The impact of tidal lagoons on the GB power market

Aurora Energy Research

22 September 2016

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Executive summary

Aurora's analysis finds that if 25GW of tidal were to enter the system by 2030,

- Tidal would provide more than 10% of GB's total power generation, enough to power 9 million households[1] in the UK
- CO_2 emission could be reduced by 36% in 2035, amounting to a total CO_2 savings of 130MT in the GB power system from 2020-2040
- This would cost the system an additional £0.7billion/year, translating to a £8-9 increase in annual household electricity bills

If Hinkley C and subsequent nuclear projects were cancelled,

- Replacing nuclear with tidal would be cheaper than replacing nuclear with wind in terms of average cost of CO_2 reduction, by around £11/tonne
- Replacing nuclear with tidal would also cost the system an additional £1.7billion, compared to replacing Hinkley with CCGT
- However, tidal would provide the system with 19MT of CO_2 savings per year, allowing UK to meet its carbon target

Our analysis also finds that tidal imposes less indirect costs on the system, compared to wind;

- 25GW of tidal could save the system up to £270million in balancing market spending, compared to adding 15GW of wind on the system
- Average intermittency costs from 2025-2040 is also lower for tidal at £14/MWh, compared to that of wind at £17.5/MWh

Most of tidal's intermittency cost is driven by the need for back-up capacity. Given the predictable nature of the back-up required, these costs could potentially be reduced through direct contracting with dispatchable capacity or other bespoke mechanisms.

1 Assuming average household consumes 4MWh of power a year

Source: Aurora Energy Research

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We ran four scenarios to examine the potential impact of tidal lagoons on the GB energy market

Scenario	Description
Base case	Aurora's base case forecast (with Hinkley C) No tidal to enter
Swansea only	0.3GW of tidal to enter in 2020
Swansea & Cardiff	3.6GW of tidal by 2027
All lagoons	25.3GW of tidal by 2030

Source: Aurora Energy Research

The entry of tidal results in less CCGT and peaking plants entering the market, but more batteries

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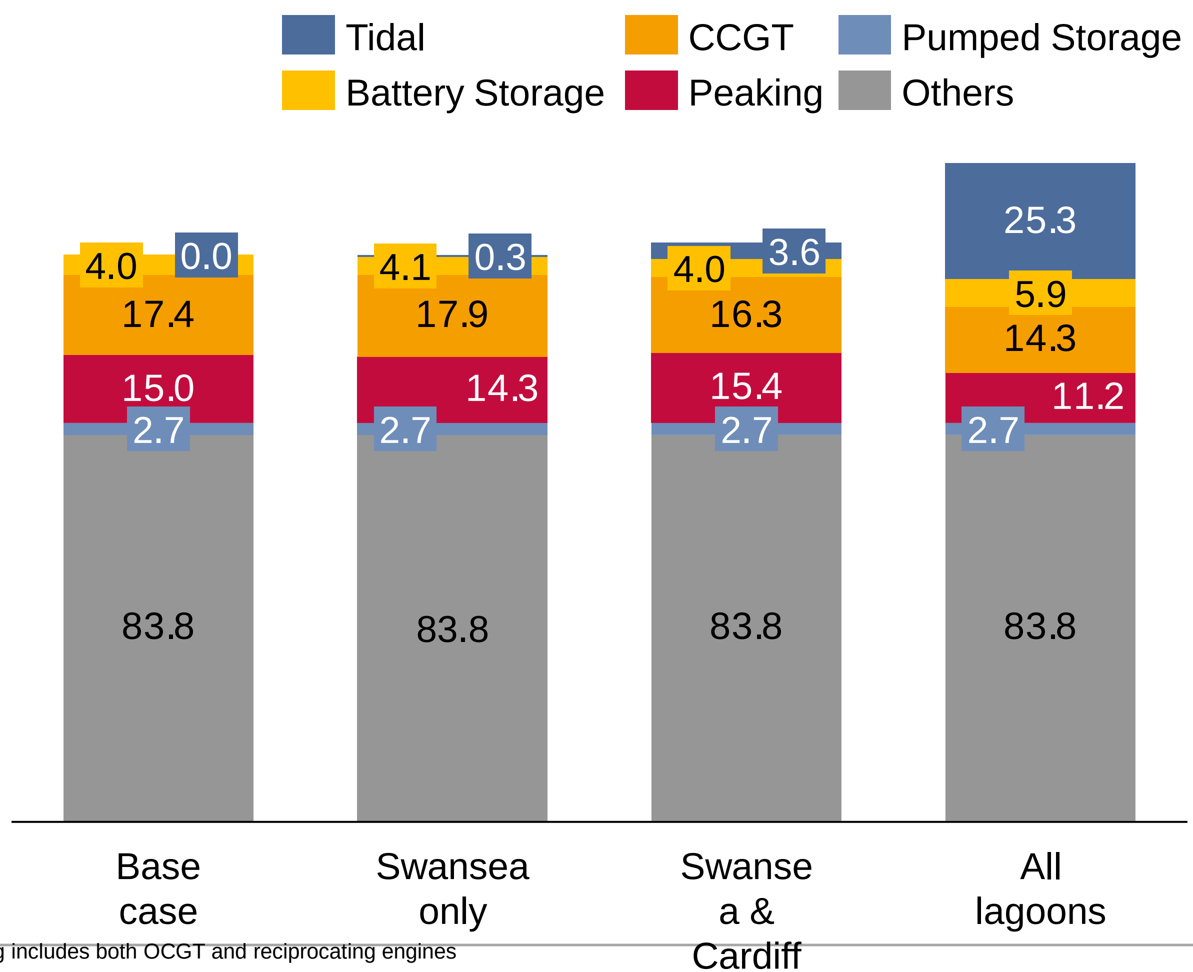
Installed capacity in 2035, GW



