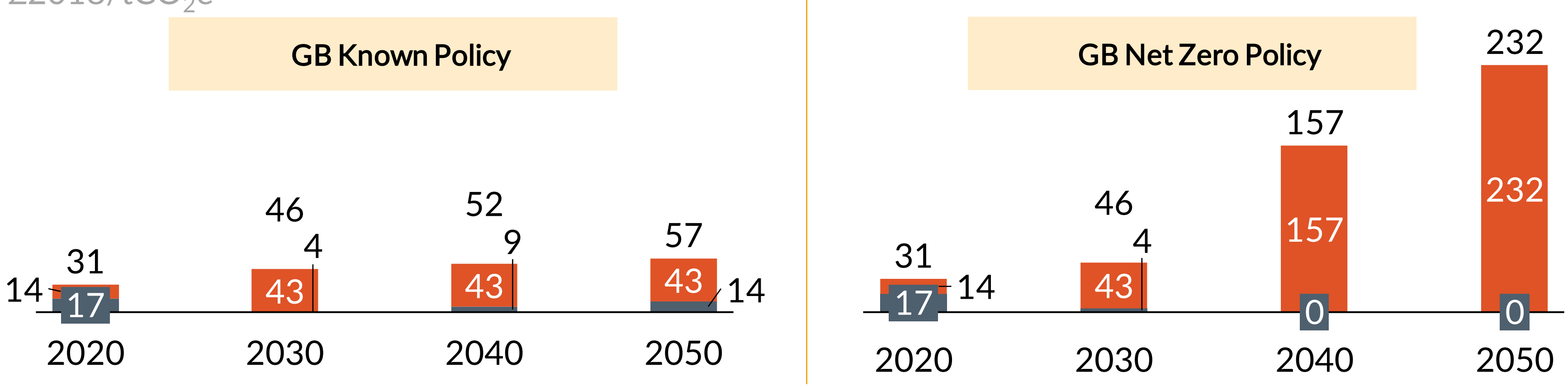
Total GB demand[1] by component

TWh



Carbon prices[1]

£2018/tCO_2e



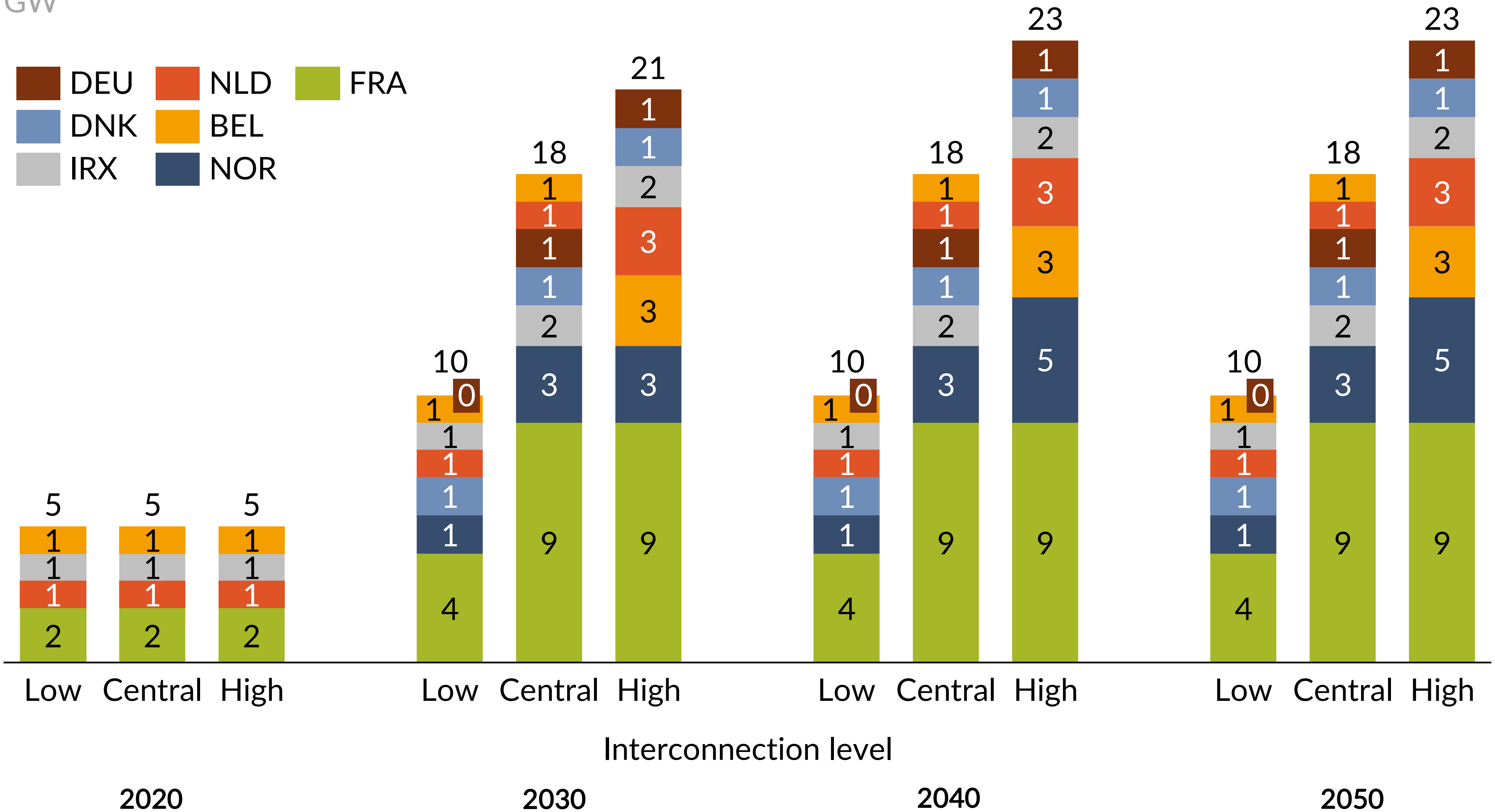
1) These input modelling assumptions were presented by the Department for Business, Energy and Industrial Strategy (BEIS)

Source: BEIS

Interconnection capacity between GB and EU double from low to central, and then increase by another 20% from central to high

Interconnection capacity[1] timelines by scenario

GW



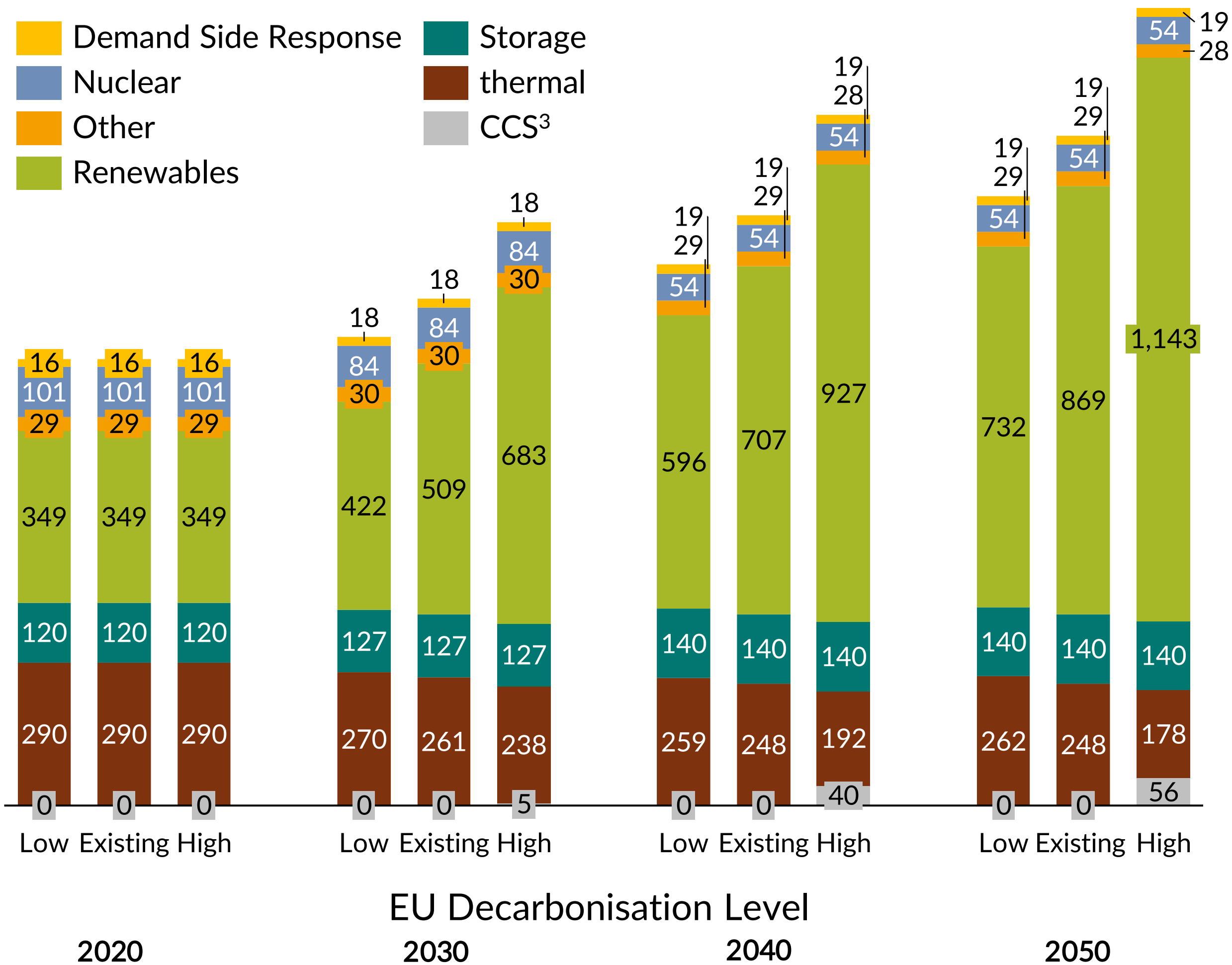
1) These input modelling assumptions were presented by the Department for Business, Energy and Industrial Strategy (BEIS)

Source: BEIS

The EU decarbonisation input assumptions were varied based on the renewables and CCS capacities across EU countries

Capacity[1] timelines for Rest-of-EU[2] countries by EU decarbonisation scenario

GW



- To model the different EU decarbonisation scenarios, the renewables energy systems (RES) and CCS capacities were varied across EU countries
- The existing case was taken based on Aurora Energy Research outlook for the various countries
- Low and high EU decarbonisation scenarios were developed by Aurora with input from BEIS
- For the low EU decarbonisation case, RES capacity was reduced by 20% and equivalent increase of thermal based on CM derating factors
- For the high EU decarbonisation case, RES capacity was increased by 40% and CCS included in selected countries

1) These input modelling assumptions were based on Aurora Energy Research central case scenario. 2) EU excluding GB 3) Carbon Capture and Storage

Source: Aurora Energy Research

Modelling uncertainty is essentially driven by three categories of underlying risk based on the model inputs

	Drivers	Provided by (UK)	Provided by (EU)
Commodities	**Gas price**	BEIS	BEIS
Commodities	**Carbon price**	Aurora Energy Research and BEIS	BEIS
Demand	**Demand**	Aurora Energy Research and BEIS	Aurora Energy Research
Demand	**EV build out**	BEIS	Aurora Energy Research
System composition	**Nuclear capacity**	Aurora Energy Research and BEIS	Aurora Energy Research
System composition	**Renewables deployment**	Aurora Energy Research and BEIS	Aurora Energy Research and BEIS
System composition	**Interconnector capacity**	BEIS	Aurora Energy Research[1]
System composition	**New plants CAPEX**	BEIS	Aurora Energy Research

- The modelling is performed through Aurora's inhouse model, with model inputs provided by BEIS and Aurora Energy Research
- Uncertainty in the modelling is due to the model assumptions and the methodology

Assumptions:

- Model assumptions were based on a combination of both Aurora's central case view of the European Power Market and BEIS's own internal views. These were agreed upon to ensure consistency with BEIS's previous studies

Methodology:

- Aurora's model is a deterministic model, and not a statistical model, in short the output scenarios are dependant on the model inputs. The scenarios output are presented within a range of uncertainties, and are not forecasted results

1) EU (non-GB) interconnection levels are based on Aurora's assumptions and are presented in the Appendix

Source: Aurora Energy Research

Contents

EU Existing Policy | GB Known Policy | GB Net Zero

On a cumulative basis, higher interconnection leads to lower emissions both in GB and EU across all scenarios

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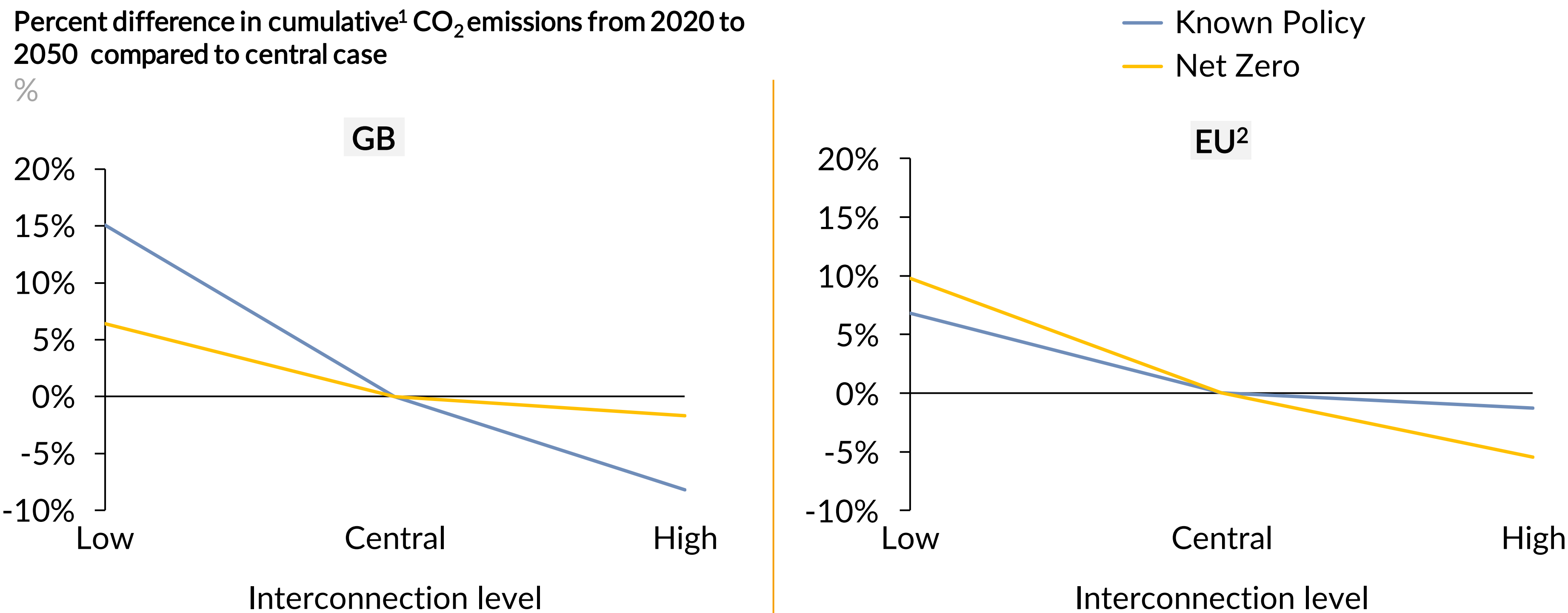
Percent difference in cumulative[1] CO_2 emissions from 2020 to 2050 compared to central case
%



- Higher interconnection benefits GB more when GB is at the Known Policy scenario while the gains are smaller when GB in a Net Zero world
- On the other hand, higher interconnection benefits EU as whole more when GB is in the Net Zero scenario
- Higher imports to GB push carbon intensive thermal generation out of the merit order which in turn reduces GB emissions
- In a Net Zero scenario, EU imports from GB increase reducing the local thermal generation across EU, which consequently reduces emissions

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Includes all EU with GB.

Source: Aurora Energy Research

Contents

GB Known Policy
EU Existing Policy

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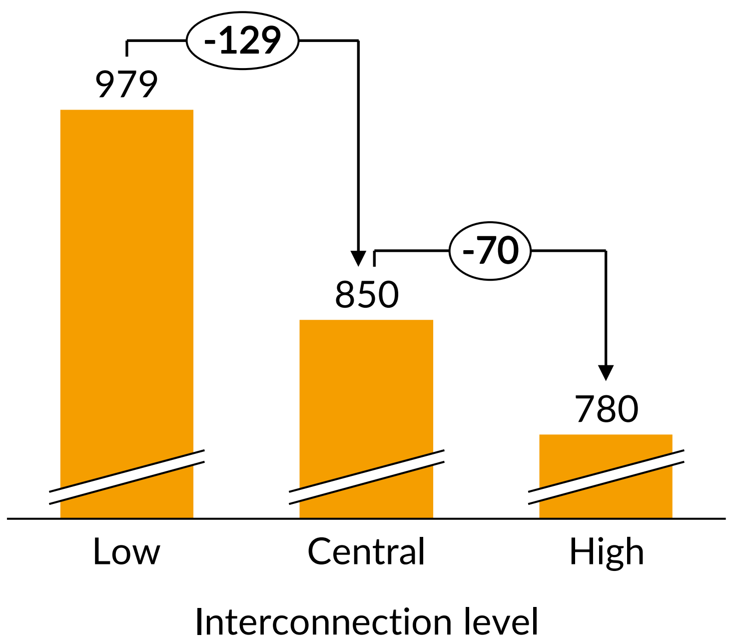
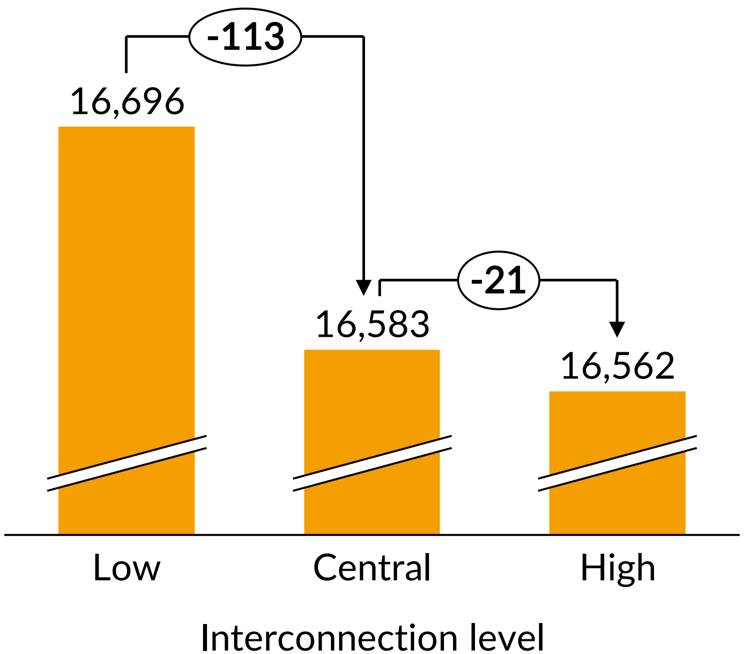
Cumulative emissions in GB and the rest-of-EU decrease as interconnection capacity increases

Total cumulative[1] CO_2 emission in GB
MtCO2e



Total cumulative[1] CO_2 emission in Rest-of-EU[2]
MtCO2e



- As interconnection level between GB and EU increases, emissions across GB and EU decrease. This is driven by the decrease in thermal generation in GB
- EU, with GB, witness a decrease in cumulative emissions with more interconnection capacity
- An increase in interconnection capacity leads to a decrease in emissions up to 2030 compared to 2050 as shown in the Appendix[3]

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Includes all EU except GB. 3) Appendix 1, Section B

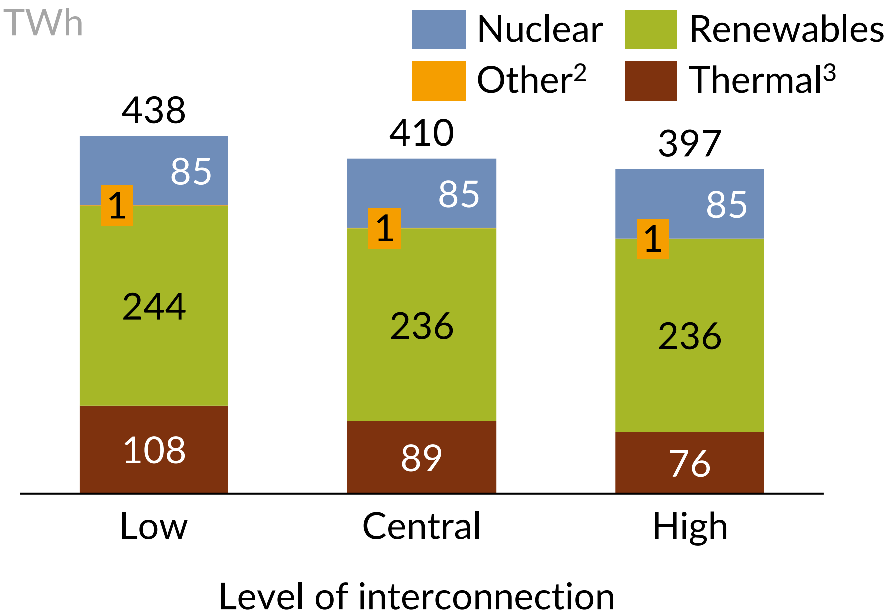
Source: Aurora Energy Research

GB Known Policy
EU Existing Policy

With an increase in interconnector capacity GB thermal generation decreases while renewables and nuclear generation in EU increase

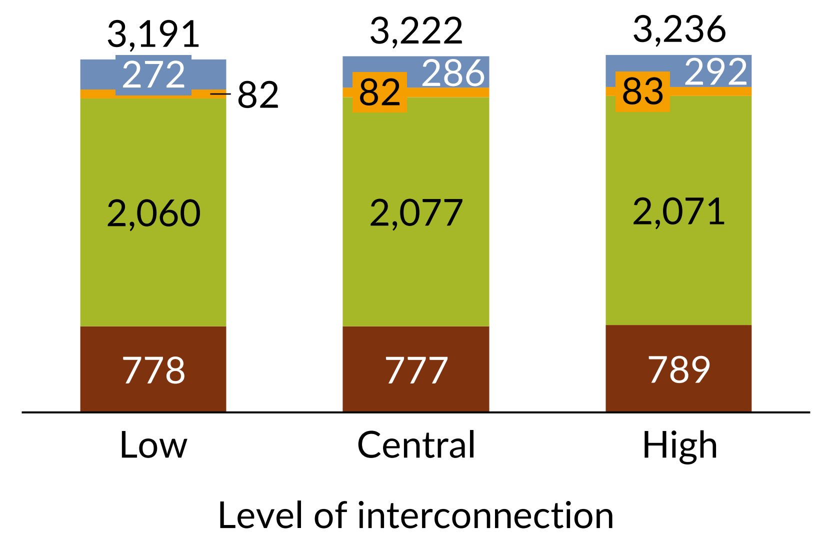
Net generation in GB in 2050

TWh



Net generation in Rest-of-EU[1] in 2050

TWh



- Higher interconnection affects directly GB thermal generation with minimal impact on renewable and nuclear generation
- The increase of generation in EU to cover GB exports is mainly from renewables and nuclear, between low and central scenarios
- In GB, an increase in interconnection level leads to a slight decrease in renewable generation as dependency on imports increases with more interconnection
- The increase in renewable generation with more interconnection across the Rest-of-EU is evident throughout the years from 2020 to 2050

1) Includes all countries in EU except GB. 2) Other technologies include micro CHPs, biogas and energy from waste plants. 3) Thermal generation includes all types of gas and coal plants.