- Tidal provides reliable and predictable generation which competes with CCGT for baseload generation, driving down CCGT entry
- More batteries also enter to take advantage of tidal's intraday production pattern
- This results in less peakers entering as batteries provide cheap flexible capacity

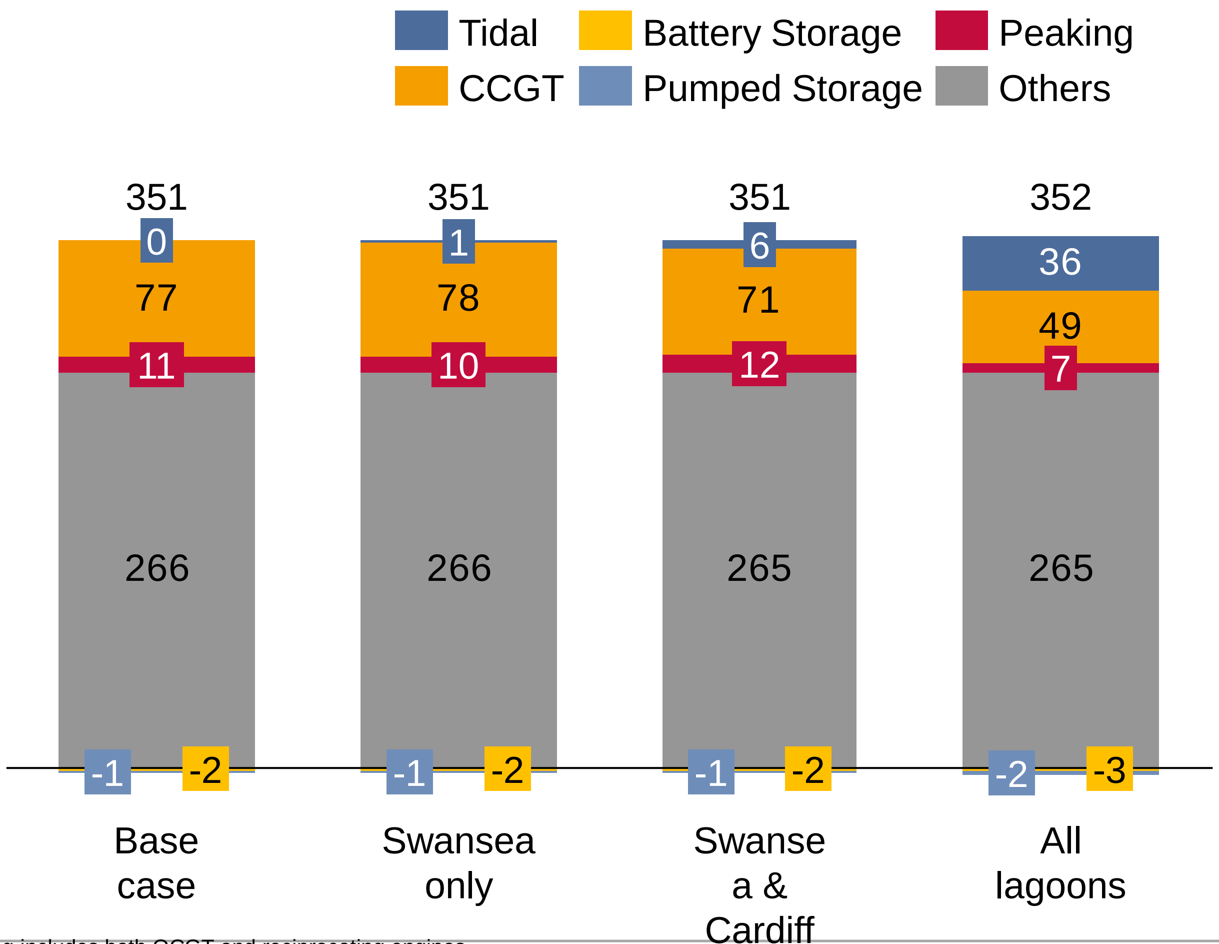
1 Peaking includes both OCGT and reciprocating engines