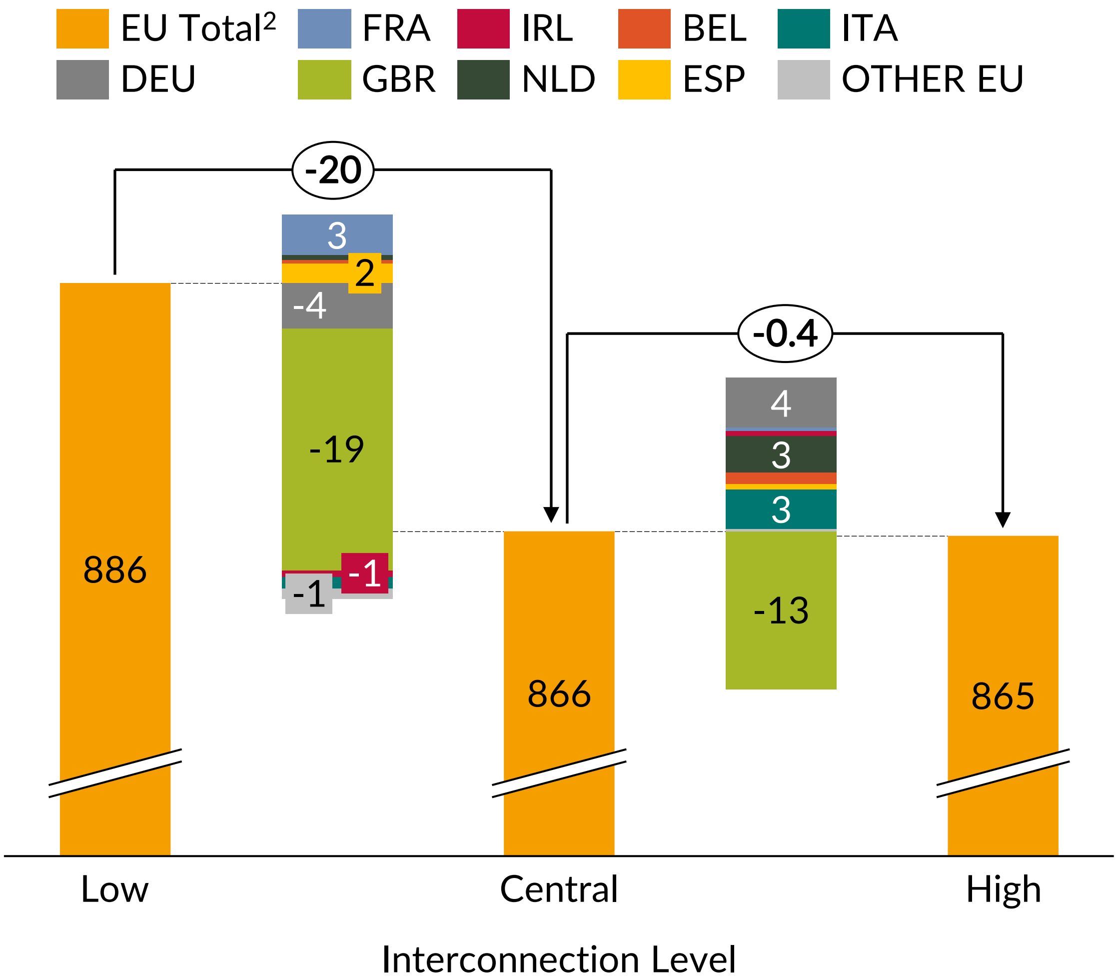
Source: Aurora Energy Research

GB Known Policy
EU Existing Policy

Thermal generation across EU decreases with more interconnection between EU and GB but the returns are diminishing

Thermal generation[1] in EU by region in 2050

TWh



- Total EU thermal generation drops by c.20 TWh when adding 9 GW more interconnection capacity (Low to Central interconnection levels) with the majority of the reduction seen in GB
- The reduction of total EU thermal generation is diminishing when adding 5 extra GW of interconnectors (Central to High interconnection levels) with GB reducing its thermal generation as much as other EU countries increase their thermal generation

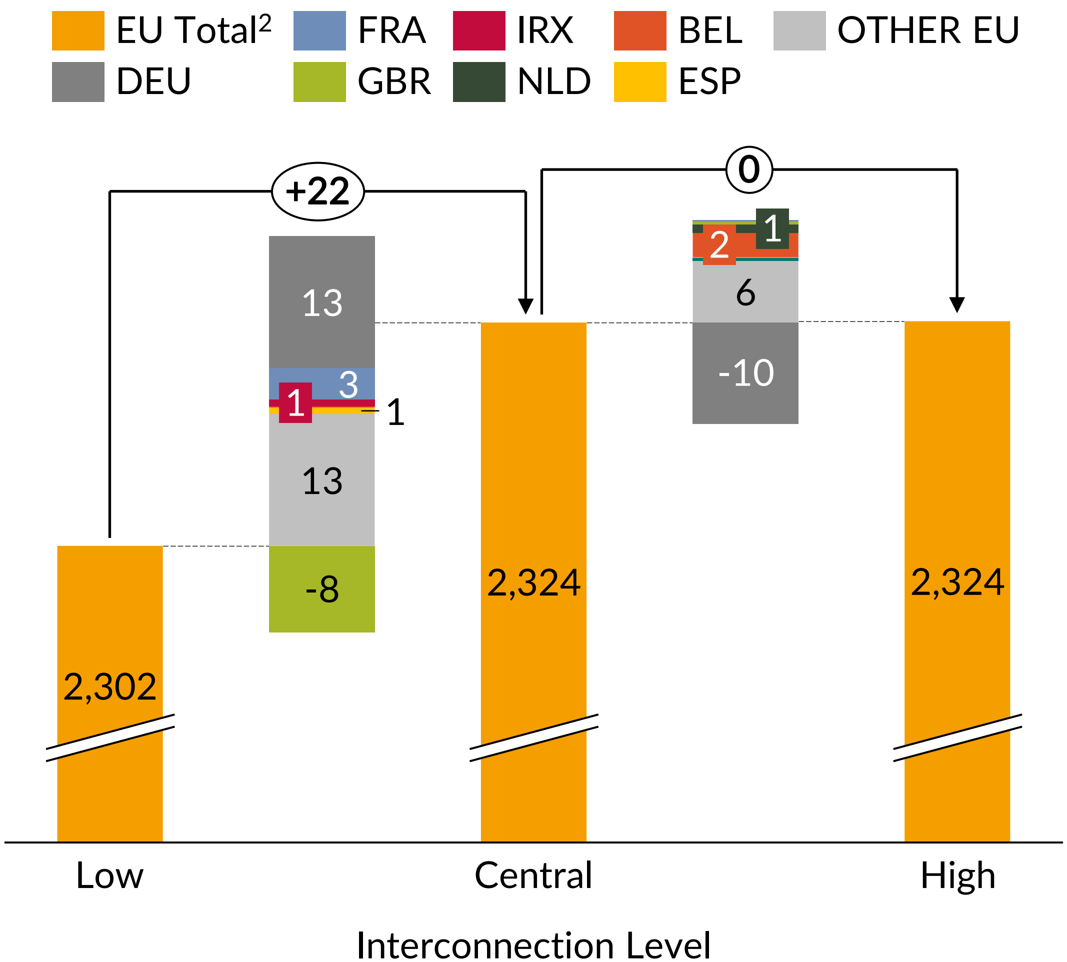
1) Thermal generation includes CCGT, Coal, CHP, Gas Peakers. 2) EU Total includes GB.

Source: Aurora Energy Research

Low-carbon generation shows very minor variations of up to 0.9% between different interconnection scenarios

Low carbon generation[1] in EU by region in 2050

TWh



- Low-carbon generation slightly increases with an increase in interconnection capacity between the Low to Central scenario, with the increase in Rest-of-EU coming from Nuclear
- RES generation remains virtually unchanged between Central and High interconnection scenarios
- This implies that the generation from RES plants in this scenario is fully absorbed into the power systems irrespective of the changes in interconnector flows

1) Low carbon generation includes nuclear, CCS, wind, solar, biomass and hydro. 2) EU Total includes GB.

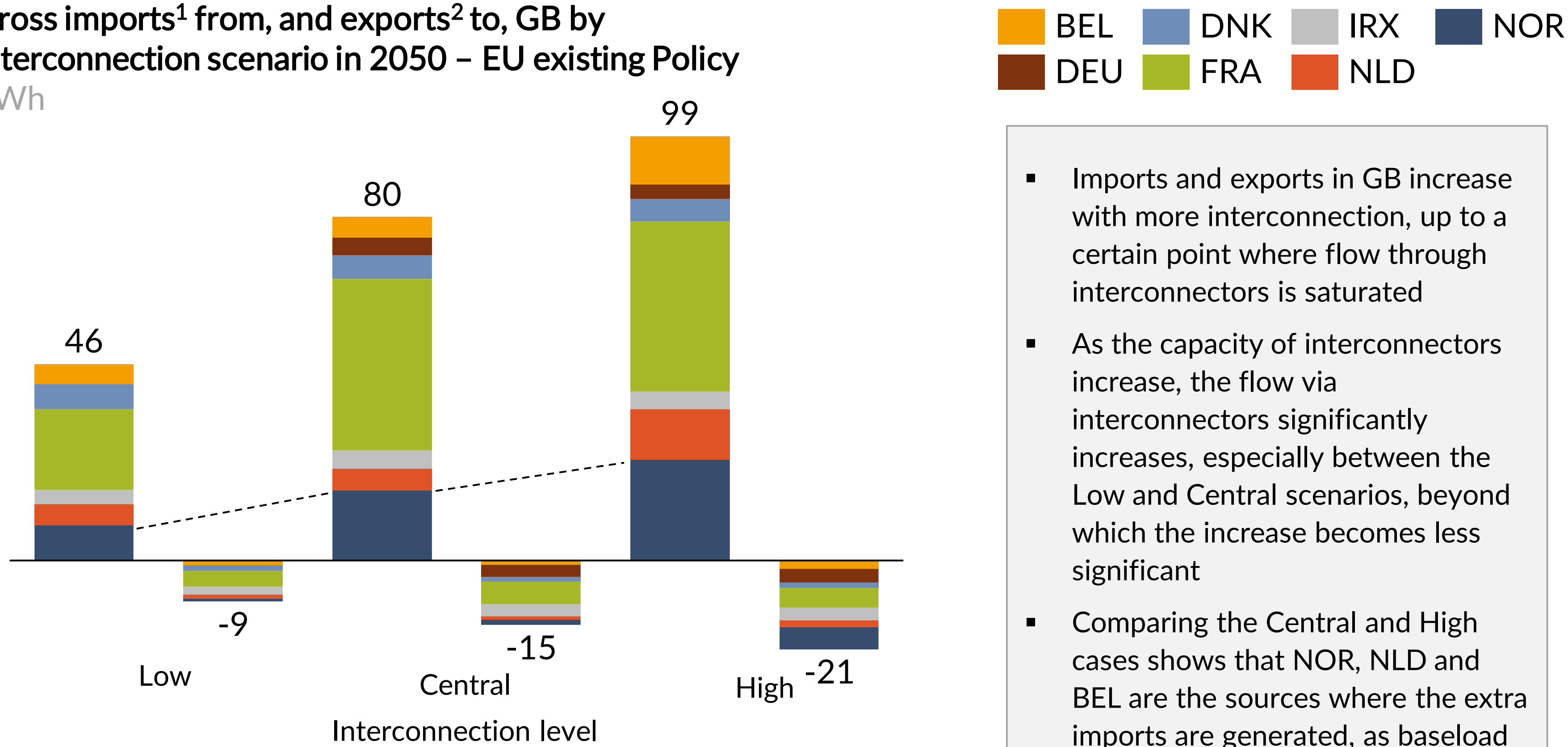
Source: Aurora Energy Research

GB Known Policy
EU Existing Policy

GB imports from Norway, a cleaner energy source, increase as interconnection capacity increases

Gross imports[1] from, and exports[2] to, GB by interconnection scenario in 2050 – EU existing Policy

TWh



Net imports in 2050

TWh

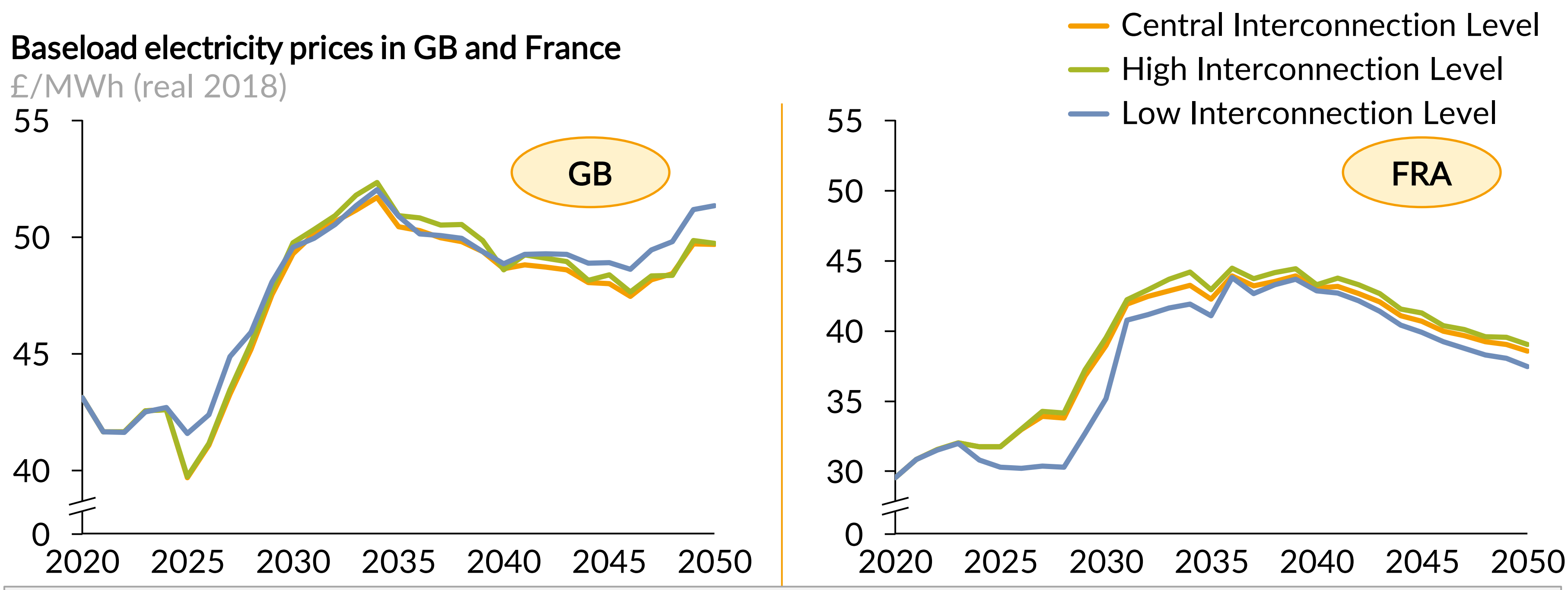
Low	Central	High
37	65	78

- Imports and exports in GB increase with more interconnection, up to a certain point where flow through interconnectors is saturated
- As the capacity of interconnectors increase, the flow via interconnectors significantly increases, especially between the Low and Central scenarios, beyond which the increase becomes less significant
- Comparing the Central and High cases shows that NOR, NLD and BEL are the sources where the extra imports are generated, as baseload prices in these countries are lower than GB
- German imports and exports are balanced

1) Imports here are depicted as positive. 2) Exports are depicted as negative.

Source: Aurora Energy Research

Less interconnection between EU and GB leads to lower baseload prices in France, and higher prices in GB



- Baseload prices in GB drop with more interconnection between GB and EU, which is driven by an increase in cheaper imports from France, consequently lowering GB prices
- In France, more interconnection leads to more exports which is covered in the most part by nuclear but also by CCGT plants which drive baseload prices up
- A change of the interconnector flows between FRA and its neighbouring countries[1] also affects baseload prices
- A similar trend to France, in baseload prices[2], is seen across Rest-of-EU, with more significant drops in those interconnected with GB

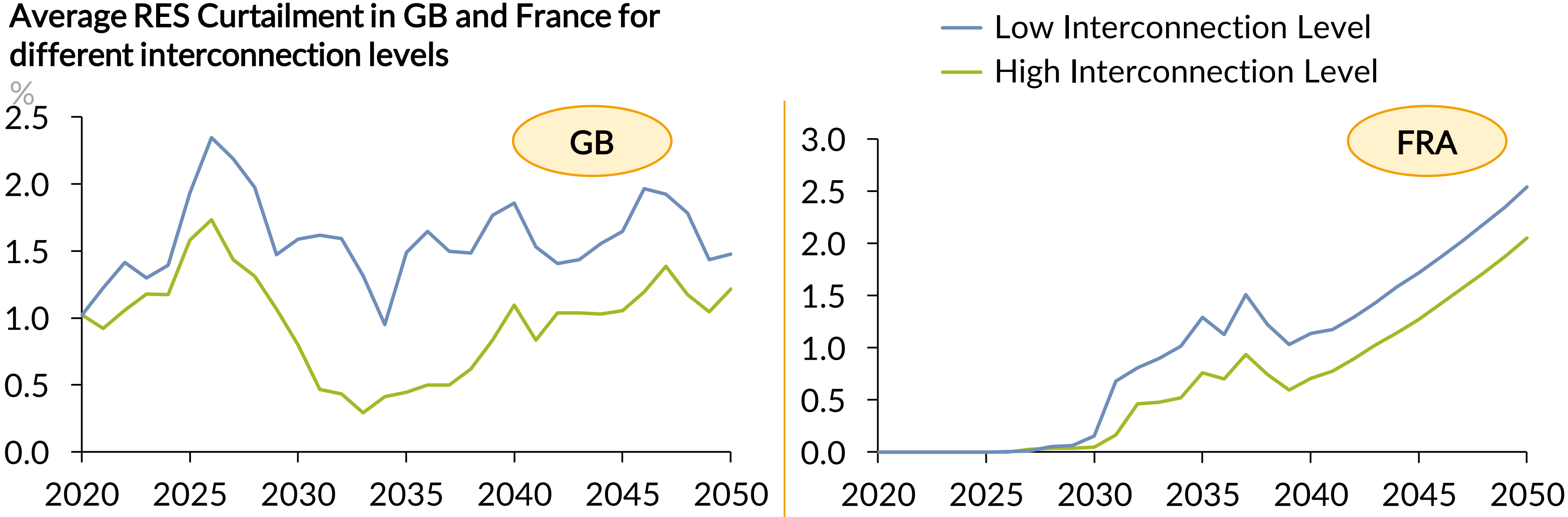
1) FRA imports slightly more from ESP in the GB high interconnection scenario which also affects its baseload price. 2) Baseload prices for other countries can be found in the accompanying data book.

Source: Aurora Energy Research

GB Known Policy
EU Existing Policy

More interconnection might allow the avoidance of RES curtailment through channelling excess RES between GB and EU

Average RES Curtailment in GB and France for different interconnection levels

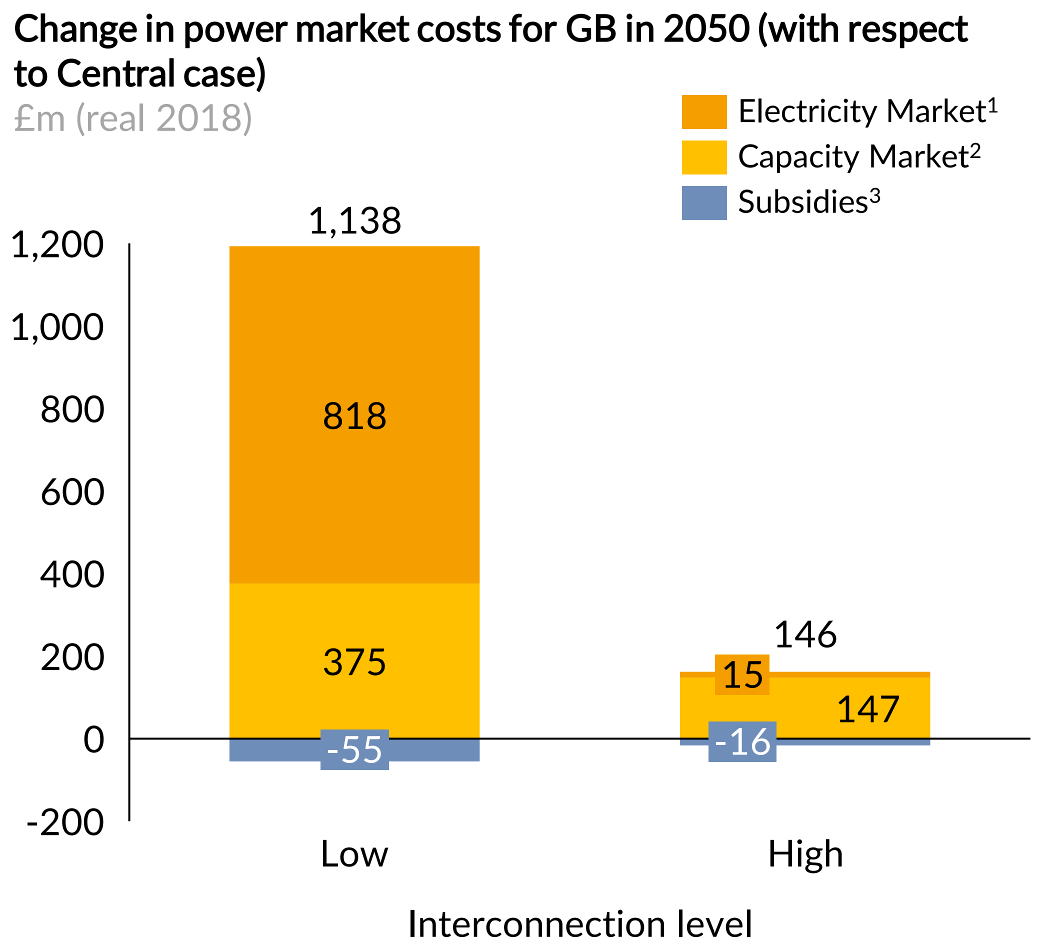


- The adjacent graph shows the average curtailment fraction of RES plants (Solar, onshore and offshore) in GB for different interconnection levels
- In a high interconnection scenario we see on average less than 1% of RES plants curtailed across the timeline, while in a low interconnection scenario this increases by around 65%
- This suggests that a high interconnection scenario allows less RES generation to be curtailed suggesting that the generation is being transferred through interconnectors to undersupplied countries

Source: Aurora Energy Research

GB Known Policy
EU Existing Policy

On a power market cost basis, interconnection capacity levels have little effect on market costs with costs changing by up to £1bn p.a



- The power market cost is affected more between the Low and Central interconnection levels while it remains nearly constant when moving towards the High interconnection scenario
- In the earlier years, the main driver of change is the capacity market spending which decreases with higher interconnection capacity due to the higher capacity market procurement target
- Between 2020 and 2050, the cumulative power market cost is lowest for the Central interconnection scenario at £703bn, followed by the High interconnection scenario at £705bn and the Low interconnection scenario at £717bn. This suggests that increasing interconnector capacity has a positive impact on system costs until a certain point where the impacts begin to flatten out

1) Electricity Market (Wholesale) spending is the product of wholesale price and demand summed over all half hours of every year. 2) Capacity Market spending is the product of the capacity market prices and the procurement target (de-rated capacity). 3) Subsidy spending is calculated based on the amount of money required to make a renewable generator "break even" on an NPV basis if it participates in the wholesale market without any subsidies.

Source: Aurora Energy Research

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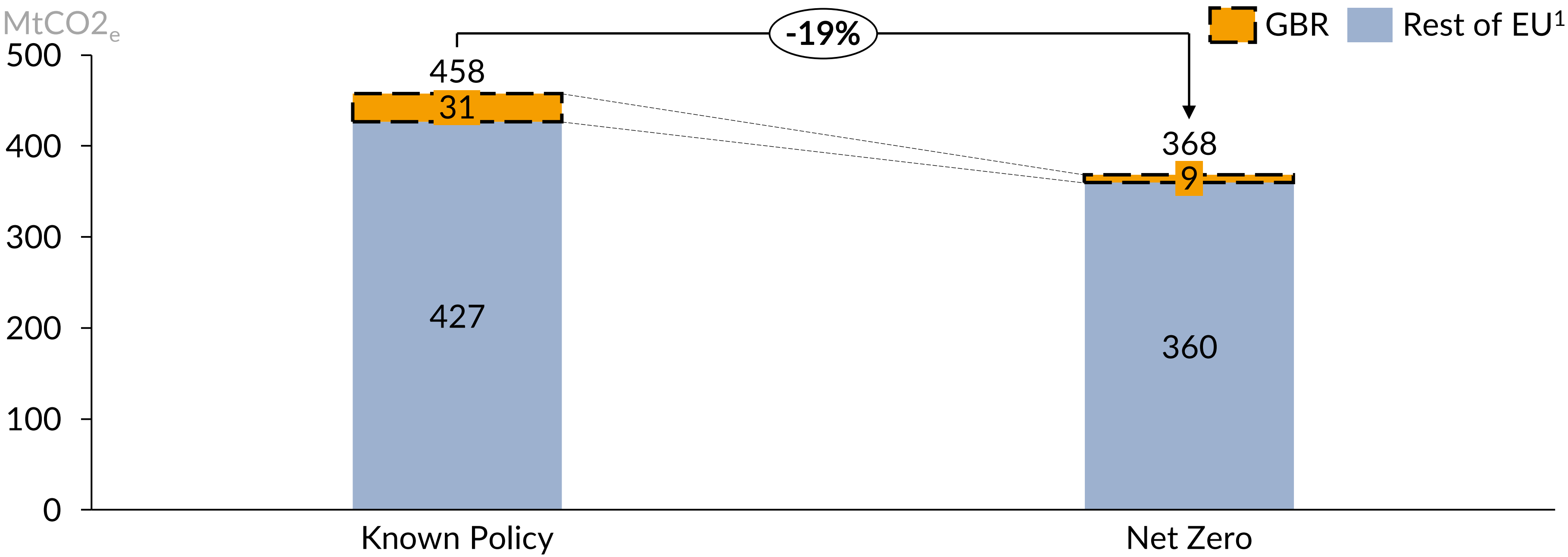
EU and GB emissions drop when GB is in a Net Zero world due to the high carbon ETS price, with GB emissions reducing by 2/3

Carbon emissions in 2050



- In a Net Zero scenario in GB, emissions decrease significantly in GB and drop to less than 9 $MtCO_2$ while emissions across EU see more moderate reductions and drop to 360 $MtCO_2$ as installed capacity in the EU remains the same in the Net Zero higher-demand scenario while installed capacity in GB changes
- The carbon price increase in the EU drives emissions down, as thermal generation is dispatching less often due to the extra cost associated with carbon. Note that this change in carbon price does not reflect what the carbon price needs to be or should be in the EU to decarbonise, it is just reflective of the assumption that was used in BEIS GB NZ Scenario.
- As a result, low-carbon generation and imports to EU from GB replace some thermal generation

1) Includes all countries in EU except GB.

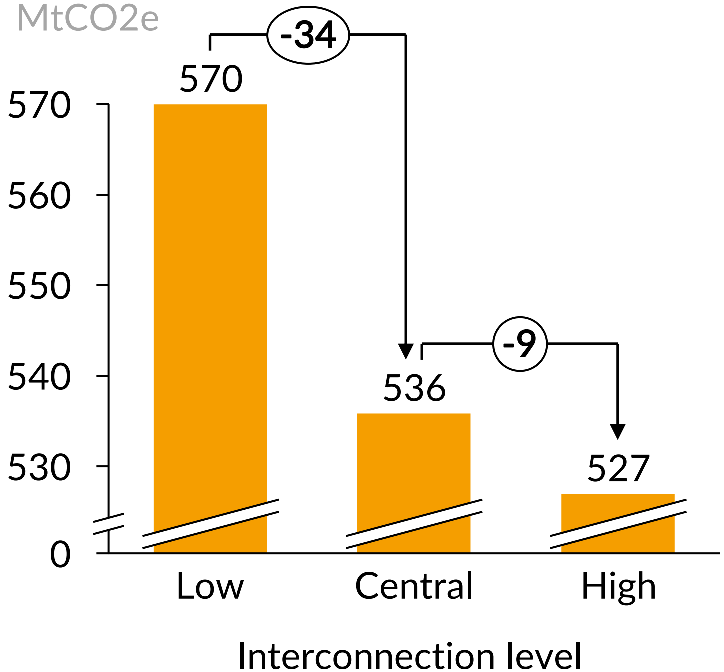
Source: Aurora Energy Research

GB Net Zero
EU Existing Policy

In a Net Zero GB scenario, CO_2 emissions in GB and Rest-of-EU decrease slightly as the installed capacity of interconnectors increases

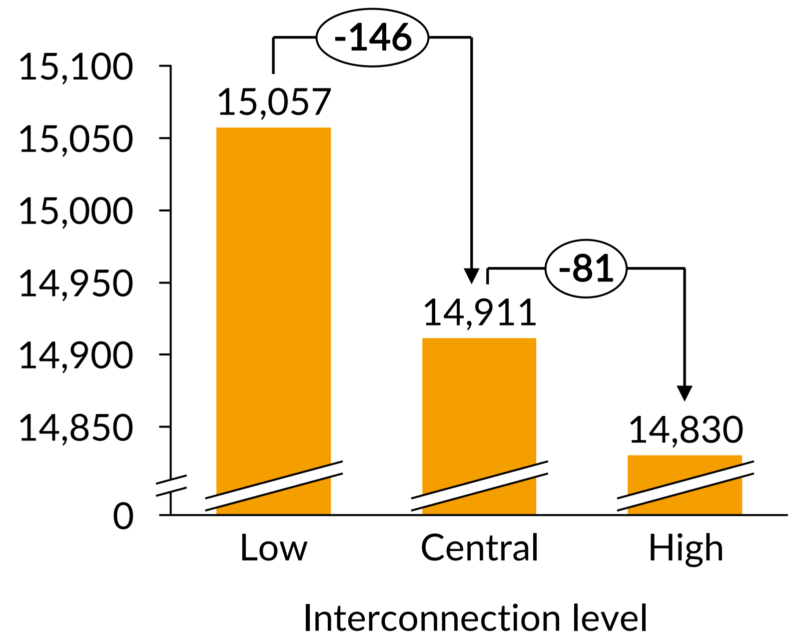
Total cumulative[1] CO_2 emission in GB

MtCO2e



Total cumulative[1] CO_2 emission in Rest-of-EU[2]

MtCO2e



- In a Net Zero scenario in GB, cumulative emissions in GB are reduced by around 40% compared to the Known Policy
- The change in interconnection level is less impactful on emissions in a Net Zero world compared to Known Policy in GB as the proportion of low-carbon generation is higher regardless of the interconnection level. Although increasing interconnection capacity still has a positive effect on cumulative emissions between 2020 and 2050
- The benefits of an increase in interconnection capacity on decreasing emissions are evident in the short- to medium-term (up to 2030) compared to the long-term (2050) as shown in the Appendix[3]

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Includes all EU except GB. 3) Appendix 1, Section B

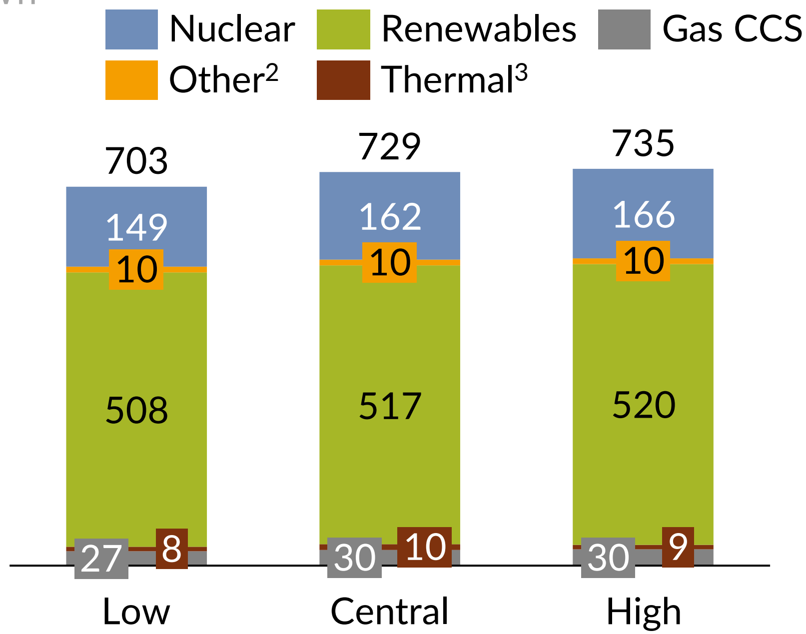
Source: Aurora Energy Research

GB Net Zero
EU Existing Policy

GB generation from nuclear and RES increases as interconnection capacity grows while thermal and nuclear generation drops in EU

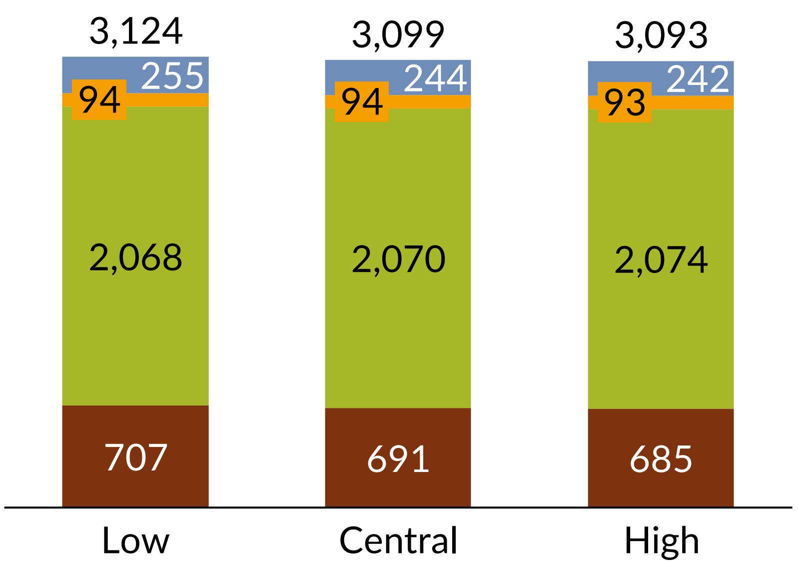
Net generation in GB in 2050

TWh



Net generation in Rest-of-EU[1] in 2050

TWh



- The increased GB exports[4] due to the higher interconnection capacity are mainly sourced from Nuclear and RES plants which implies the EU is receiving clean imports in this scenario
- Due to the increased imports from GB, the rest of EU sees a drop in thermal and Nuclear generation to keep total generation the same

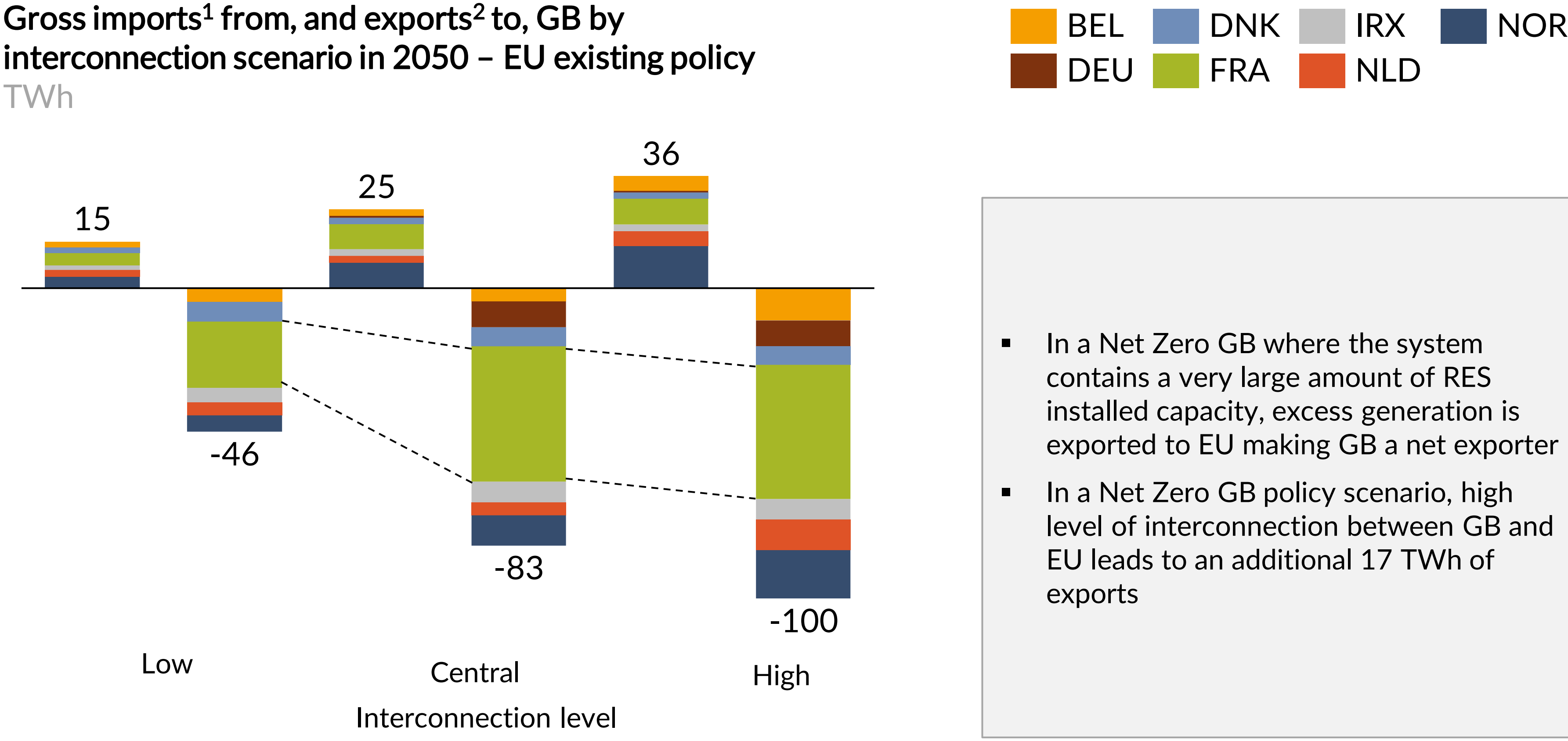
1) Includes all countries in EU except GB. 2) Other technologies include DSR, micro CHPs, biogas and energy from waste plants. 3) Thermal generation includes all types of gas and coal plants. 4) 31,58, and 64 TWh for the Low, Central and High interconnection levels respectively.

Source: Aurora Energy Research

Under a GB Net Zero scenario with current EU Policy, GB increasingly becomes a net exporter towards 2050

Gross imports[1] from, and exports[2] to, GB by interconnection scenario in 2050 – EU existing policy

TWh



- In a Net Zero GB where the system contains a very large amount of RES installed capacity, excess generation is exported to EU making GB a net exporter
- In a Net Zero GB policy scenario, high level of interconnection between GB and EU leads to an additional 17 TWh of exports

Net[3] imports in 2050

TWh

Low	Central	High
-31	-58	-64

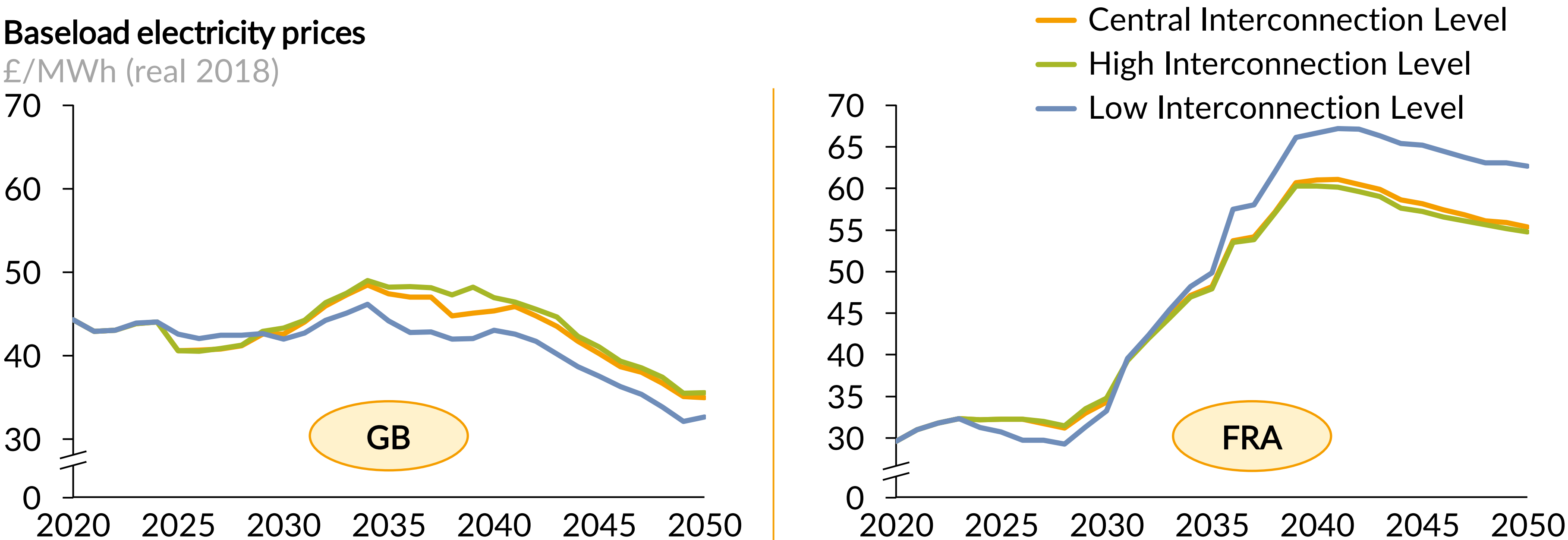
1) Imports here are depicted as positive. 2) Exports are depicted as negative. 3) Net is shown as the sum of imports and exports. Negative net imports are essentially net exports.

Source: Aurora Energy Research

GB Net Zero
EU Existing Policy

Less interconnection between EU and GB leads to lower baseload prices in GB, and higher prices in FRA

Baseload electricity prices
£/MWh (real 2018)

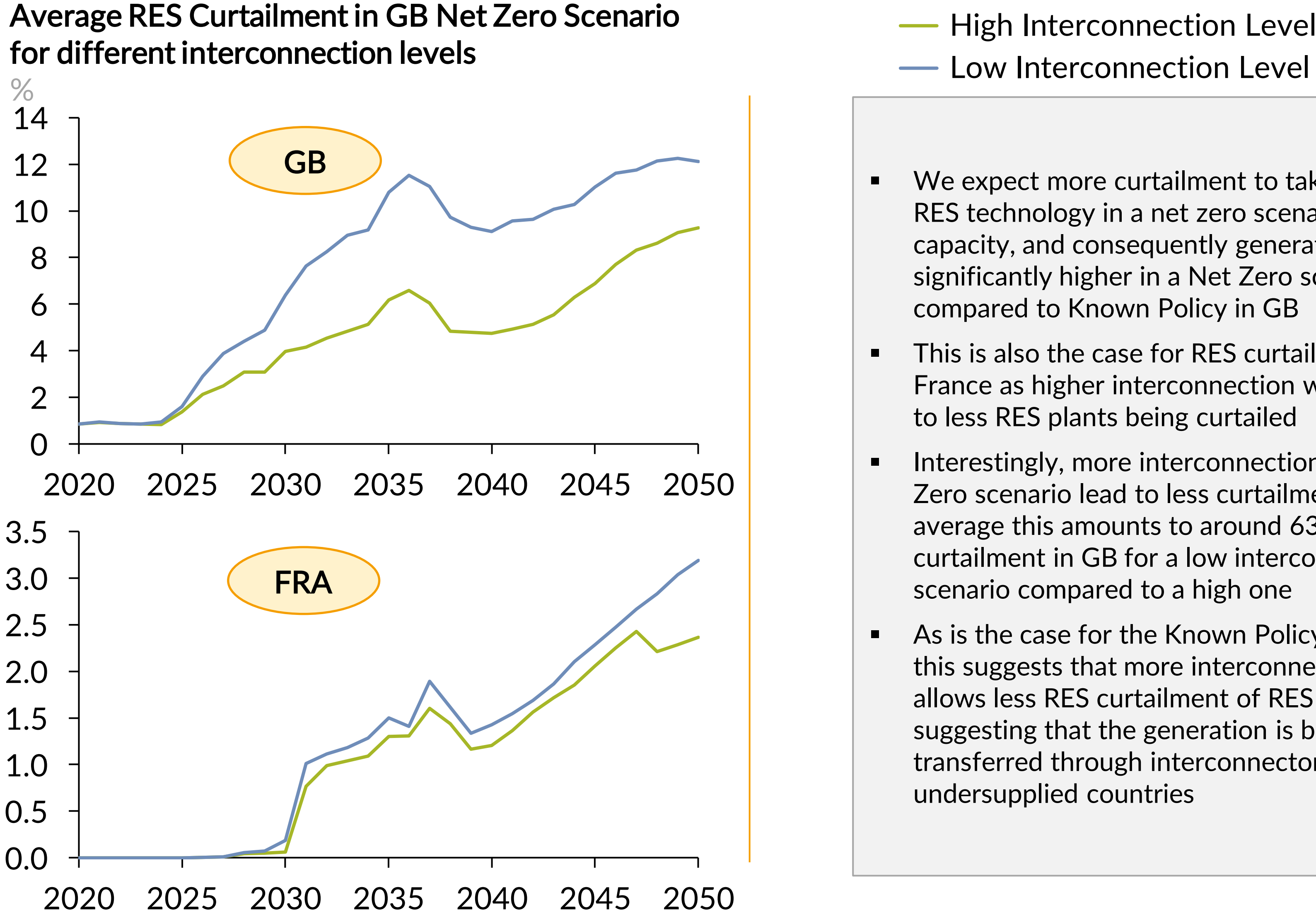


- In a GB Net Zero scenario, higher interconnection results in higher power prices, opposite to that in GB Known Policy scenario
- In GB, reduced interconnection capacity leads to lower baseload prices as renewable generation is high in a Net Zero scenario
- In France, baseload prices follow an opposite trend with prices increasing significantly as France becomes less dependent on cheaper imports from GB (FRA imports less from GB in a low interconnection scenario) and therefore needs to increase thermal generation in order to meet demand
- A similar trend to the baseload prices in France is shown in the rest of EU, except in Germany for instance where baseload prices continuously increase with time

Source: Aurora Energy Research

More interconnection might allow the avoidance of RES curtailment through channelling excess RES between GB and EU

Average RES Curtailment in GB Net Zero Scenario for different interconnection levels



- We expect more curtailment to take place for RES technology in a net zero scenario as RES capacity, and consequently generation, is significantly higher in a Net Zero scenario compared to Known Policy in GB
- This is also the case for RES curtailment in France as higher interconnection with GB leads to less RES plants being curtailed
- Interestingly, more interconnection in a Net Zero scenario lead to less curtailment, on average this amounts to around 63% higher curtailment in GB for a low interconnection scenario compared to a high one
- As is the case for the Known Policy scenario, this suggests that more interconnection capacity allows less RES curtailment of RES generation, suggesting that the generation is being transferred through interconnectors to undersupplied countries

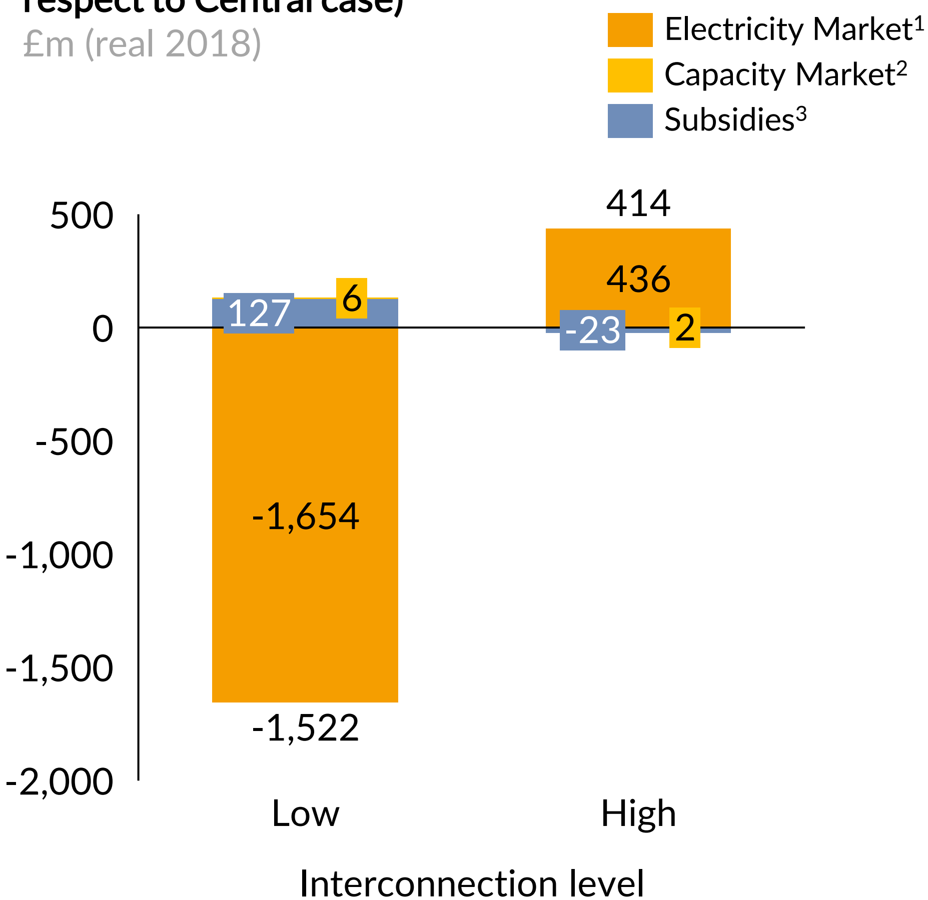
Source: Aurora Energy Research

GB Net Zero
EU Existing Policy

In a Net Zero scenario in GB, power market costs show little change with interconnection level, only increasing slightly

Change in power market costs for GB in 2050 (with respect to Central case)

£m (real 2018)



- In a Net Zero scenario in GB, the change in power market cost with a change in interconnector capacity follows an opposite trend to that of the Known Policy
- Total system cost increases as interconnector capacity between GB and Rest-of-EU increases, with a more significant change between the Low and Central interconnection levels
- An increase in interconnection level in GB increases the renewable generation, whose electricity price is set to zero or negative (for subsidized renewables)
- More interconnectors reduces the need for curtailment, which in turn increases electricity market costs
- On average, between 2020 and 2050, the cumulative power market cost is lowest for the Low interconnection scenario at £805bn, followed by the Central interconnection scenario at £808bn and the High interconnection scenario at £809bn. The small differences between scenarios show how increasing interconnector capacity has little impact on system costs
- Note that, in these scenarios, low-carbon capacities in GB do not change as a result of higher interconnection capacity. If we were to look at an optimised system then increasing interconnection may lead to less other capacity being needed thus altering costs

1) Electricity Market (Wholesale) spending is the product of wholesale price and demand summed over all half hours of every year. 2) Capacity Market spending is the product of the capacity market prices and the procurement target (de-rated capacity). 3) Subsidy spending is calculated based on the amount of money required to make a renewable generator "break even" on an NPV basis if it participates in the wholesale market without any subsidies.