2 Others include all renewables (biomass, solar, onshore & offshore wind, hydro and marine), nuclear and interconnector

Source: Aurora Energy Research

Tidal also provides significant amount of baseload generation, reducing the need for CCGT

Power generation in 2035, TWh



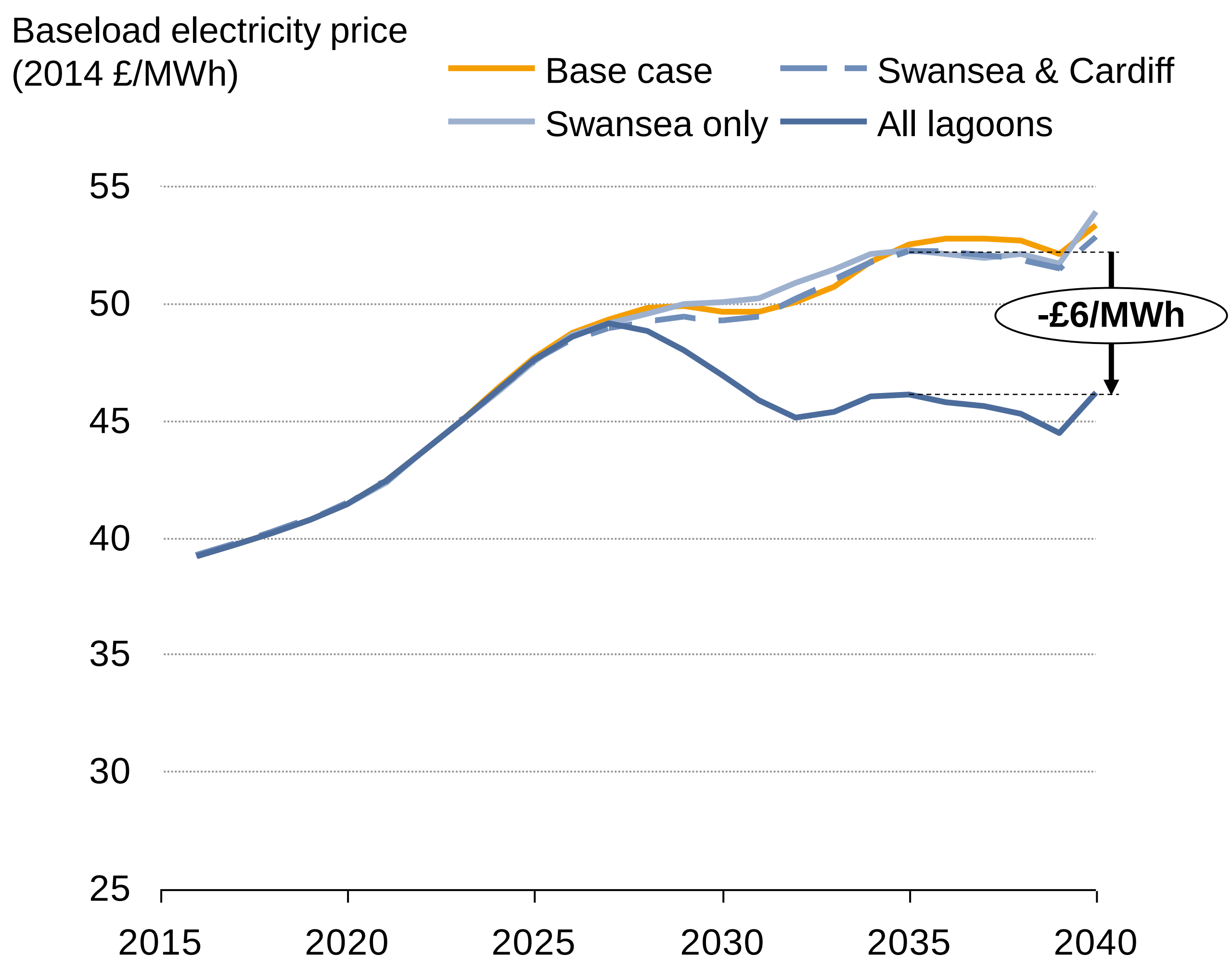
- By 2035, 25GW of tidal provides more than 10% of total power generation
- Power generation from CCGT reduces by 35% from the base case as less CCGT enters and existing CCGTs run fewer hours