Source: Aurora Energy Research

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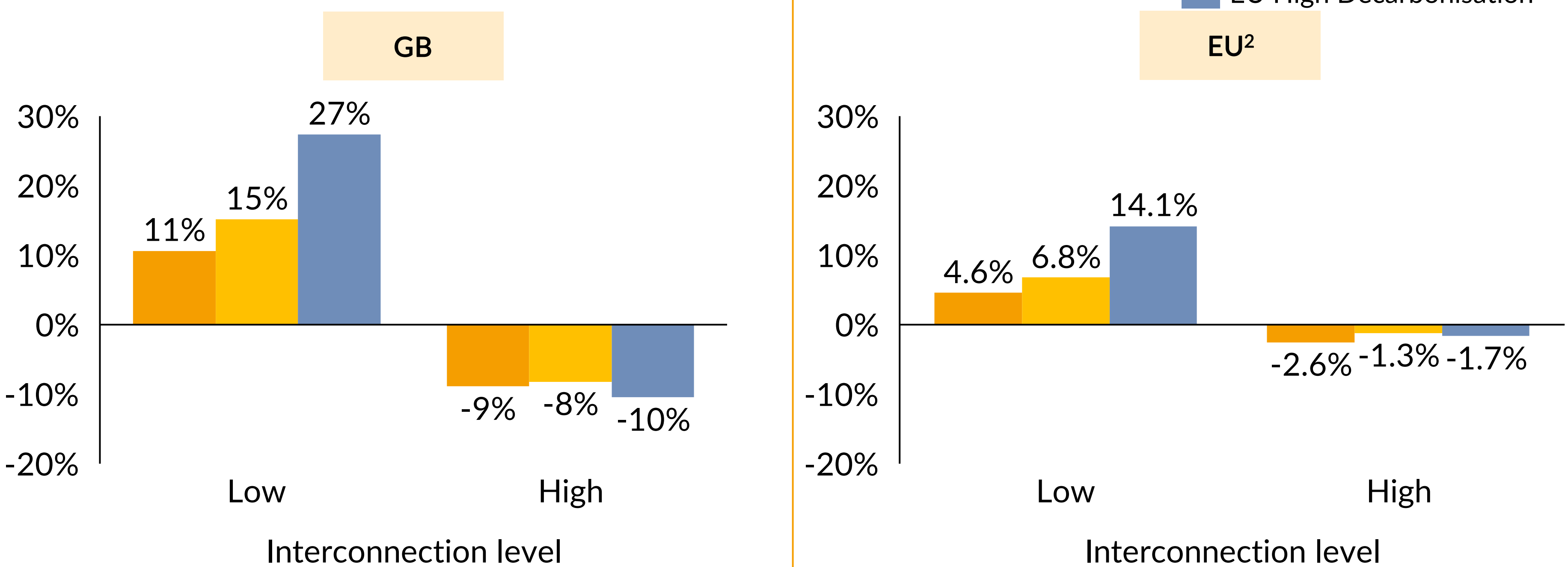
Emissions in GB generally decrease with interconnection regardless of EU and GB policy ambition

AURORA ENERGY RESEARCH

Percent difference in cumulative[1] CO_2 emissions for GB Known Policy (with respect to Central case) %



- EU decarbonisation policy affects the rate at which the decrease in emissions takes place in GB, with a highly decarbonised EU leading to faster decrease in emissions compared to low decarbonised EU
- A high decarbonisation policy in EU leads to a more significant impact of interconnection on decarbonisation however, regardless of EU decarbonisation levels, high interconnector capacity leads to less emissions in both GB and EU

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Include all countries in EU with GB.

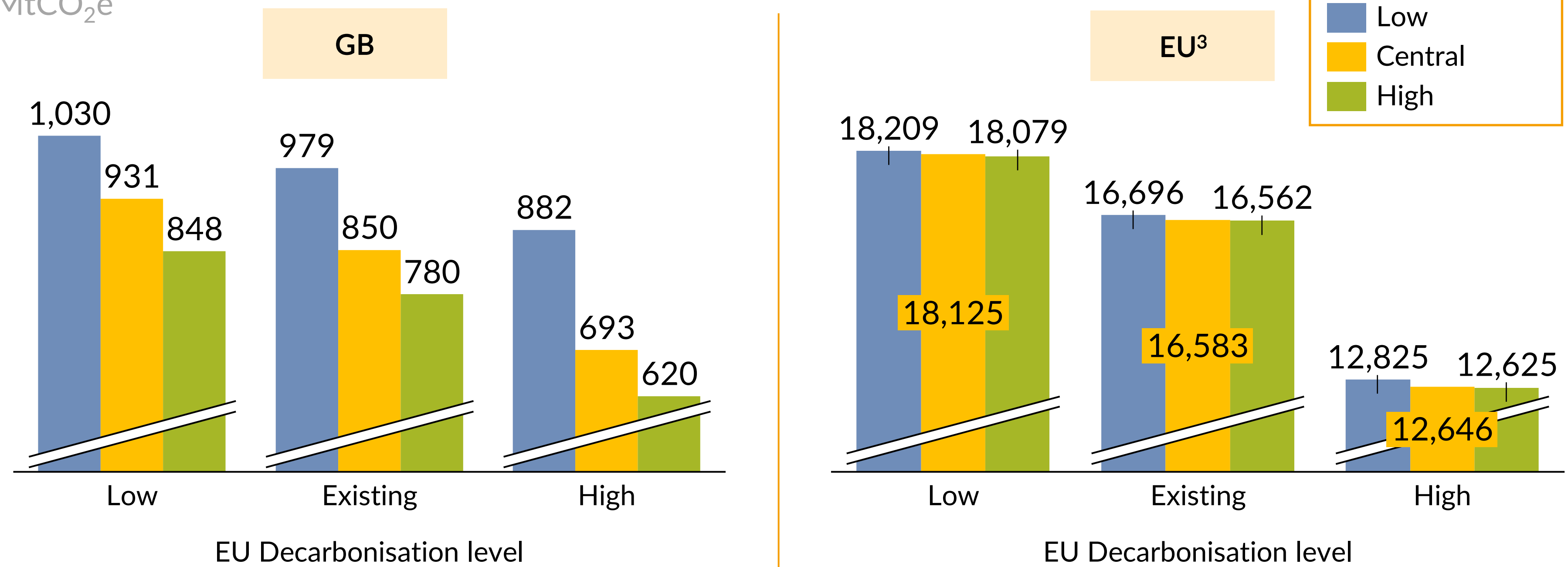
Source: Aurora Energy Research

An increase in interconnection capacity decreases emissions in GB, as does a more ambitious EU decarbonisation policy

AURORA ENERGY RESEARCH

Total cumulative[1] CO_2 emissions for GB Known Policy

MtCO$_2$e



- Total emissions in GB decrease significantly if EU follow a high decarbonisation policy as clean imports from EU increase
- In a high decarbonisation scenario, emissions in EU decrease by around 4,000 MtCO$_2$e as dependency on renewable generation and CCS increases across EU
- The benefits of a more ambitious EU scenario on decreasing emissions in both GB and EU are observable in the short- to medium-term (up to 2030), while they decrease in the long-term (2050) as shown in the Appendix[3]

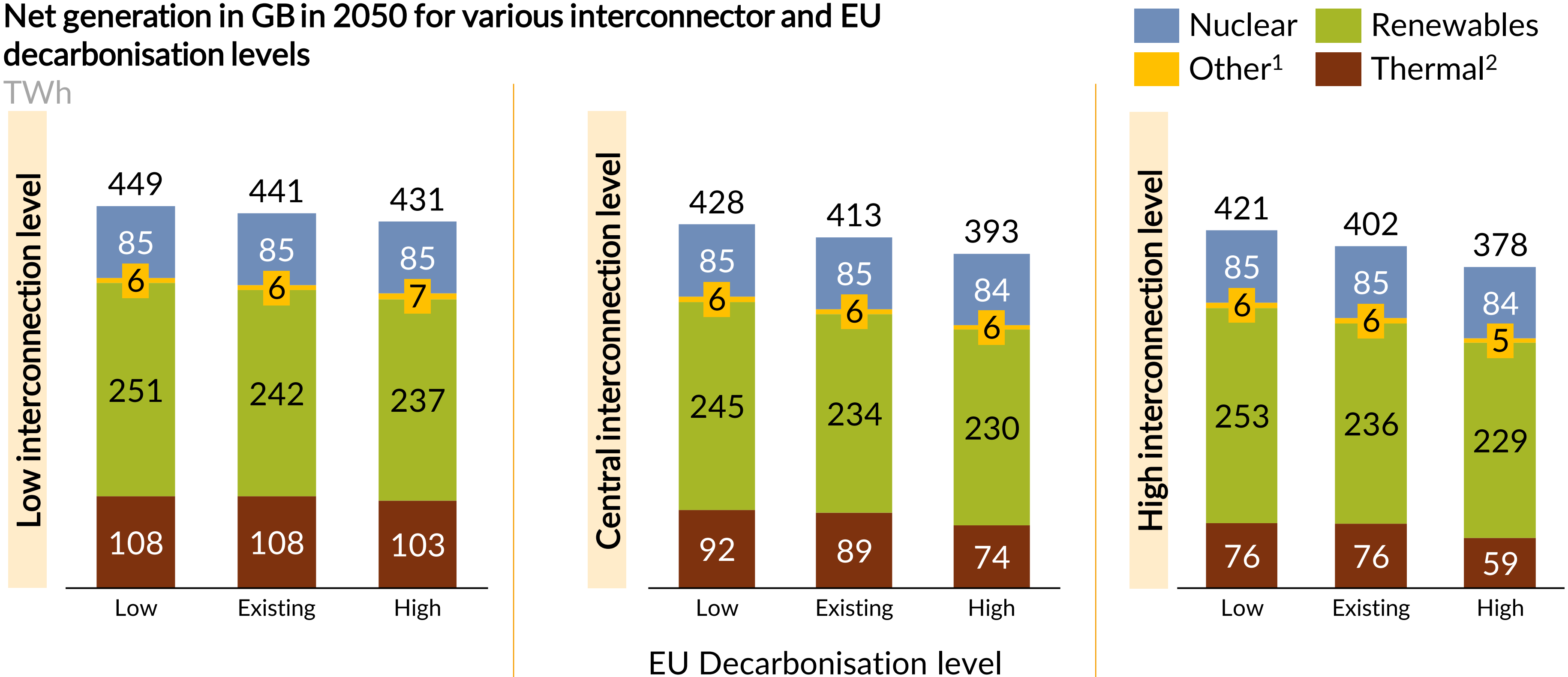
1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Include all countries in EU with GB. 3) Appendix 1, Section B

Source: Aurora Energy Research

Increasing interconnection capacity reduces thermal generation in GB across different scenarios of EU decarbonisation policy

Net generation in GB in 2050 for various interconnector and EU decarbonisation levels

TWh



- An increase in interconnection level, along with a change towards a more decarbonised EU, increases renewable generation and reduces carbon emissions in GB
- Total generation in GB decreases as the EU switches to high decarbonisation policy, due to an increase in imports from EU to GB
- A highly decarbonised EU increases renewable generation in GB in 2050 by 47 TWh while thermal generation is reduced by 48 TWh

1) Other technologies include DSR, micro CHPs, biogas and energy from waste plants and Gas CCS. 2) Thermal generation includes all types of gas and coal plants.

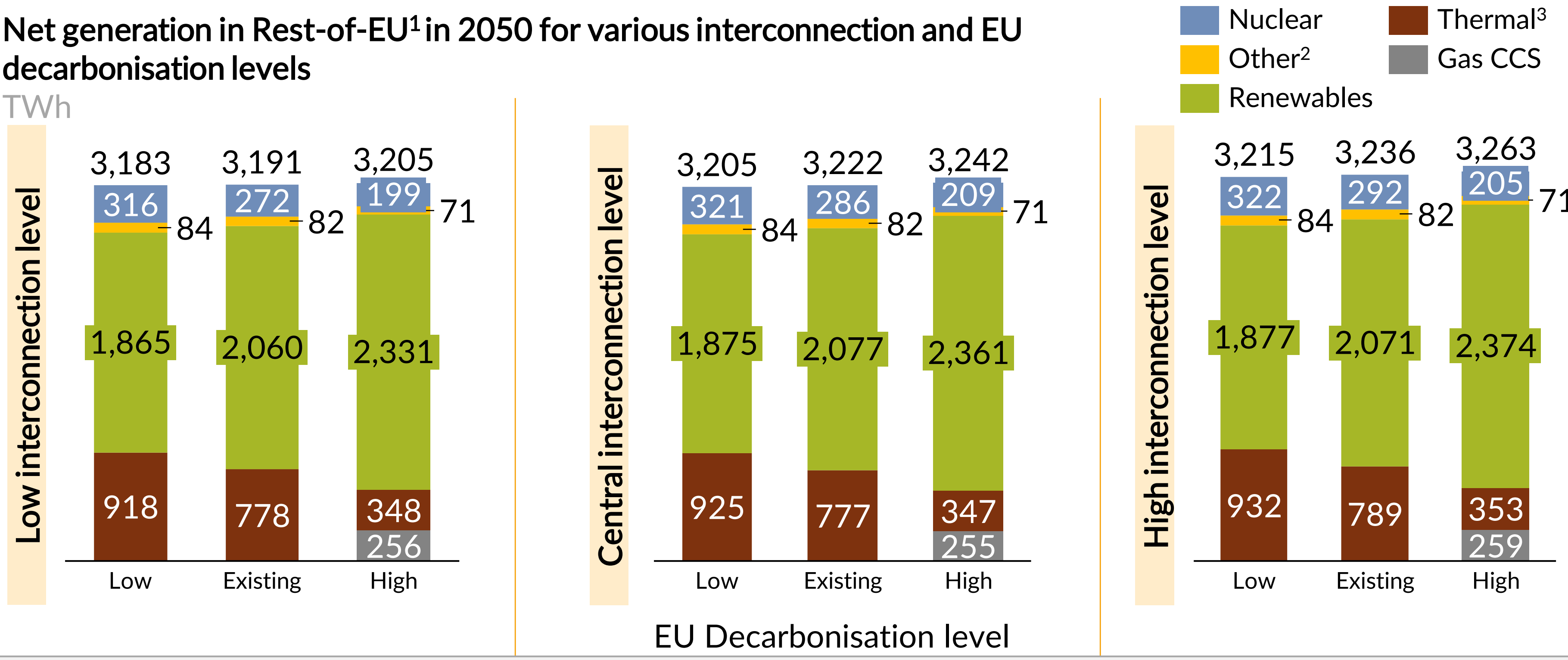
Source: Aurora Energy Research

An increase in interconnection capacity increases renewables generation, and decreases thermal generation across EU

AURORA ENERGY RESEARCH

Net generation in Rest-of-EU[1] in 2050 for various interconnection and EU decarbonisation levels

TWh



- Interconnection increase between GB and EU drives down total generation across EU as GB becomes a net exporter
- With an increase in interconnection level, and a drive towards more decarbonisation in EU, renewable generation increases, and emissions decrease
- In a highly decarbonised EU, Nuclear generation reduces as more flexible Gas CCS is used to help balance the variable renewable output
- A detailed breakdown of the renewable and thermal generation by country is shown in Appendix 1, C

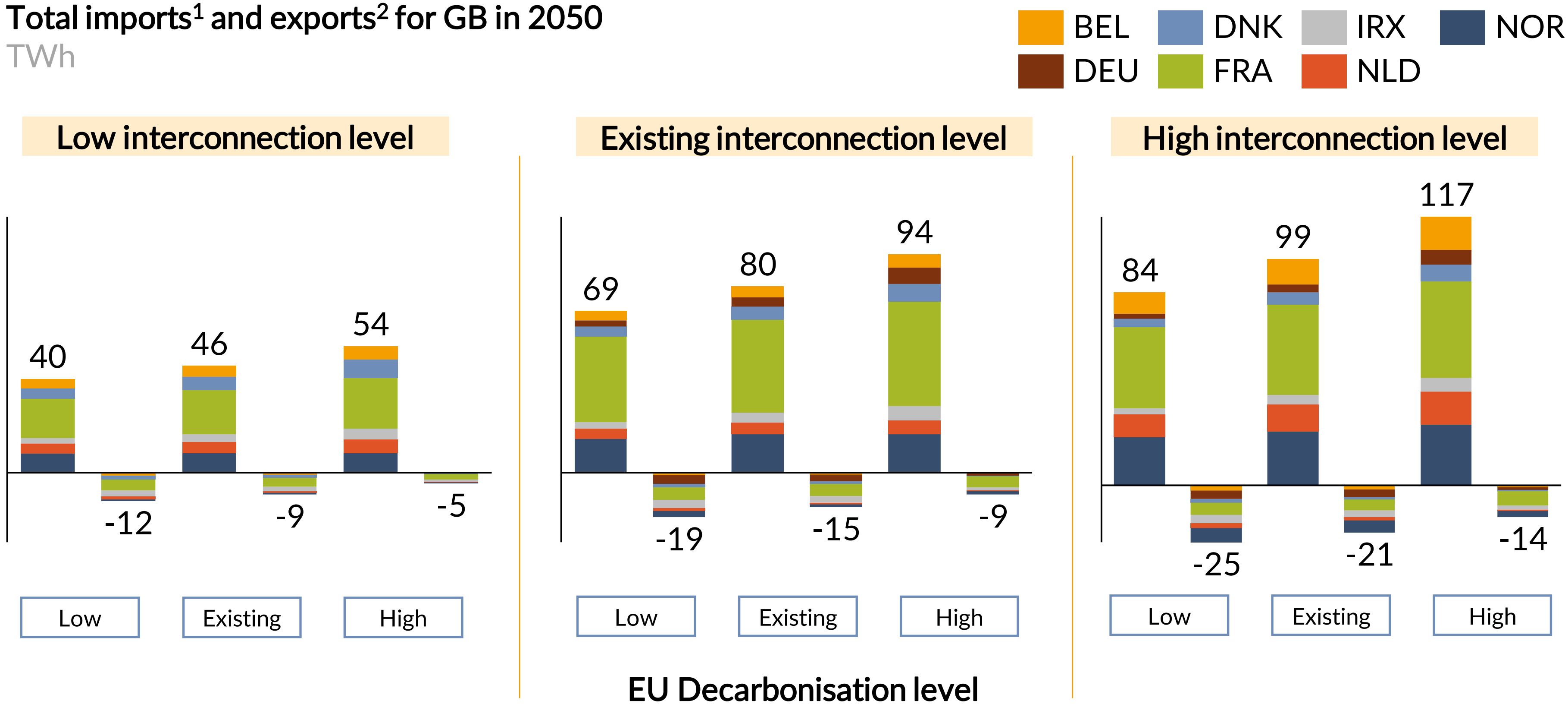
1) Includes all countries in EU except GB. 2) Other includes Other technologies include DSR, micro CHPs, biogas and energy from waste plants. 3) Thermal generation includes all types of Gas and Coal plants (except Gas CCS).

Source: Aurora Energy Research

The impact of interconnection on imports is higher with a more ambitious decarbonisation plan in EU

Total imports[1] and exports[2] for GB in 2050

TWh



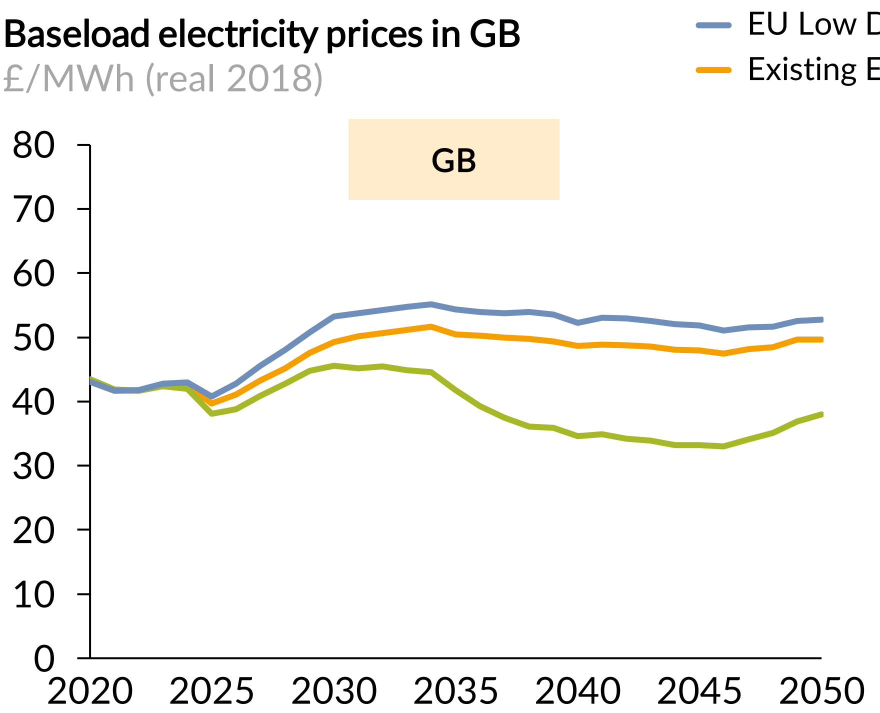
- As EU becomes more decarbonised, both imports to, and exports from, GB increase
- In a low decarbonisation scenario in EU, GB exports increase as renewable generation in GB increases
- Imports and exports between EU and GB are driven by baseload price differentials between the two areas

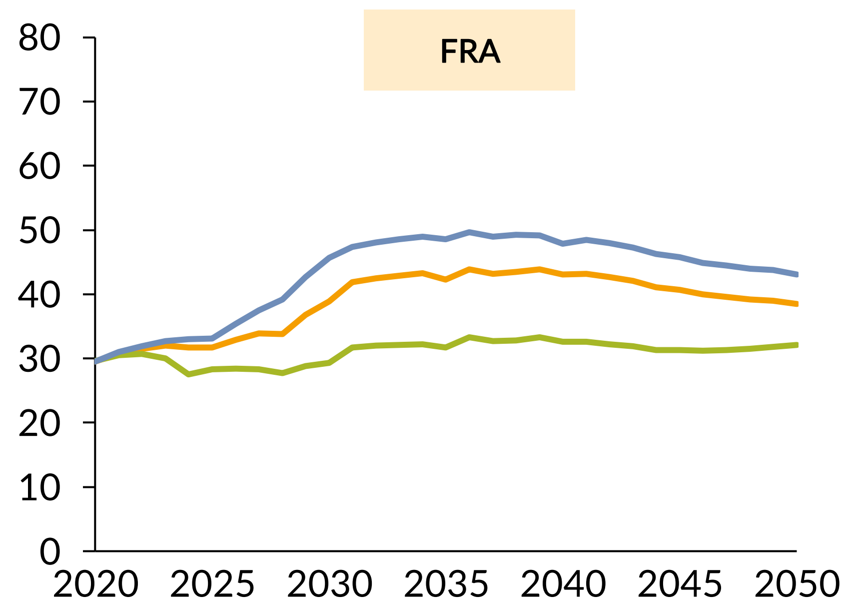
1) Imports are depicted as positive. 2) Exports are depicted as negative.

Source: Aurora Energy Research

More decarbonisation across EU leads to lower baseload prices in GB due to higher generation from low marginal cost sources

Baseload electricity prices in GB
£/MWh (real 2018)





- Increased decarbonisation in EU drives GB prices down due to low-price imports from EU countries where renewables are the main source of generation, similar to the effect of an increase in interconnection level between EU and GB
- A switch to a high decarbonisation scenario in EU drives down baseload prices in France with prices varying between £32/MWh to £43/MWh, as dependency on renewable generation increases
- Baseload price difference between France and GB explains the increase in imports from France reaching 45 TWh in 2050

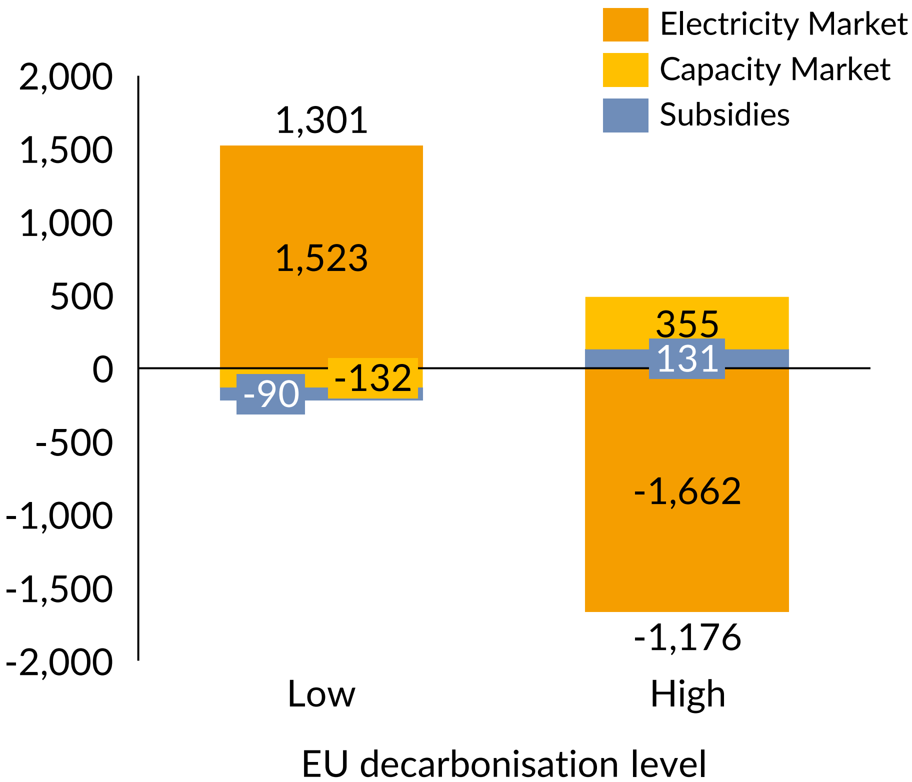
Source: Aurora Energy Research

Higher EU decarbonisation leads to lower market costs in GB driven by the wholesale market price reduction

AURORA ENERGY RESEARCH

Change in power market costs for GB in 2050 (with respect to Existing EU decarbonisation level)

£m (real 2018)



- The power market cost is highly driven by the baseload prices between EU decarbonisation scenarios
- With higher decarbonisation ambition in EU, baseload prices in GB drop, reducing the EM spending
- Subsidies spending increases with EU decarbonisation ambition as baseload prices decrease, and the RES generators' revenues from the wholesale market decrease
- Capacity market spending is affected by the de-rated capacity available and as interconnectors capacity increases, CCGT capacity decreases
- The impact on cumulative power market costs of varying EU decarbonisation policy is 4x as great as the range observed by varying interconnection levels, with more stringent EU policy reducing total costs
- These results align with the ones in section 5; with more interconnection and a drive towards a decarbonised rest-of-EU, the total power market costs in GB decrease

1) Electricity Market (Wholesale) spending is the product of wholesale price and demand summed over all half hours of every year. 2) Capacity Market spending is the product of the capacity market prices and the procurement target (de-rated capacity). 3) Subsidy spending is calculated based on the amount of money required to make a renewable generator "break even" on an NPV basis if it participates in the wholesale market without any subsidies.

Source: Aurora Energy Research

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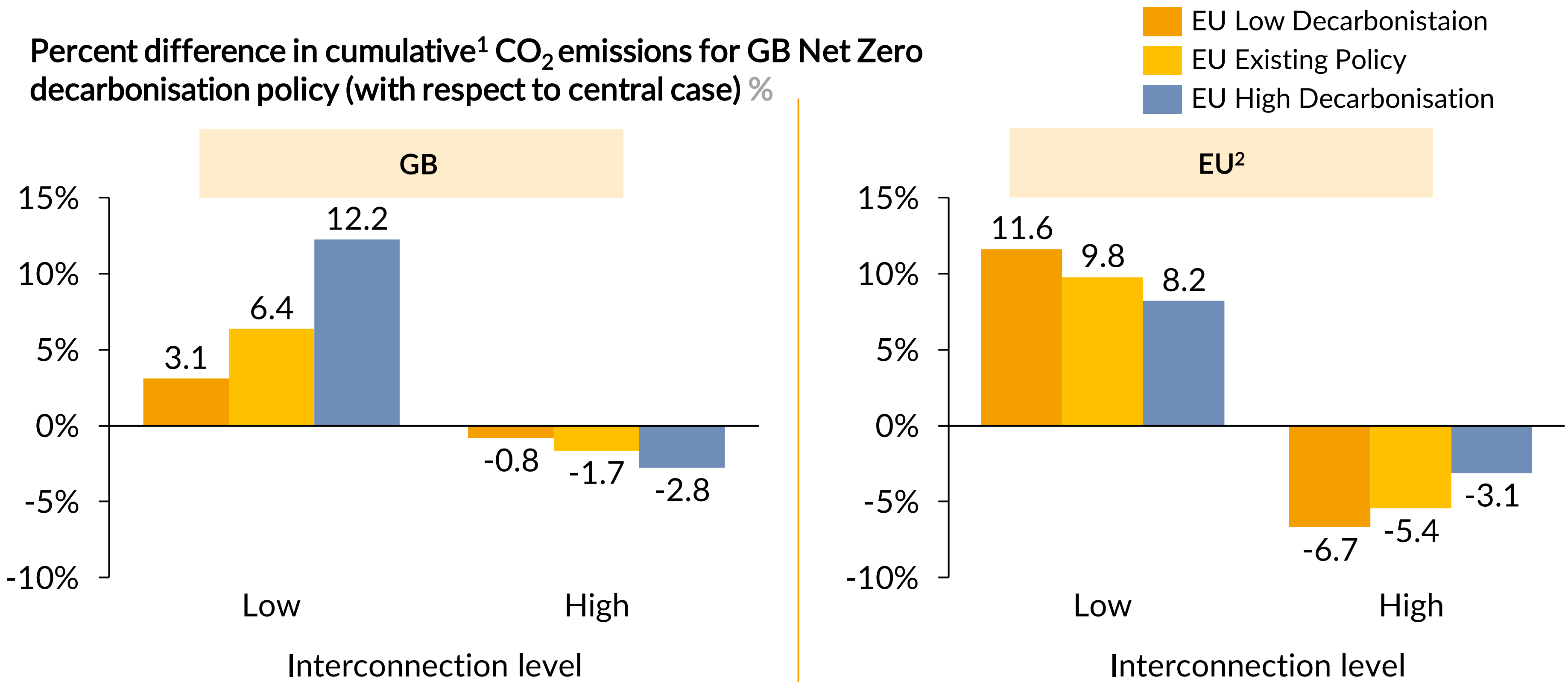
Emissions in GB generally decrease with interconnection regardless of EU and GB policy ambition

AURORA ENERGY RESEARCH

Percent difference in cumulative[1] CO_2 emissions for GB Net Zero decarbonisation policy (with respect to central case) %



- Interconnection level leads to a bigger difference in CO_2 emissions across GB if GB follows the Known Policy compared to a change to Net Zero
- The decrease in emissions is due to the marginal technology becoming more low-carbon generation as GB shift toward a Net Zero Policy
- Cumulative emissions in EU decrease with interconnection level regardless of the decarbonisation policy in GB and EU

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Include all countries in EU with GB.

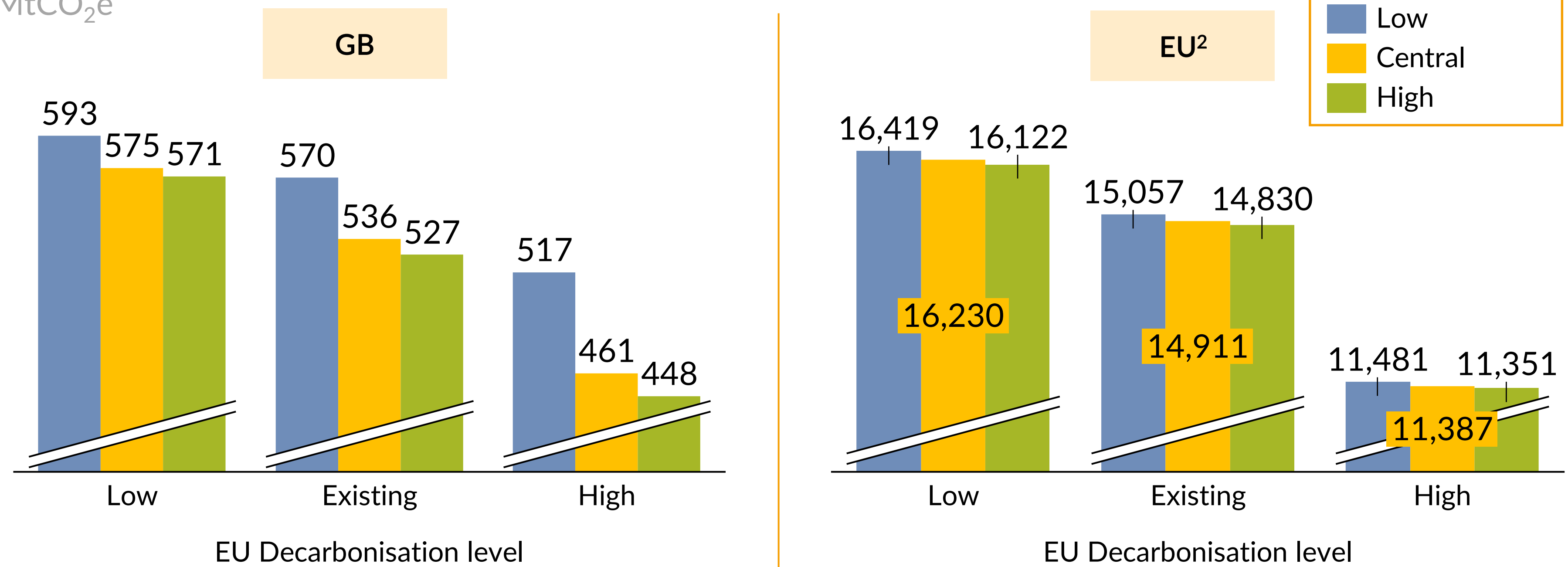
Source: Aurora Energy Research

An increase in interconnection decreases emissions in GB, with a tighter EU decarbonisation policy decreasing emissions further

AURORA ENERGY RESEARCH

Total cumulative[1] CO_2 emissions for GB Net Zero Policy

MtCO$_2$e



- Total cumulative emissions in GB in a Net Zero decarbonisation policy is around 40% lower than that for Known Policy as low carbon generation increase in a Net Zero scenario
- In EU, cumulative emissions are reduced compared to the equivalent GB Known Policy scenarios as clean imports from GB increase as well as dependency on low-carbon generation across EU
- The benefits of more ambitious EU scenarios on decreasing emissions in both GB and EU are clear up to 2035, where they peak, and then, between 2035 and 2050, start plateauing with time as shown in the Appendix[3]

1) Cumulative refers to the total emissions across 30 years from 2020 to 2050. 2) Include all countries in EU with GB. 3) Appendix 1, Section B

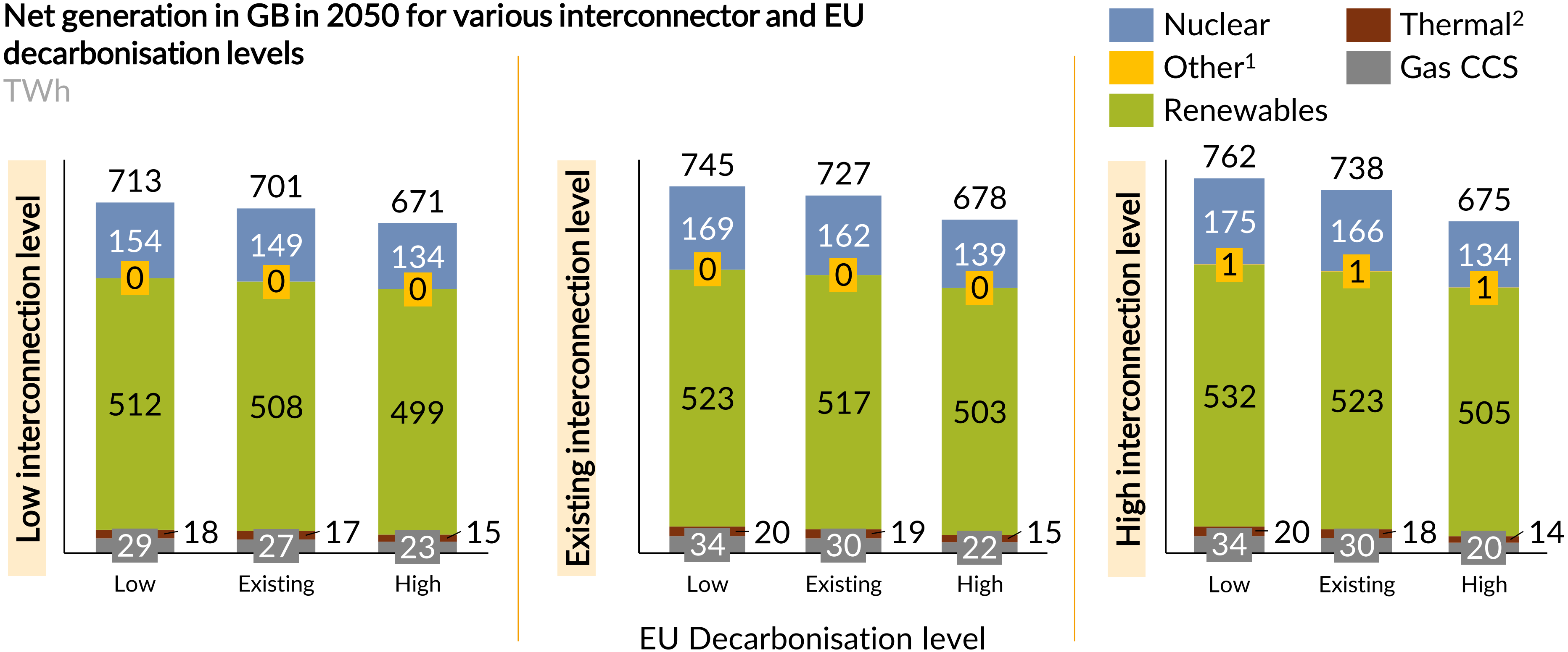
Source: Aurora Energy Research

GB in a Net Zero world generates more than it consumes, with generation decreasing as interconnection level with EU increases

AURORA ENERGY RESEARCH

Net generation in GB in 2050 for various interconnector and EU decarbonisation levels

TWh



- An increase in interconnection leads to more renewable generation, so with a low decarbonisation policy implemented in rest-of-EU, generation in GB increases to meet the demand across EU. This leads to a decrease in curtailment in GB
- In a Net Zero GB scenario, total generation in GB decreases as the EU switches to high decarbonisation policy, but remains significantly higher than the total generation in Known Policy GB
- The benefits of interconnection capacity in reducing emissions and driving up renewable generation is seen throughout the different EU decarbonisation scenarios

1) Other technologies include DSR, micro CHPs, biogas and energy from waste plants. 2) Thermal generation includes all types of Gas and Coal plants (except Gas CCS).

In a Net Zero scenario in GB, generation in EU decreases with more interconnection as dependency on imports from GB increases

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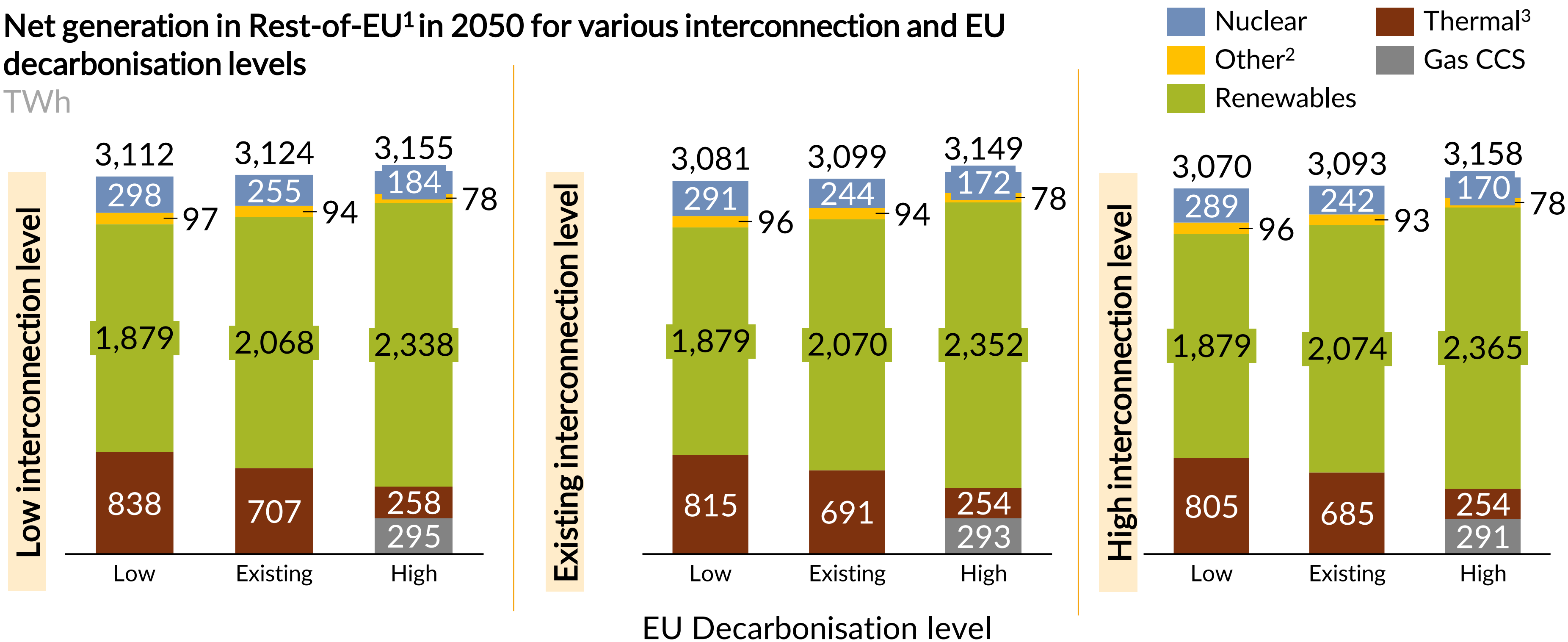
Net generation in Rest-of-EU[1] in 2050 for various interconnection and EU decarbonisation levels

TWh



- Generation in EU increases as EU decarbonisation policy becomes more ambitious, while an increase in interconnection level only slightly increases generation since GB is less dependent on imports in a Net Zero GB scenario
- In a Net Zero scenario in GB, EU total generation decreases compared to Known Policy as dependency on imports from GB increases
- Thermal generation in EU decreases by 62% as EU switches to a high decarbonisation policy

1) Includes all countries in EU except GB. 2) Other technologies include DSR, micro CHPs, biogas and energy from waste plants 3) Thermal generation includes all types of gas and coal plants

Source: Aurora Energy Research

GB will become a net exporter in Net Zero scenario, with exports to EU increasing with more interconnection

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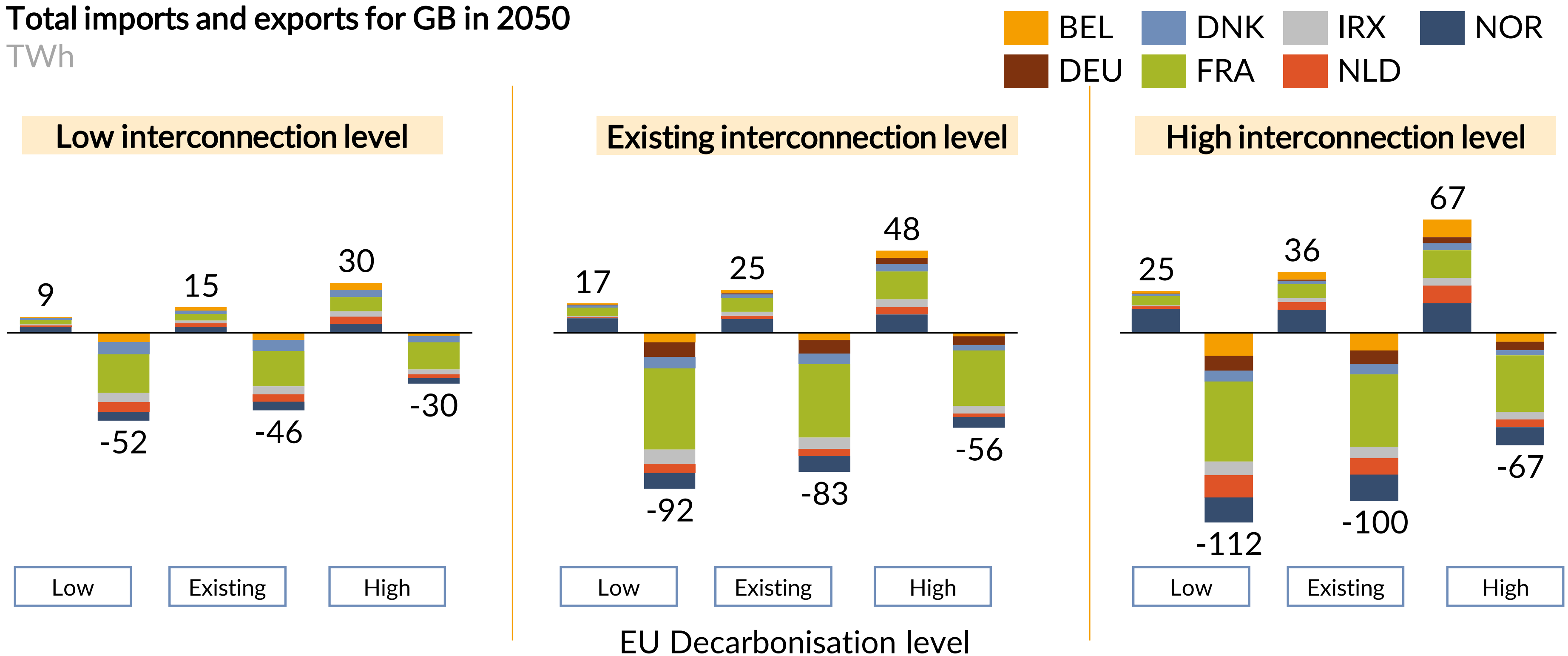
Total imports and exports for GB in 2050