1 Peaking includes both OCGT and reciprocating engines

2 Others include all renewables (biomass, solar, onshore & offshore wind, hydro and marine), nuclear and interconnector

Source: Aurora Energy Research

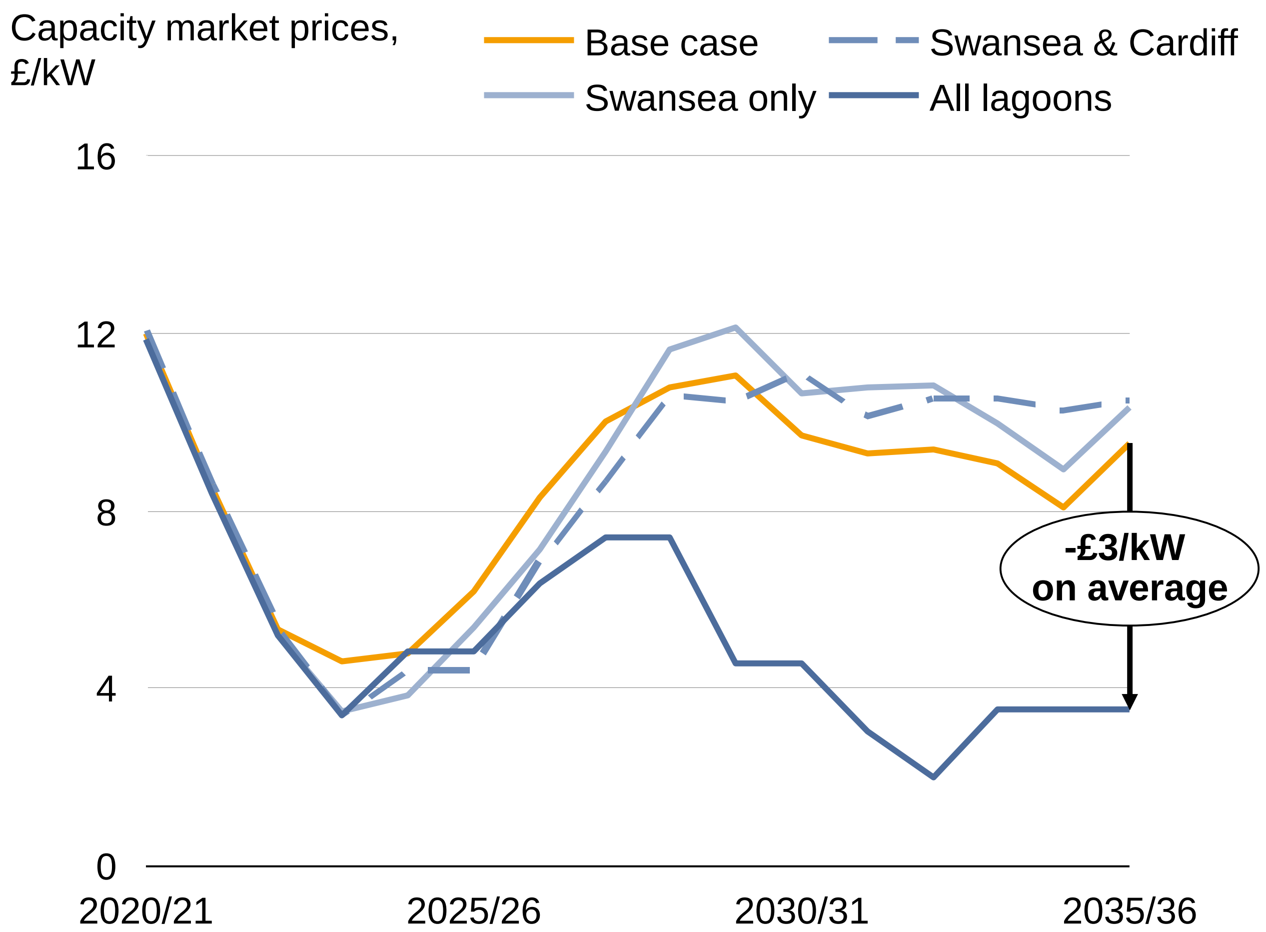
Tidal reduces wholesale prices in the 2030s