TWh

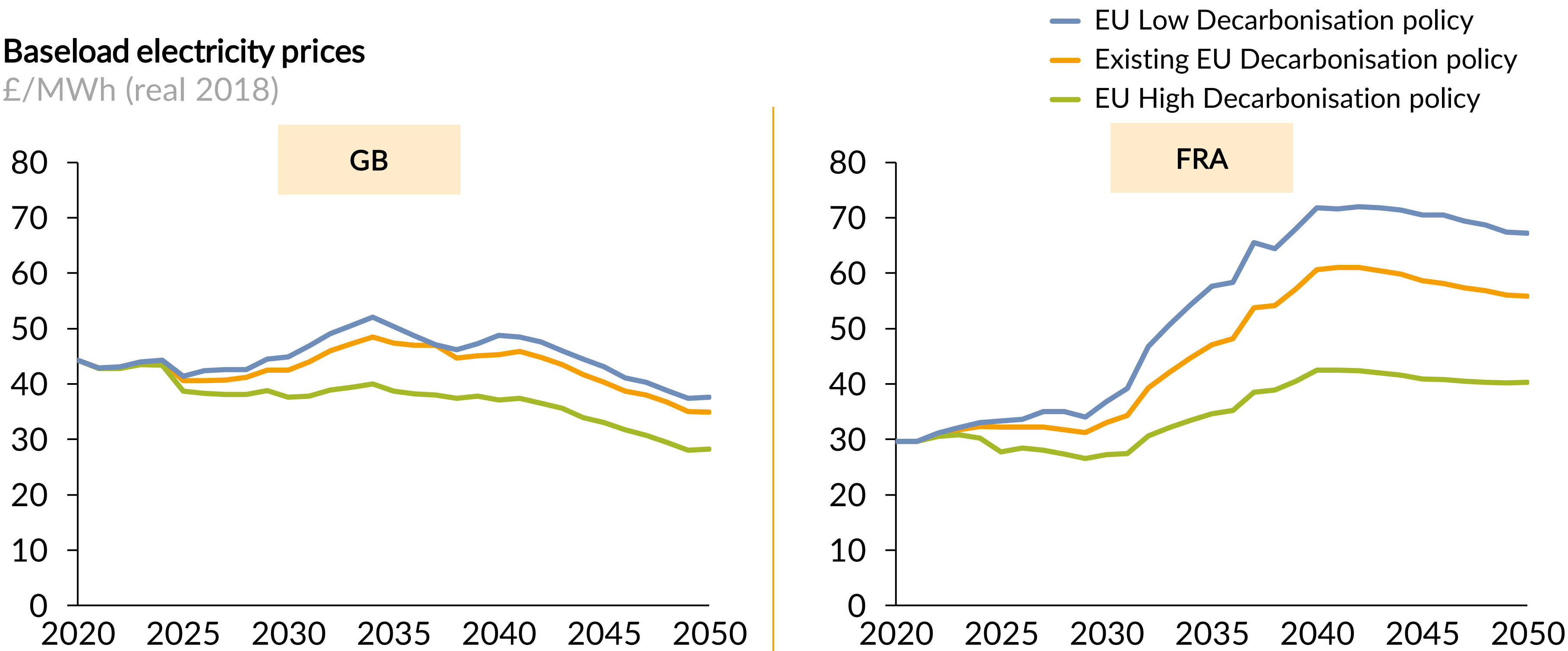


- In a Net Zero scenario in GB, an increase in interconnection level has a bigger impact on exports from GB to EU compared to a change in the EU decarbonisation policy
- Imports to GB from EU increase as EU becomes more decarbonised, while exports decrease irrespective of interconnection levels
- In a Net Zero scenario in GB, following from the existing policies in EU, exports from GB to EU increase 5.5 times to reach 83 TWh in 2050

Source: Aurora Energy Research

In a Net Zero GB scenario, baseload prices in FRA increase significantly, while in GB they decrease

Baseload electricity prices
£/MWh (real 2018)



- Baseload prices in France increase by 45% in 2050 as GB moves toward a Net Zero Policy with imports from GB to France increasing significantly
- In a Net Zero scenario in GB, prices decrease as EU becomes more decarbonised driven by the low price imports from the high renewable generation from EU
- Baseload price difference between France and GB explains the significant increase in exports to France reaching 33 TWh in 2050

Source: Aurora Energy Research

Higher EU decarbonisation leads to lower market costs driven by the wholesale market price reduction

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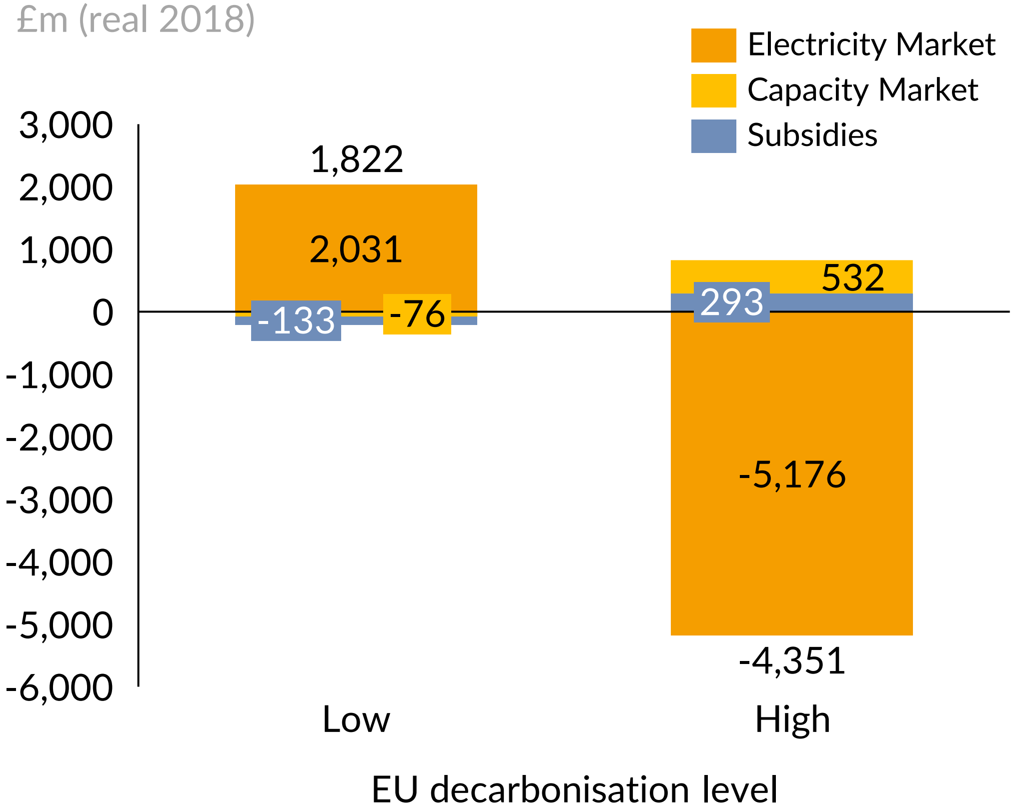
Change in power market costs for GB in 2050 (with respect to existing EU decarbonisation level)

£m (real 2018)



- The EM spend constitutes the biggest portion of the power market costs, regardless of GB decarbonisation policy
- In a Net Zero scenario in GB, total power costs are less compared to Known Policy scenario, as baseload prices drops from 30% to 40%
- Subsidies spending increases with EU decarbonisation ambition as RES generators' revenues from the wholesale market decrease, especially in a high decarbonised EU scenario
- Cumulative GB power market costs reduce with more stringent EU decarbonisation policy, with the cumulative cost reduction between 2020 and 2050 from Low to High scenarios 30% greater for GB Net Zero than for GB Known Policy scenarios
- Capacity Market spend increase as EU becomes more decarbonised due to the lower electricity revenues requiring generators to bid higher in the Capacity Market

1) Electricity Market (Wholesale) spending is the product of wholesale price and demand summed over all half hours of every year. 2) Capacity Market spending is the product of the capacity market prices and the procurement target (de-rated capacity). 3) Subsidy spending is calculated based on the amount of money required to make a renewable generator "break even" on an NPV basis if it participates in the wholesale market without any subsidies.

Source: Aurora Energy Research

Report key takeaways

- GB and the EU both have high decarbonisation ambitions towards Net Zero emissions, with GB having legislated this target by 2050
- The degree to which the EU decarbonisation level benefits GB depends on the level on interconnection between both regions, with more interconnection leading to less emissions
    - Increased interconnection capacity can help reduce renewable curtailment by helping spread excess renewable generation across interconnected countries
    - Better utilisation of RES and nuclear generation decreases carbon emissions in both GB and EU, as thermal generation decreases
- The impact of interconnection on baseload prices will depend on the relative levels of decarbonisation between GB and the EU:
    - with high interconnection capacity, ambitious decarbonisation policies in both GB and the EU reduce baseload price
    - with high interconnection capacity and lower decarbonisation ambitions in GB compared to the EU, baseload prices decrease as imports from France increase
- Total system costs decrease with more interconnections, up to a certain point

Source: Aurora Energy Research

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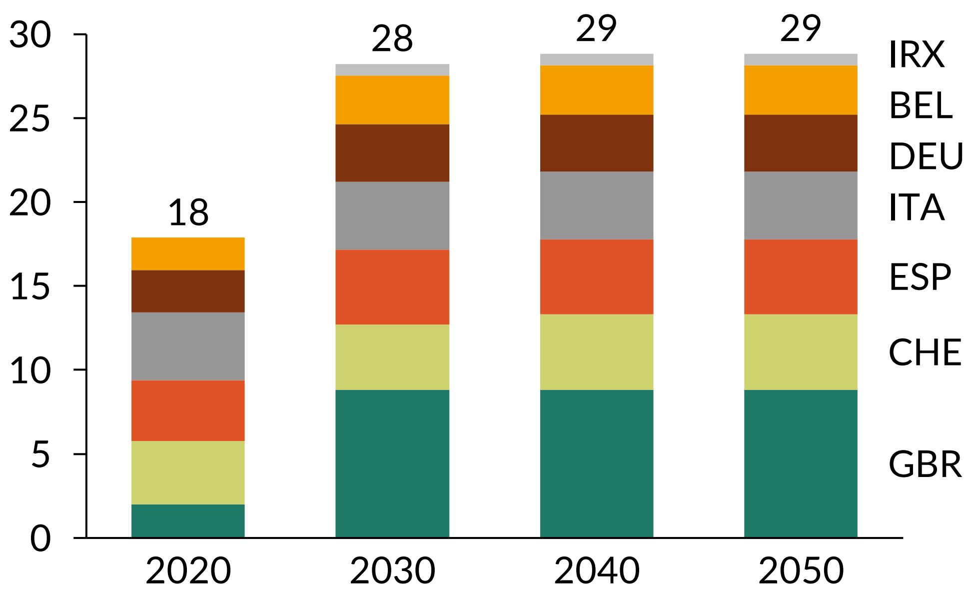
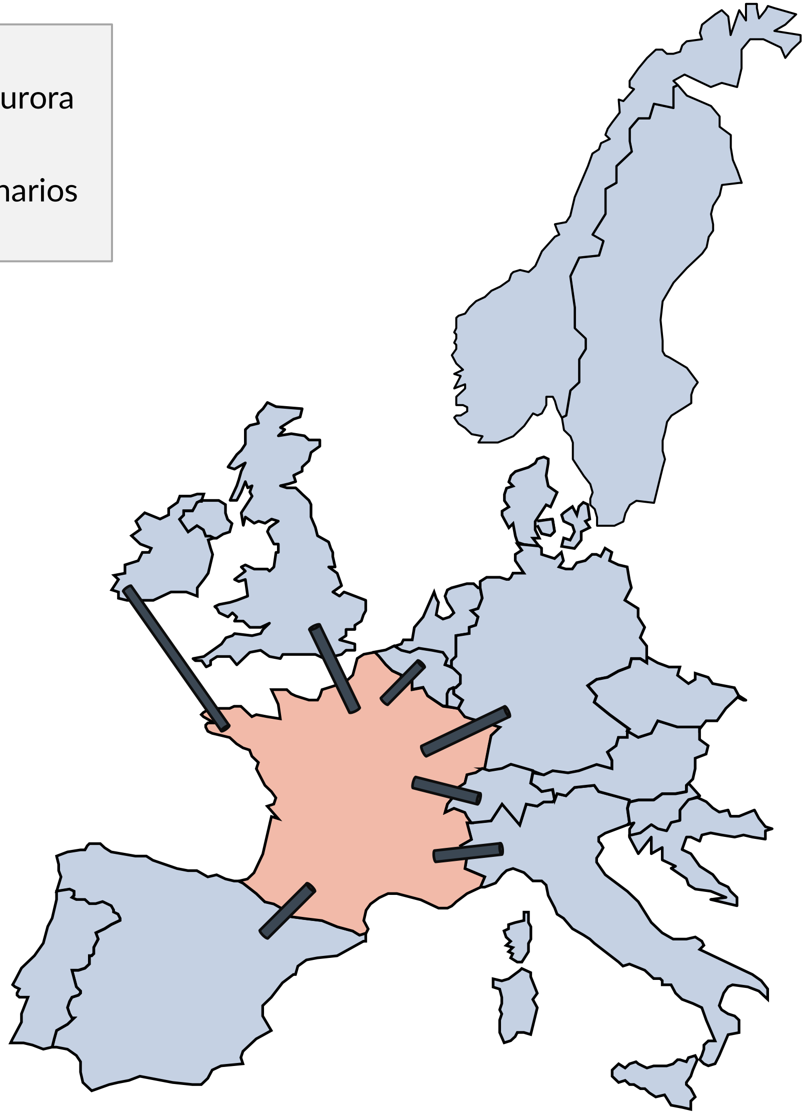
EU interconnection levels are treated exogenously

- EU interconnection levels are modelled as varying exogenously, per Aurora forecasts
- Interconnection levels therefore do not vary dynamically with GB scenarios

France interconnector capacities by country
GW

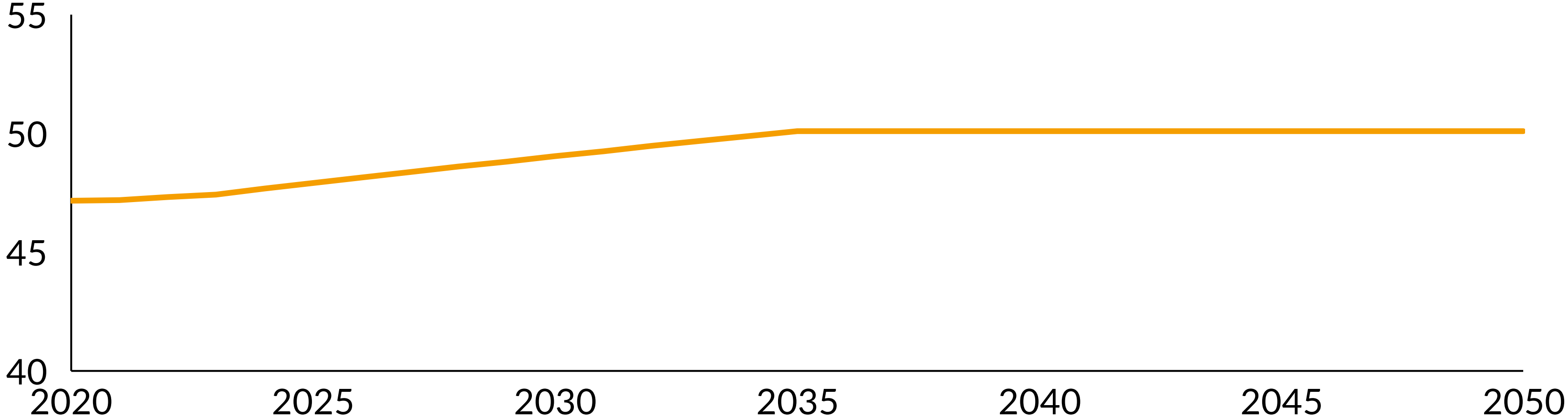




Coal and gas price assumptions

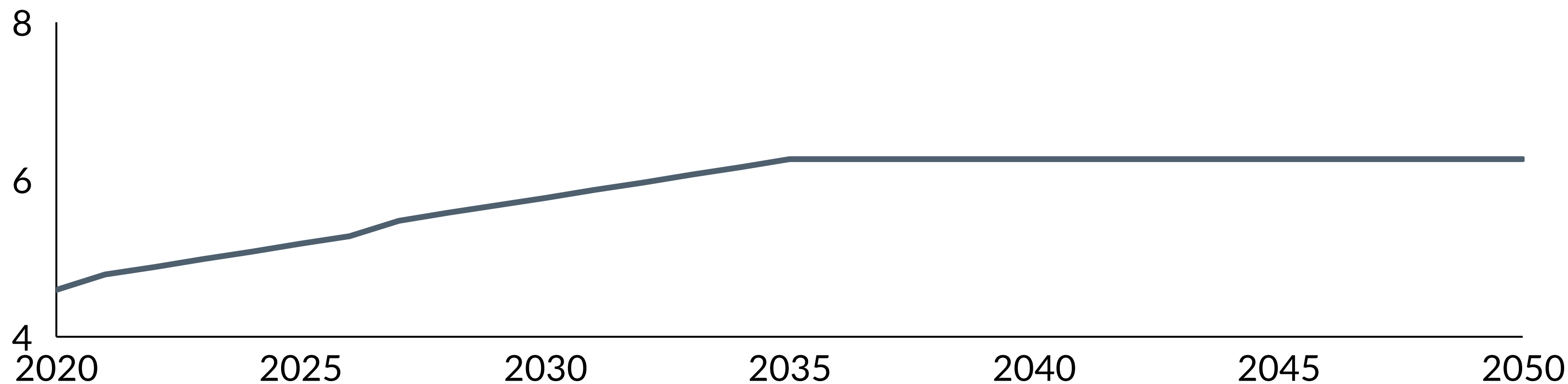
Coal prices for both GB policy scenarios

£2018/tonne



Gas prices for both GB policy scenarios

£2018/MMBtu

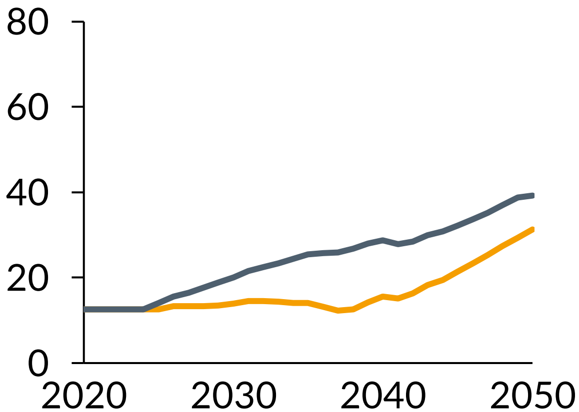


Source: Aurora Energy Research

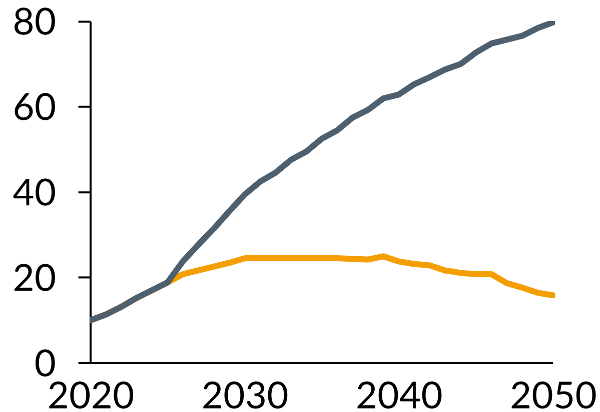
Renewables capacity timelines assumptions

Known Policy | Net Zero

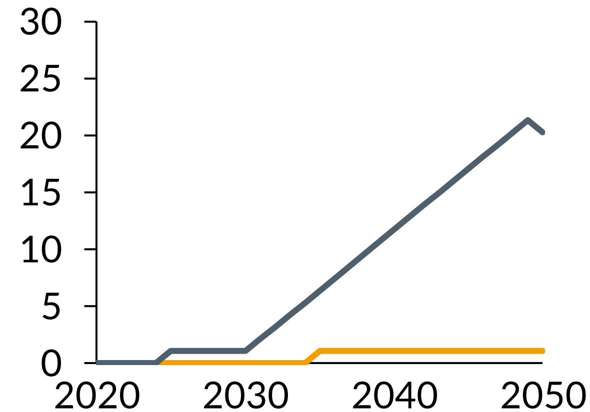
Onshore wind capacity
GW



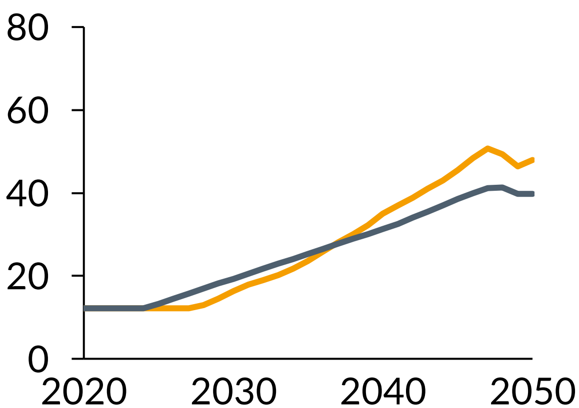
Offshore wind capacity
GW



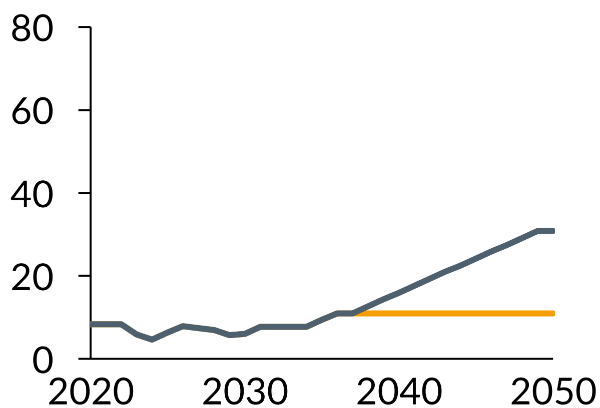
Gas CCS
GW



Solar PV capacity
GW



Nuclear capacity
GW



- The following graphs shows the difference in renewable capacities between the GB Known Policy and Net Zero Scenarios
- These capacity assumptions were fixed inputs into the model, while other technologies were not

Source: Aurora Energy Research

Additional assumptions

Input	Known Policy	Net Zero
Demand	Low electrification of heat and transport	High electrification of heat and transport
Capacity timeline	Capacities of low carbon technologies (RES, nuclear, and CCS) are fixed into the model, while other technologies (thermal and others) are allowed to build based on economic decisions	
CAPEX	BEIS medium range	BEIS medium range
OPEX (fixed and variable)	BEIS medium range	
Exchange rates	BEIS	
Capacity market target	Aurora's assumptions based on demand provided	
Demand profile	Aurora's granular profile based on half hourly data from a historical sample year	
EV types	Lower share of smart[1] EVs	Higher share of smart EVs

1) Aurora model three types of electric vehicles. The first is based on a fixed charging profile (similar to the power demand profile). The second is based on a fixed charging profile which has less peaks and is smoother (simulates non-peak charging i.e. Overnight). The third type is based on a dynamic charging profile which is solved by the model The last two types of EVs belong to the smart categories.

Source: Aurora Energy Research

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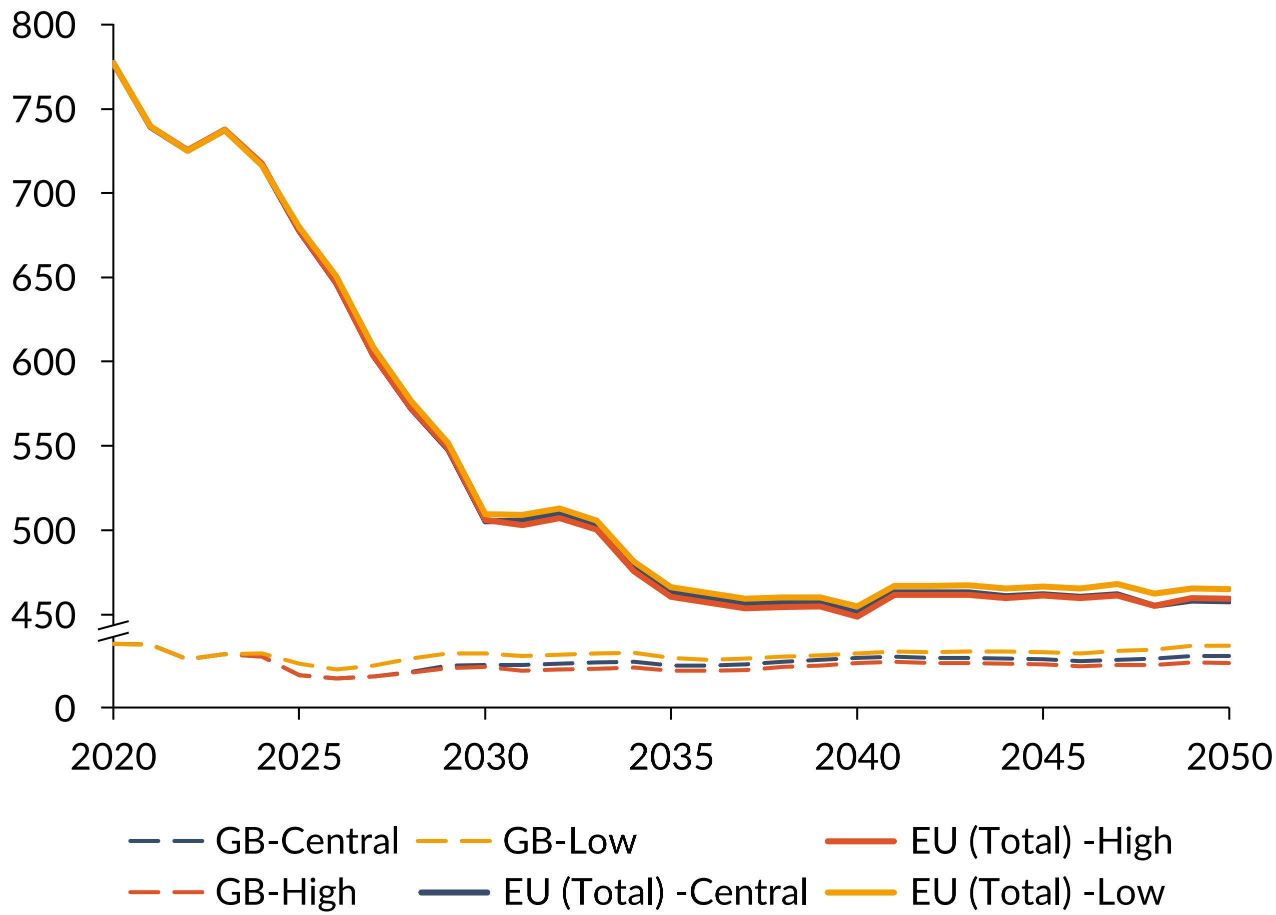
Higher interconnection leads to a faster reduction of CO2 emissions in GB

CO2 emissions GB and EU total

MtCO2e

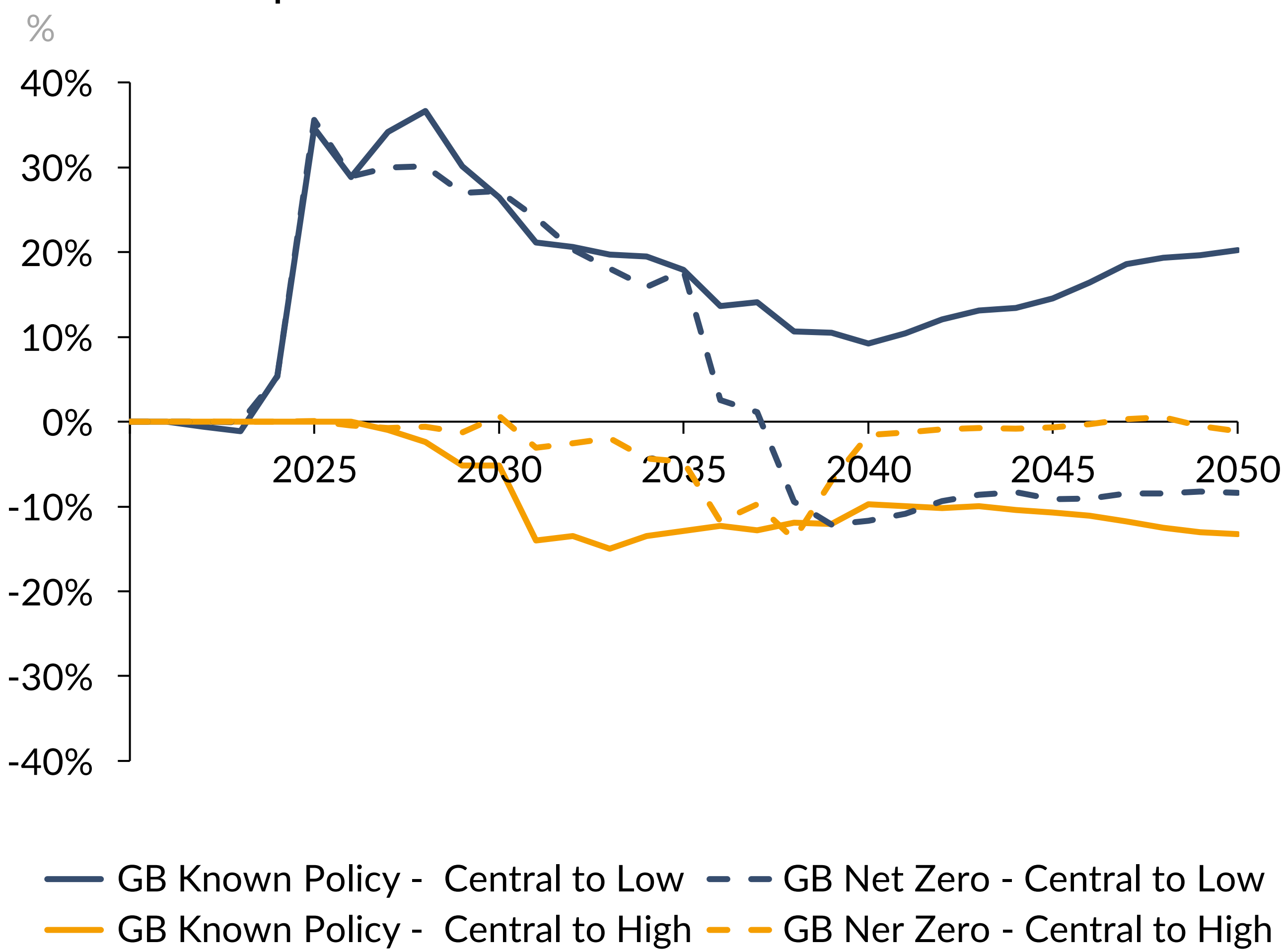


- GB emissions decrease with more interconnection level as imports to GB from EU increase
- EU emissions decrease with more interconnection since the countries with lower power prices export more to countries with higher prices
- Low carbon generation sources (nuclear, wind, solar) have lower marginal costs compared to thermal plants leading to lower baseload prices

Source: Aurora Energy Research

Under central EU policy, GB emissions vary by interconnection level and do not follow a consistent trajectory over time

CO2 emissions percent difference between interconnection scenarios

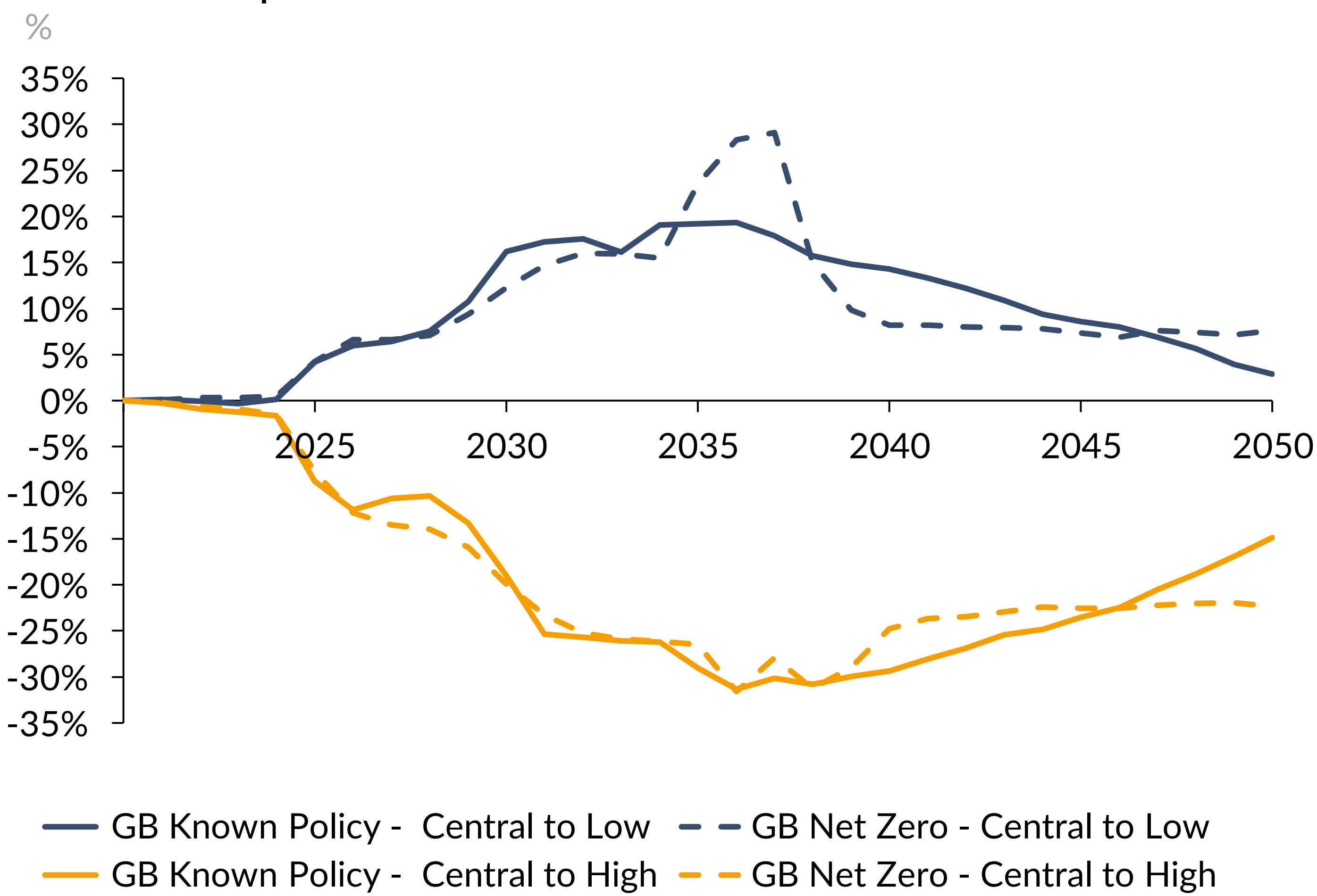


- Central to Low % difference follows a very different pattern when GB is under Known Policy scenario and when it is under the Net Zero scenario
- Central to low variation is largest during the 2020s and changes direction after 2038 in the GB Net Zero scenario
- This shows that, for both GB Known Policy and Net Zero, most of the benefits in terms of emissions are earlier on. This suggests there is more benefit to more interconnection in the short- to medium-term compared to the long-term

Source: Aurora Energy Research

Under central interconnection levels, the % difference in emissions between EU decarbonisation scenarios is largest in the 2030s

CO2 emissions percent difference between EU decarbonisation scenarios



- When EU decarbonisation is changed, the trajectories of CO_2 emissions are consistent in both GB Known Policy and GB Net Zero scenarios
- The largest CO_2 emissions difference between scenarios peaks in the 2030s and minimises towards 2050

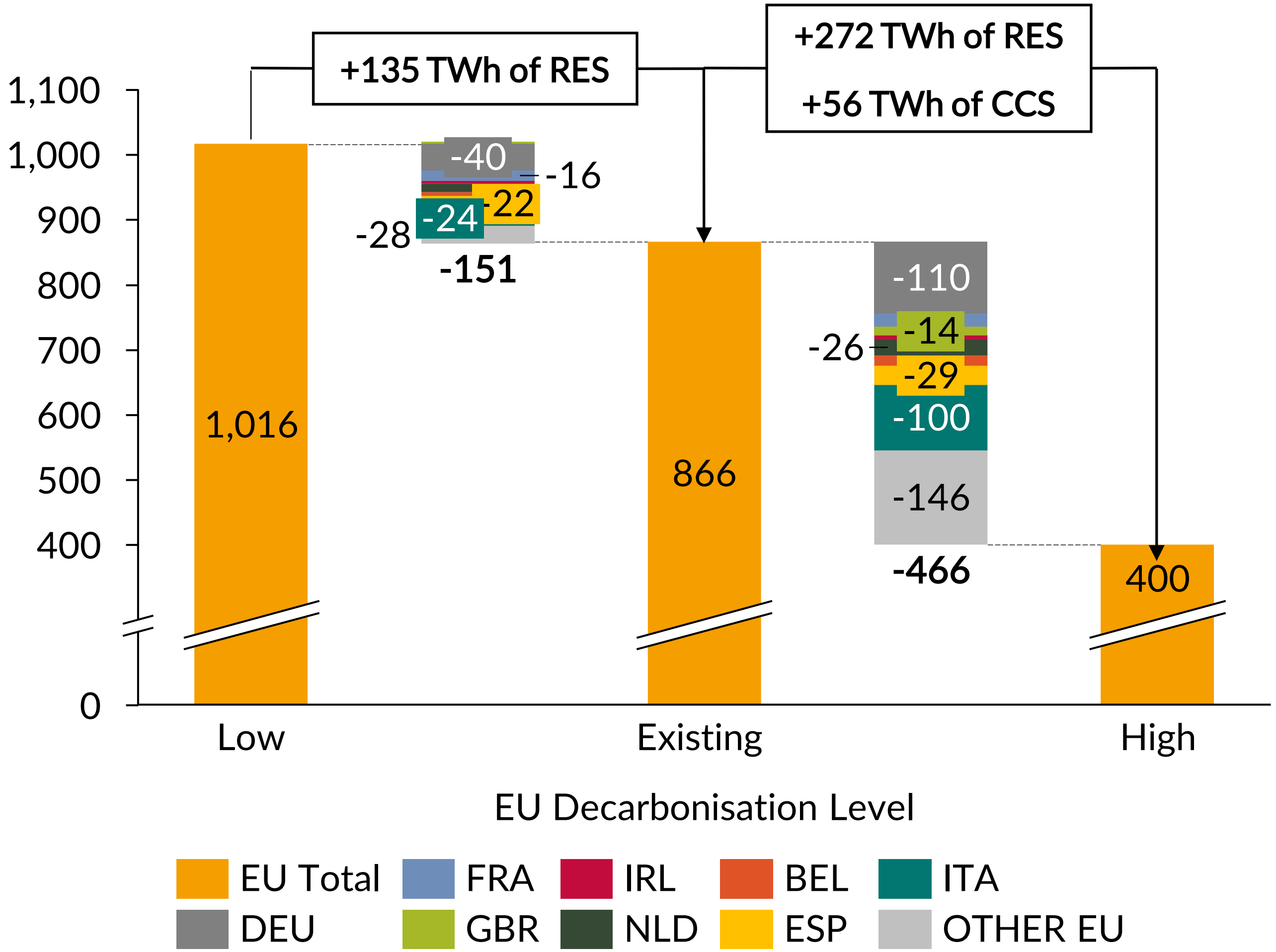
Source: Aurora Energy Research

Contents

Thermal generation in EU varies significantly depending on EU's decarbonisation ambition

Thermal generation[1] in EU by EU decarbonisation ambition in 2050

TWh



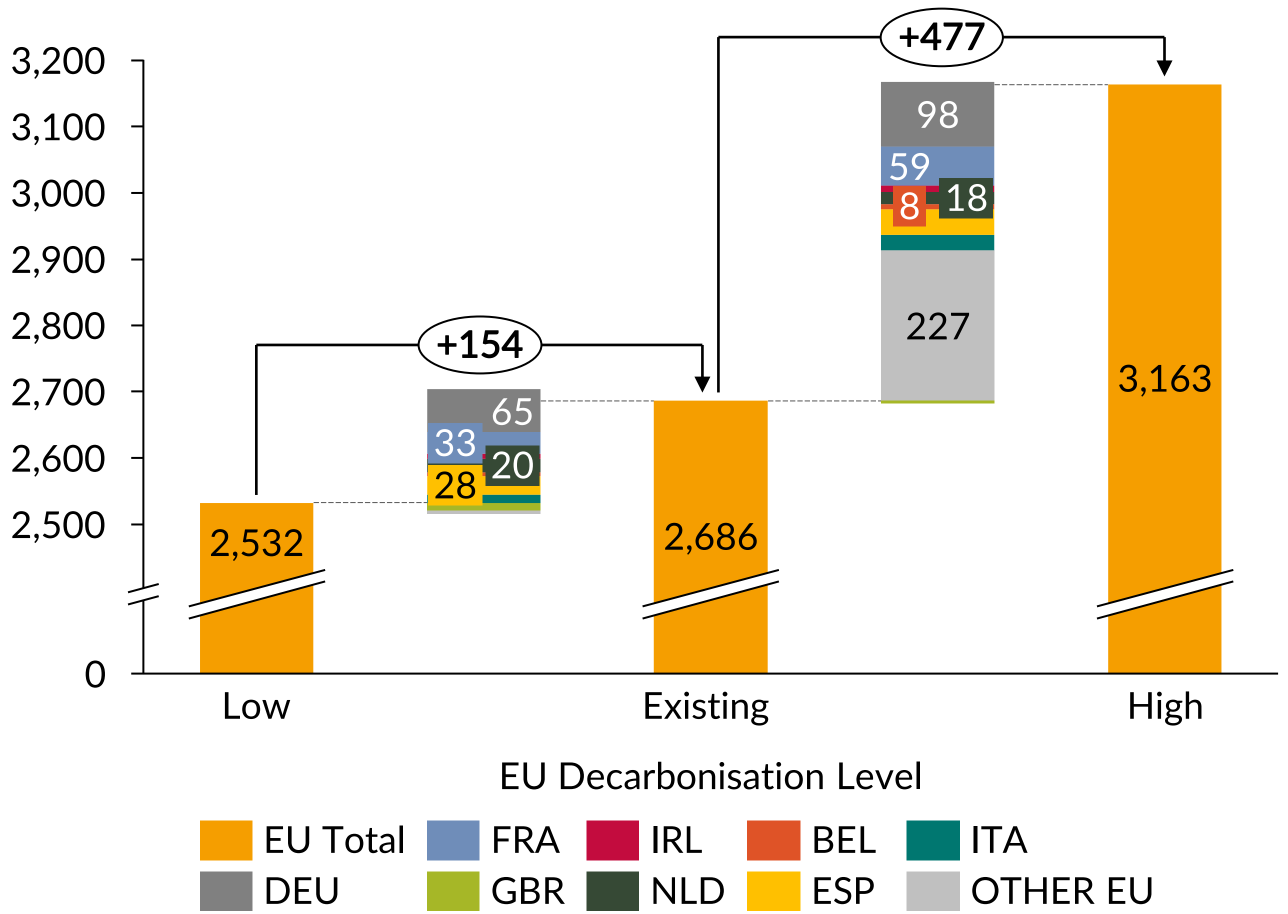
- The high decarbonisation scenario in Rest-of-EU does not reflect the net-zero scenario the associated countries and rather a change in renewable capacities[2]
- EU thermal generation reduces by over 50% in the high decarbonisation scenario compared to the central scenario with RES and CCS displacing over 450TWh of generation
- The largest gains are from carbon intensive regions such as Germany and Italy

1) Thermal generation include CCGT, Coal, CHP, Gas Peakers. 2) refer to page 25

Low carbon generation fills the gaps from the reduction of thermal generation in the different scenarios

Low carbon generation[1] in EU by EU decarbonisation ambition in 2050

TWh



- RES and CCS drive the uptake of low-carbon generation between scenarios
- The amount of RES and CCS deployed in EU was proportionally increased based on each country's system size and capacity mix
- The increase of low carbon generation together with the decrease of thermal generation, drop emissions in EU by c.45% from the central to the high decarbonisation ambition

1) Low carbon generation includes nuclear, CCS, wind, solar, biomass and hydro.

Source: Aurora Energy Research

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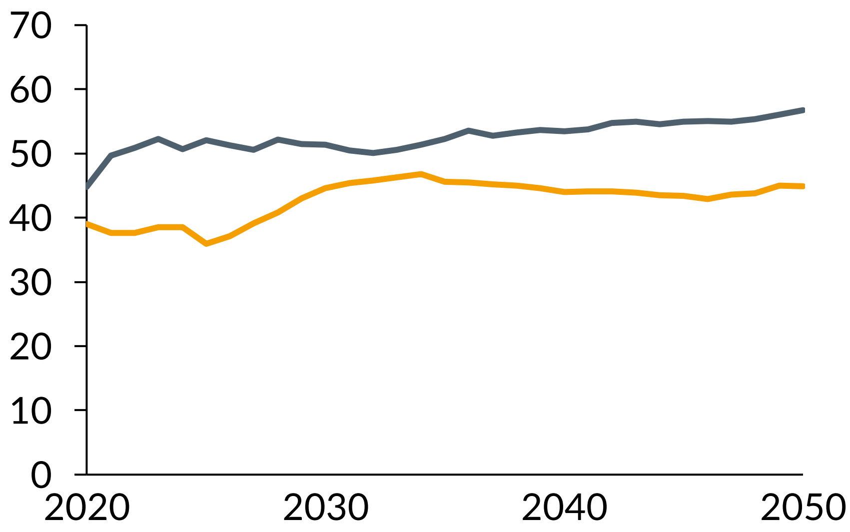
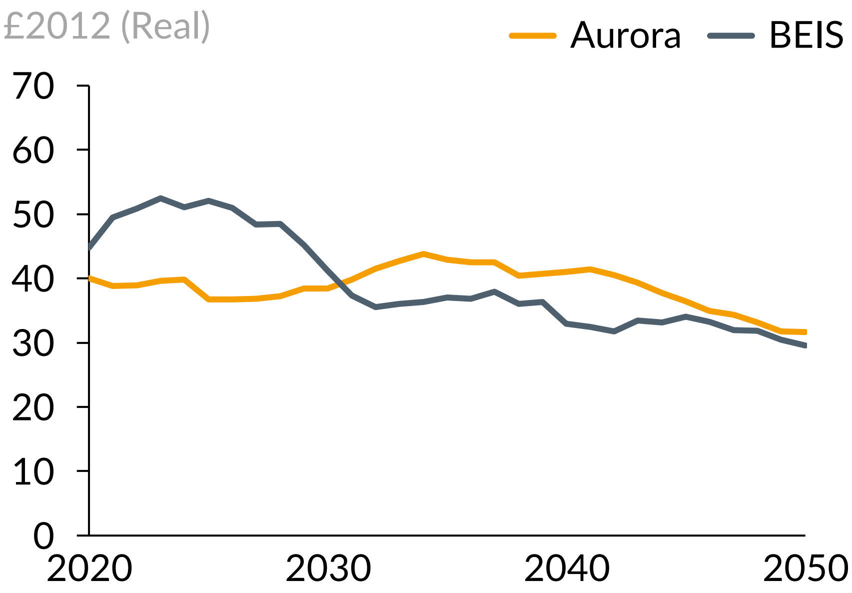
Baseload prices – Aurora versus BEIS model outputs

- The difference between Aurora and BEIS model outputs could be due to the following changes:
  - CAPEX and OPEX applied to Aurora's model takes the medium case from BEIS model
  - CM target taken by Aurora is higher than that of BEIS
  - Demand profile (for power, heat pumps and EVs) used by Aurora is more granular
  - WM and CM dispatch decision varies between different models; Aurora's model is based on a detailed economic modelling and iterations of each market
  - Plant specific operating parameters; Aurora models each plant on a granular level

GB Known Policy
£2012 (Real)



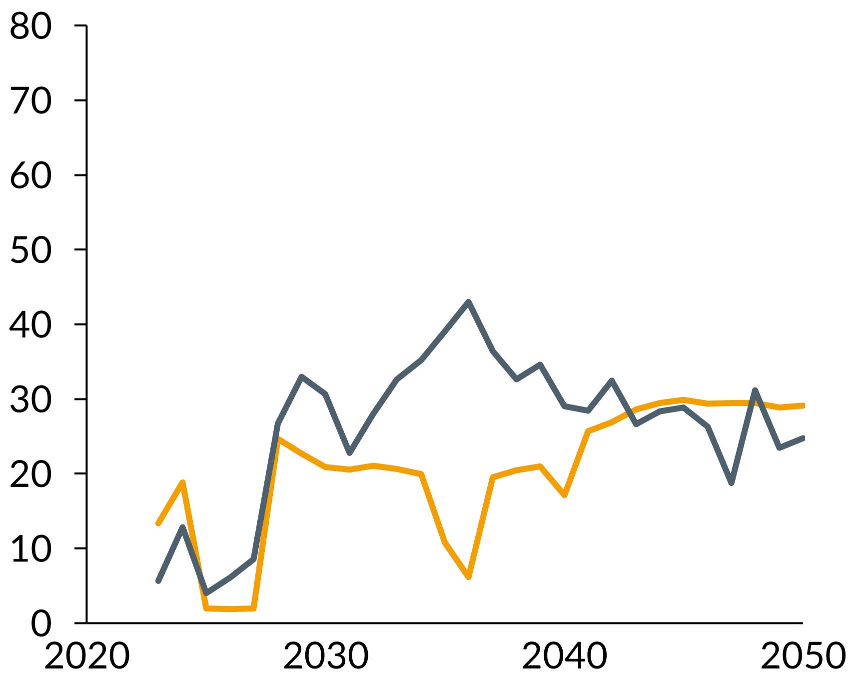
GB Net Zero
£2012 (Real)