- With all lagoons in place by 2030, baseload electricity price is reduced significantly. This is because tidal
  - pushes more expensive plant out of merit
  - sets the price in some periods; tidal sets the price 4% of the time in 2030

Source: Aurora Energy Research

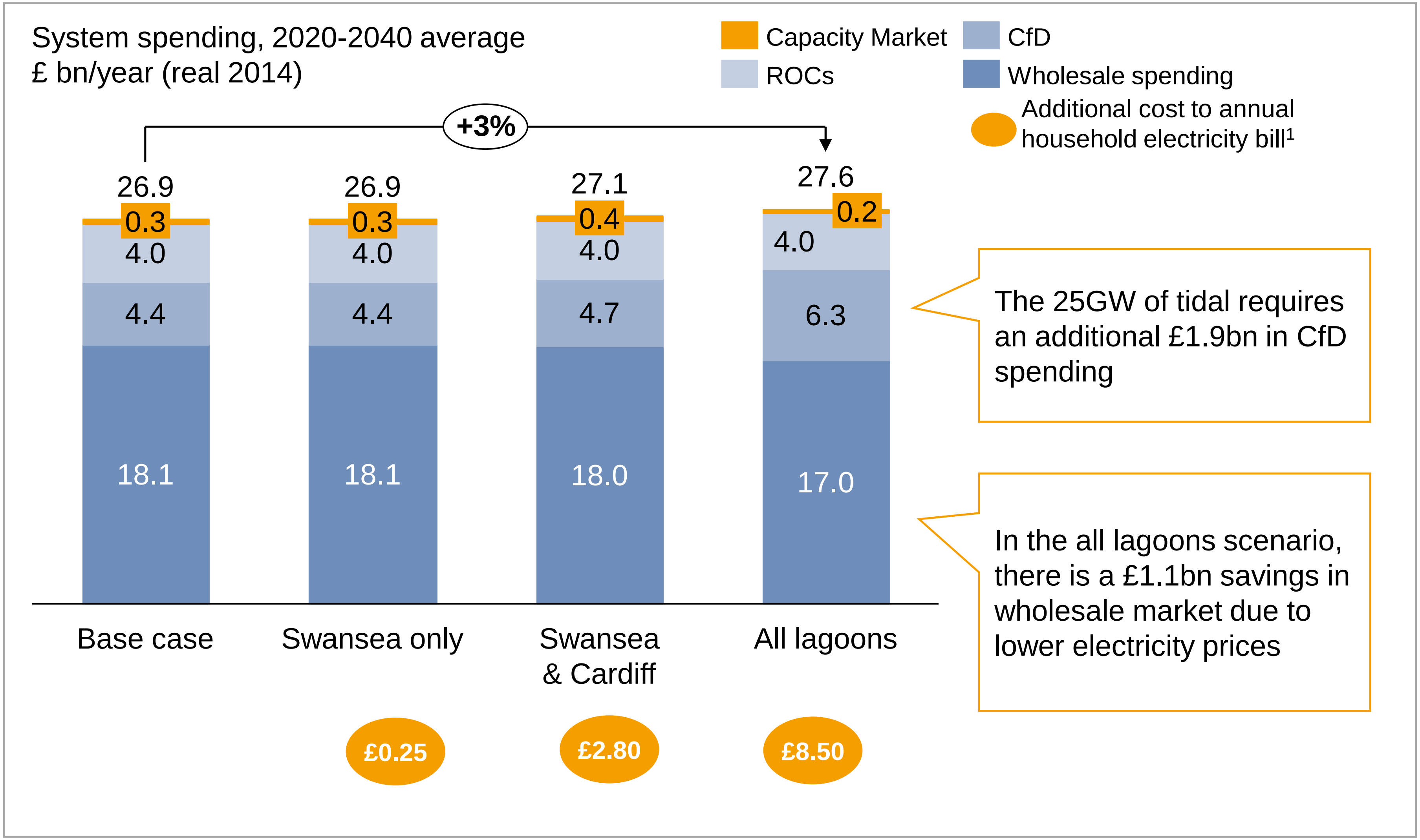
The capacity market could cost £150m/year less on average, with CM prices £3/kW lower