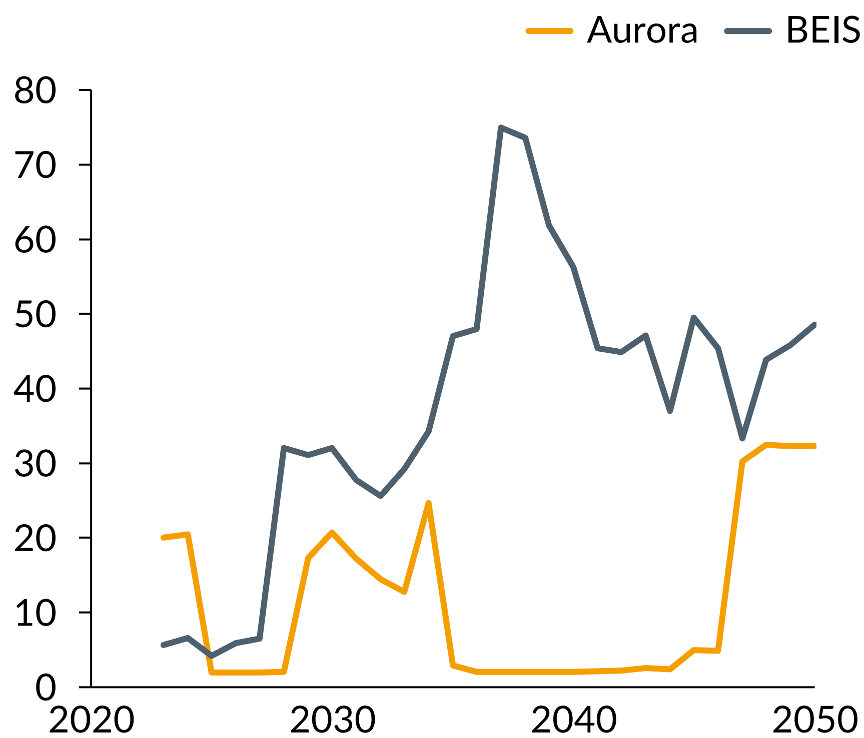
Source: Aurora Energy Research

Capacity market T-4 prices – Aurora versus BEIS model outputs

GB Known Policy
£2012 (Real)

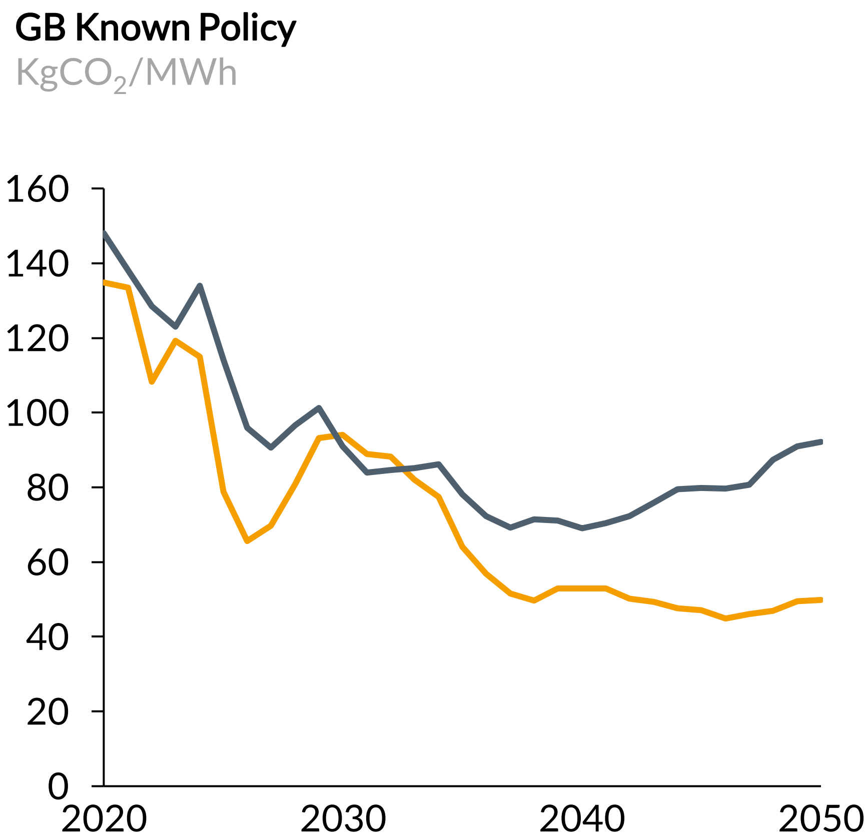


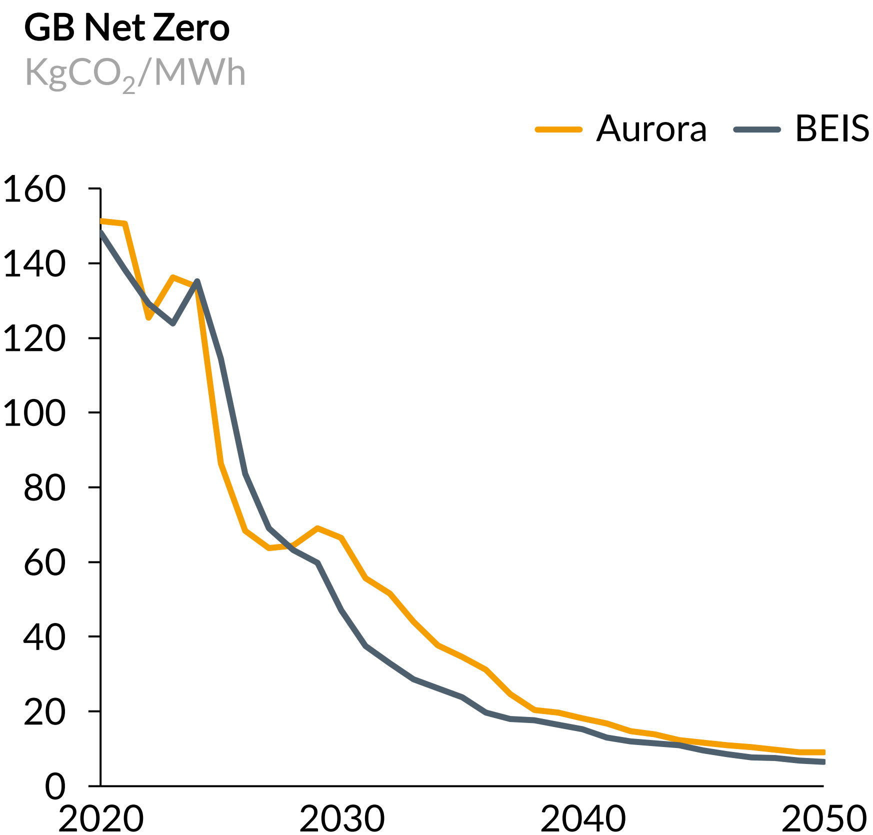
GB Net Zero
£2012 (Real)



Source: Aurora Energy Research

Carbon intensity – Aurora versus BEIS model outputs





Source: Aurora Energy Research

Capacity mix, BEIS model outputs minus Aurora model outputs in GB Known Policy scenario

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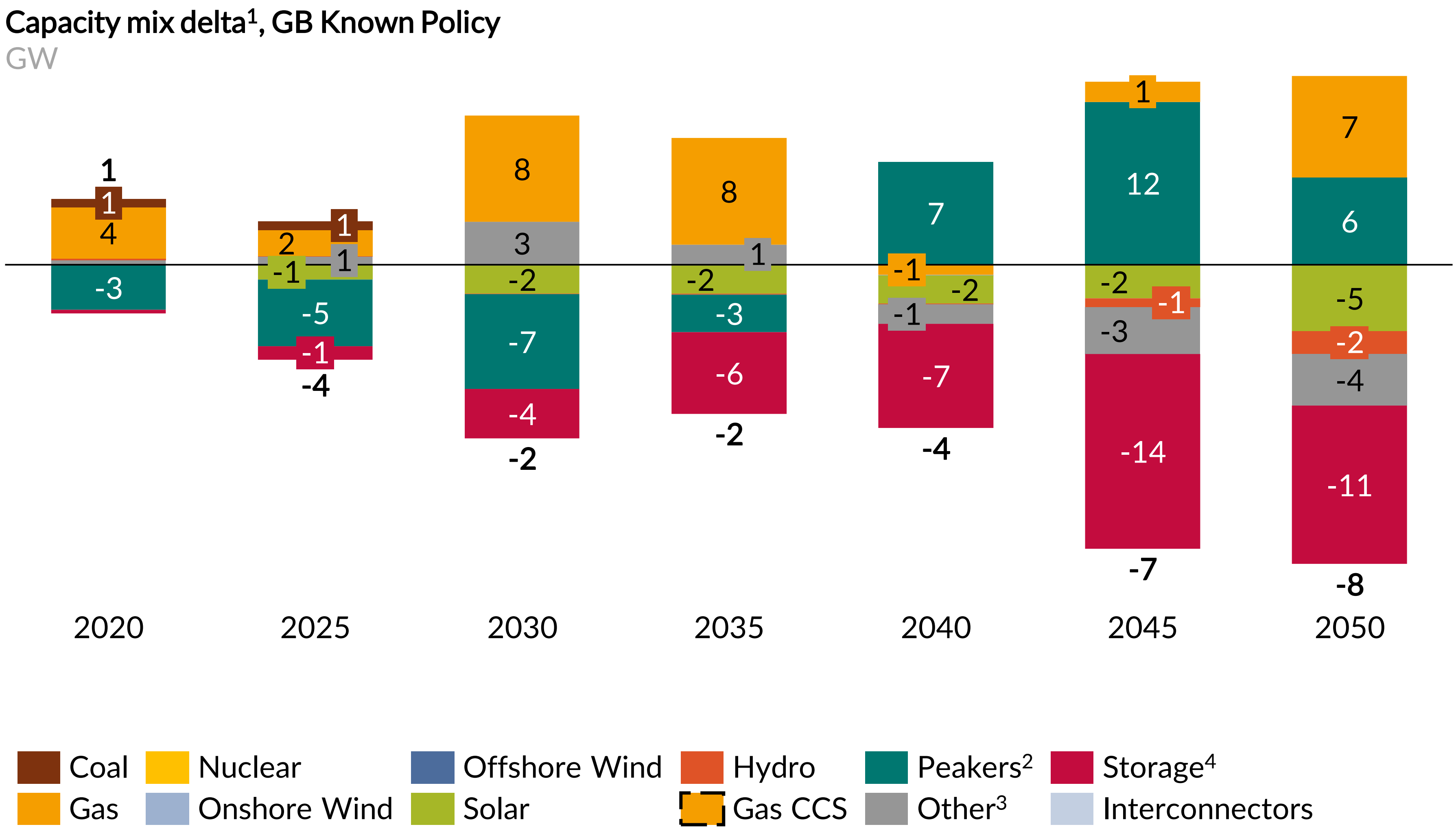

1) Positive delta indicates higher values in BEIS model outputs. 2) Peakers include OCGT, recips, oil peakers and DSR. 3) Other includes biomass and micro CHP. 4) Storage includes pumped storage and battery storage.

Source: Aurora Energy Research

Capacity mix, BEIS model outputs minus Aurora model outputs in GB Net Zero scenario

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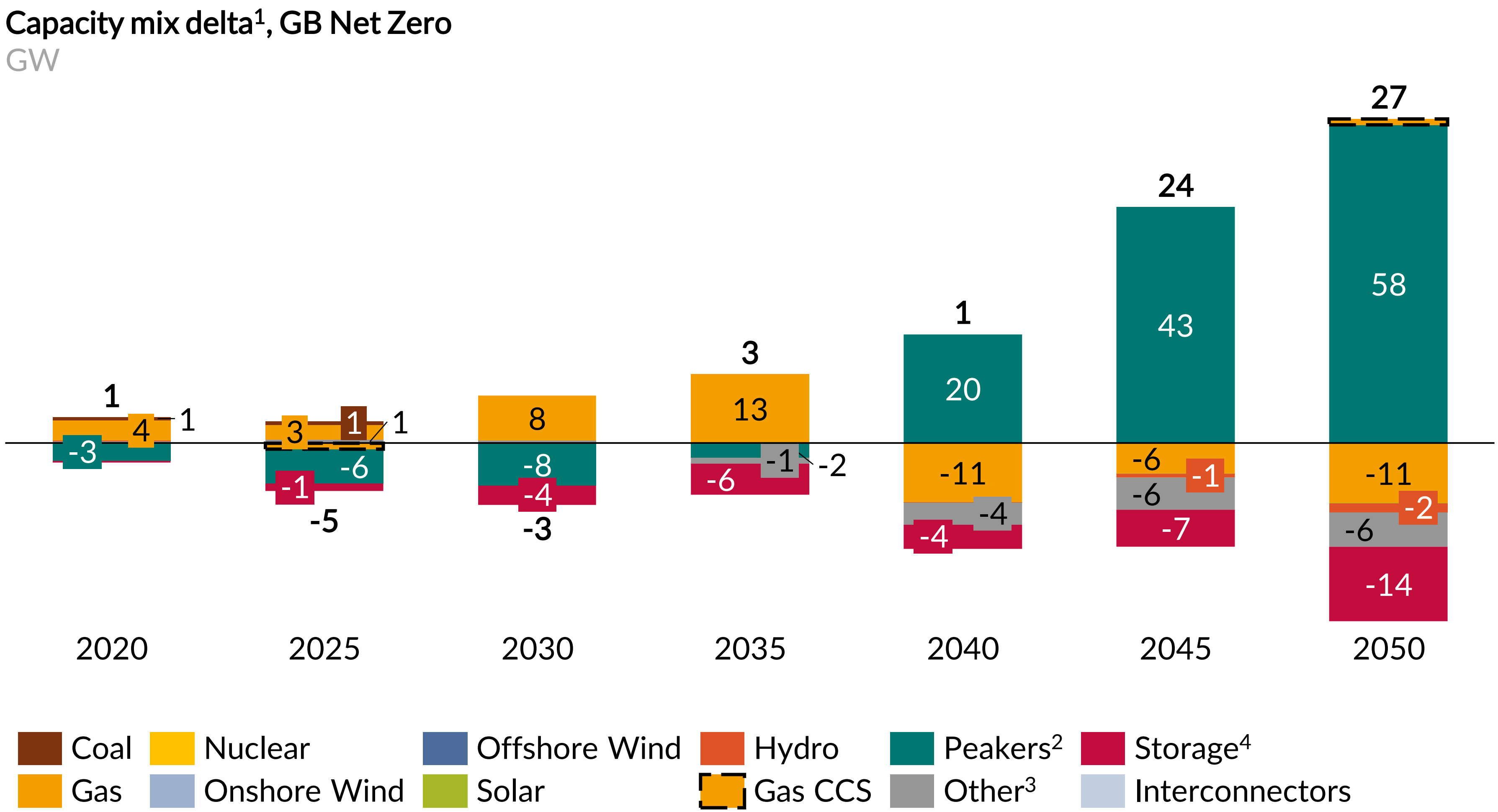

1) Positive delta indicates higher values in BEIS model outputs. 2) Peakers include OCGT, recips, oil peakers and DSR. 3) Other includes biomass and micro CHP. 4) Storage includes pumped storage and battery storage.

Source: Aurora Energy Research

Generation mix, BEIS model outputs minus Aurora model outputs in GB Known Policy scenario

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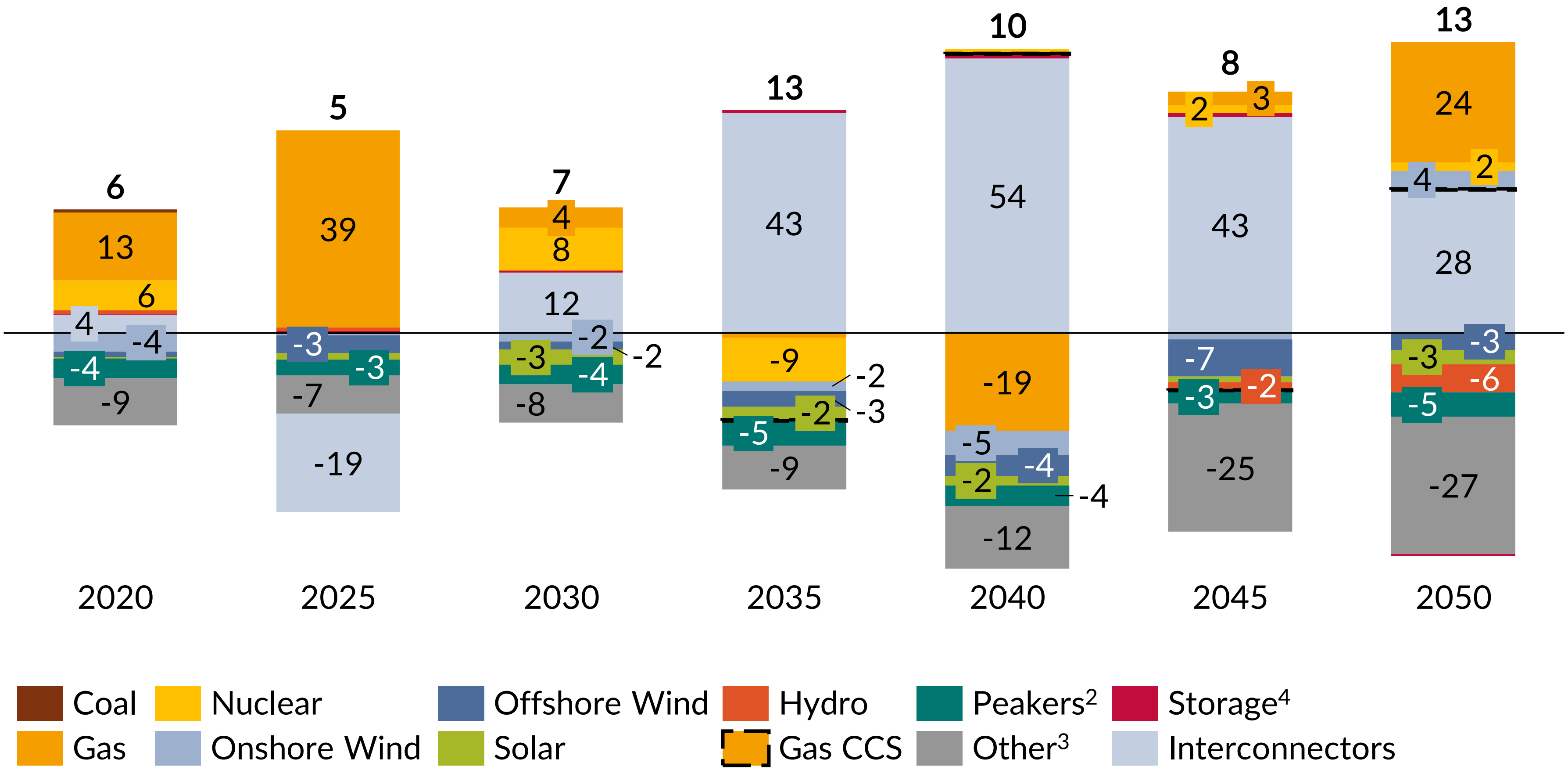
Generation mix delta[1], GB Known Policy

TWh



1) Total deltas are not equal to zero due to a difference in the input demand provided by BEIS and outputs (generation plus net imports) from BEIS model. 2) Peakers include OCGT, recips, oil peakers and DSR. 3) Other includes biomass and micro CHP. 4) Storage includes pumped storage and battery storage.

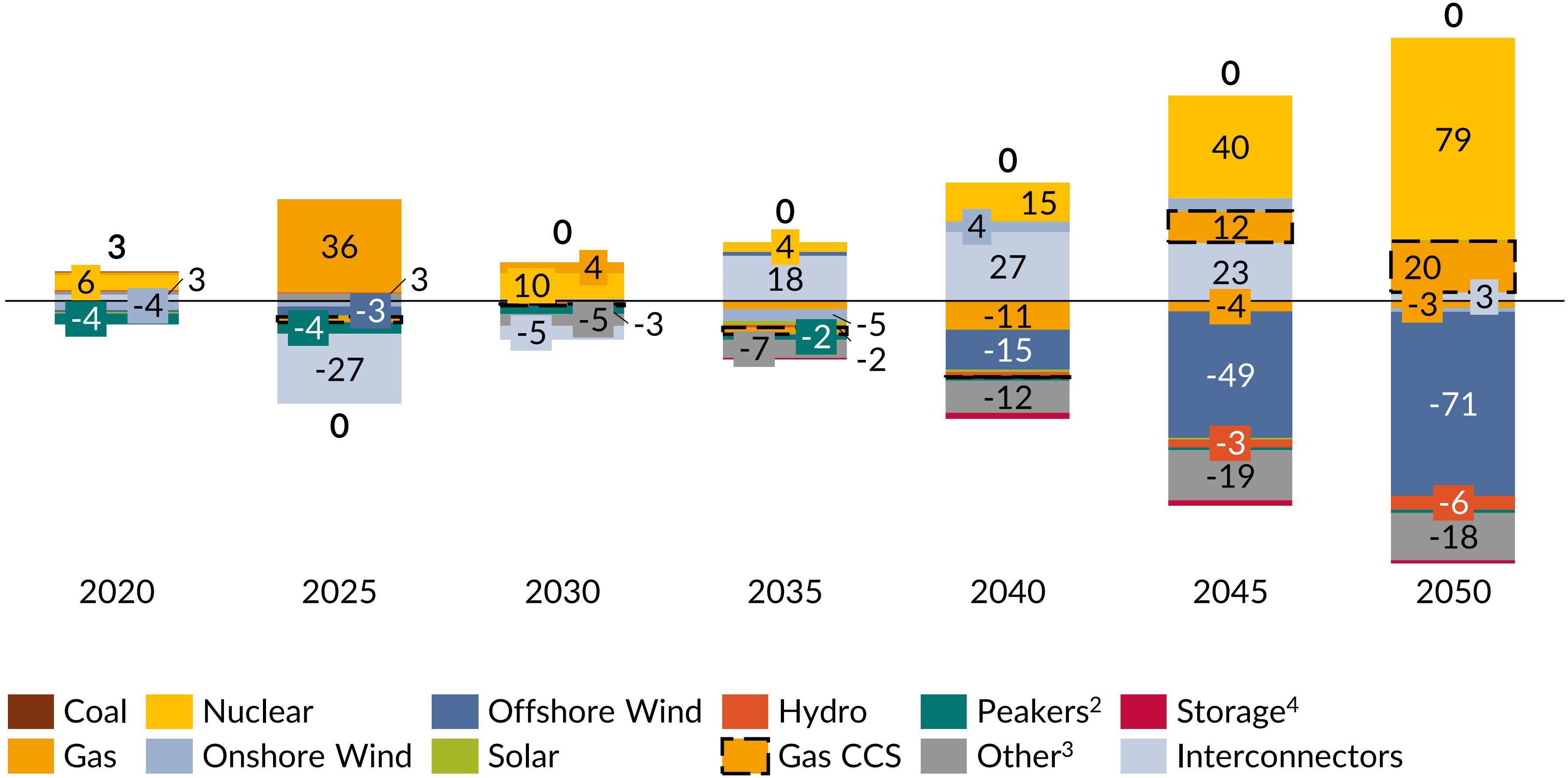
Source: Aurora Energy Research

Generation mix, BEIS model outputs minus Aurora model outputs in GB Net Zero scenario

AURORA ENERGY RESEARCH

Generation mix delta[1], GB Net Zero

TWh



1) Positive delta indicates higher values in BEIS model outputs. 2) Peakers include OCGT, recips, oil peakers and DSR. 3) Other includes biomass and micro CHP. 4) Storage includes pumped storage and battery storage.

Source: Aurora Energy Research

Report details and disclaimer

Publication	Date	Prepared by	Approved by
The impact of interconnectors on decarbonisation	02/10/2020	Ayoub AbiRafeh (ayoub.abirafeh@auroraer.com) Panos Kefalas (panos.kefalas@auroraer.com) Modeller: Luke Robins	Felix Chow-Kambitsch (felix.chow@auroraer.com)

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