- Tidal provides significant amount of baseload generation
- This reduces the need to procure additional CCGTs through the capacity market, resulting in lower CM prices
- The lower CM prices save the system £150m/year on average from 2020 - 2035

Source: Aurora Energy Research

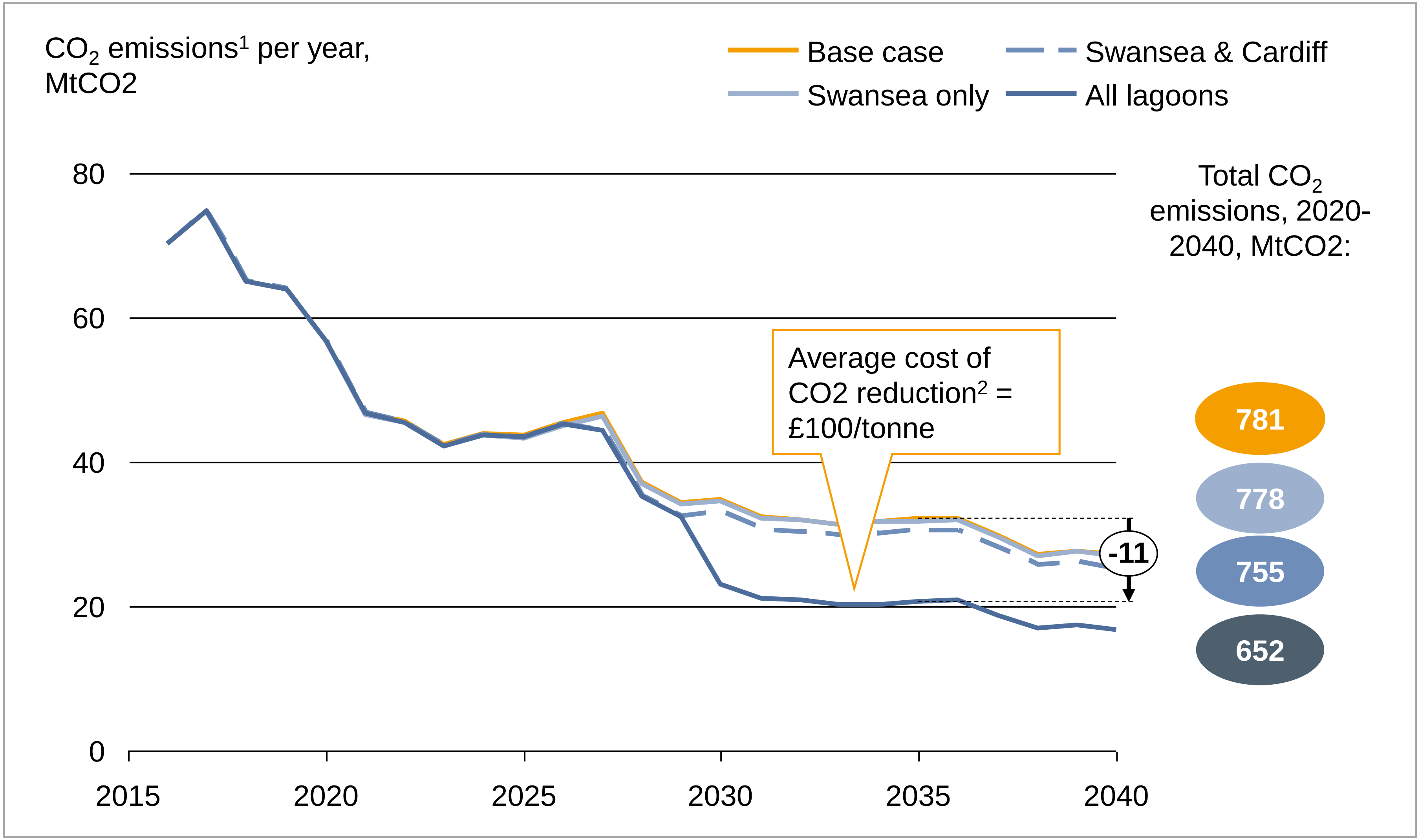
Household electricity bills increase by £8-9/year due to higher CfD costs



1. Calculated based on the following assumptions: domestic consumes 30% of total UK power generation and total number of households in UK projected to be 27million in 2030

Source: Aurora Energy Research

Tidal reduces power system CO2 emission by 11MT per year



1. Our emissions data are calculated on a per plant basis using an econometric model of historical plant dispatch, emissions and fuel use.
2. Average cost calculated based on average of 2027-2040 CO2 emissions and system spending

Source: Aurora Energy Research

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We also ran three scenarios where Hinkley does not get built

Scenario[1]	Description
CCGT to replace Hinkley	Most economically efficient alternatives However, carbon target is not met
Wind to replace Hinkley	Additional 15GW of wind on top of current level enters to replace nuclear capacity Carbon target is met
Tidal to replace Hinkley	25GW of Tidal enters to replace nuclear capacity Carbon target is met

1. We assume that if Hinkley C does not get built, all proposed nuclear projects in the UK are subsequently delayed indefinitely (Sizewell C, Wylfa Newydd, Oldbury B, Moorside, Bradwell B)

Source: Aurora Energy Research

Wholesale electricity prices are lower when Hinkley is replaced by wind or tidal, compared to CCGT

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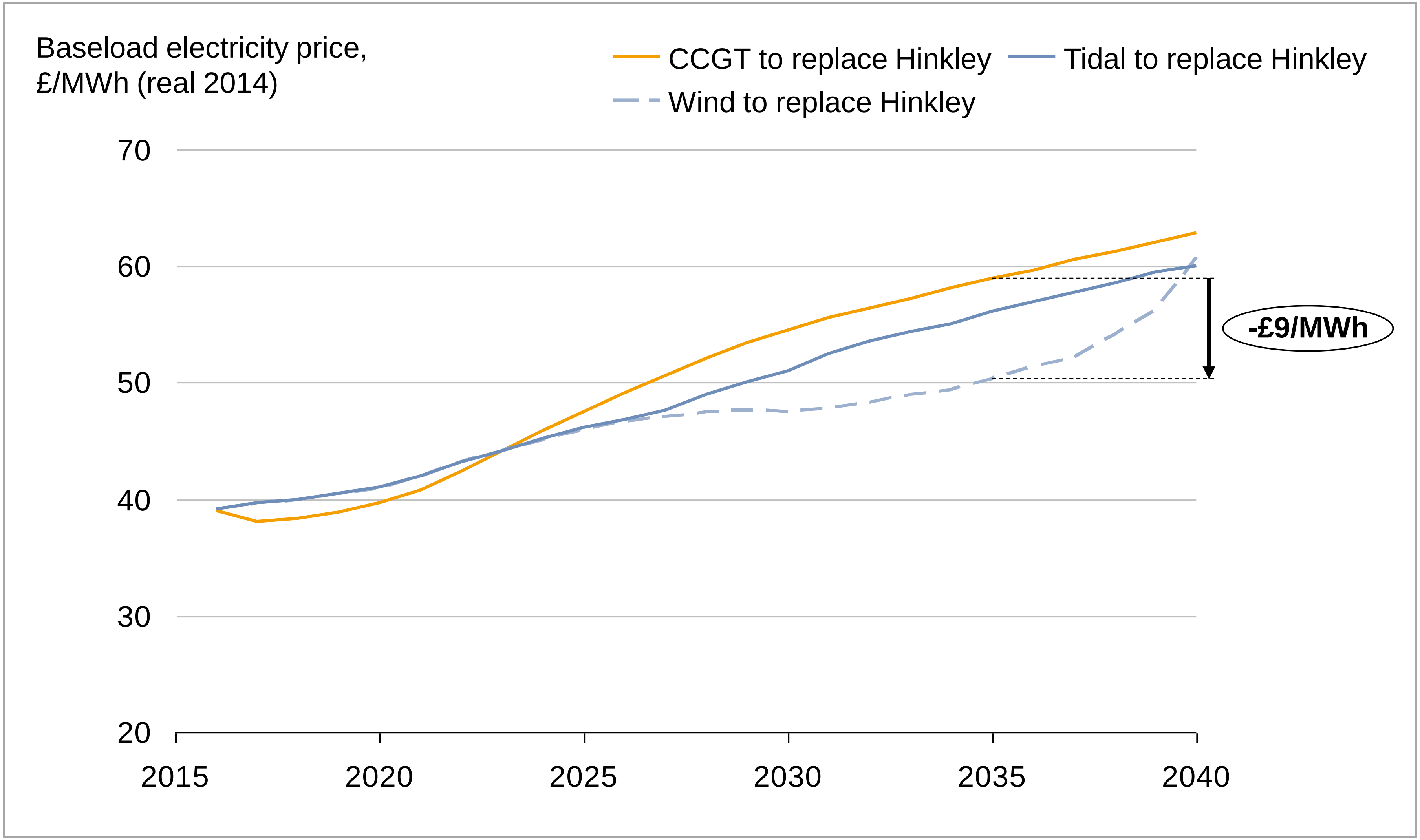
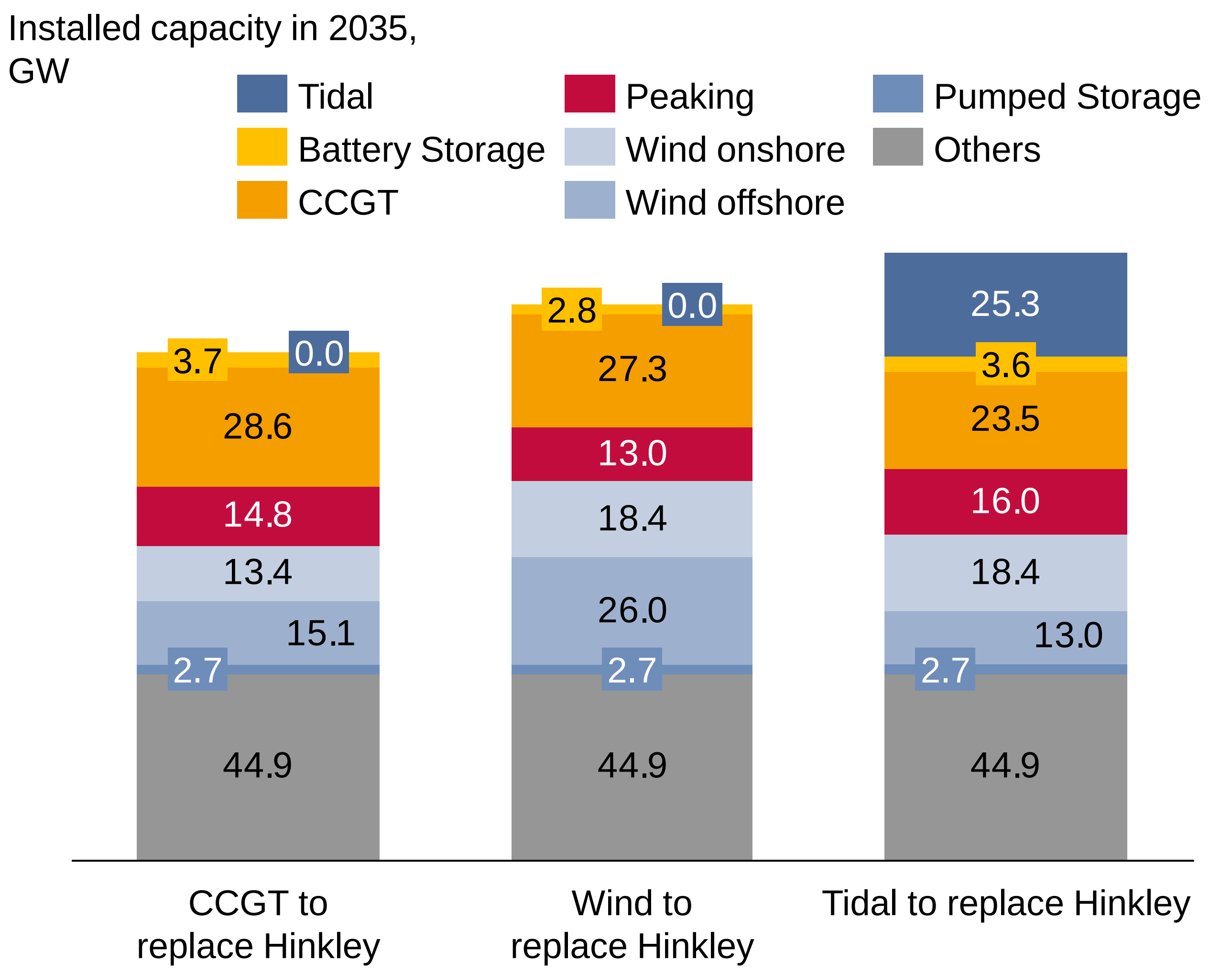


Source: Aurora Energy Research

There would be 3.8GW less CCGT on the system if tidal were to replace Hinkley, compared to wind replacing Hinkley



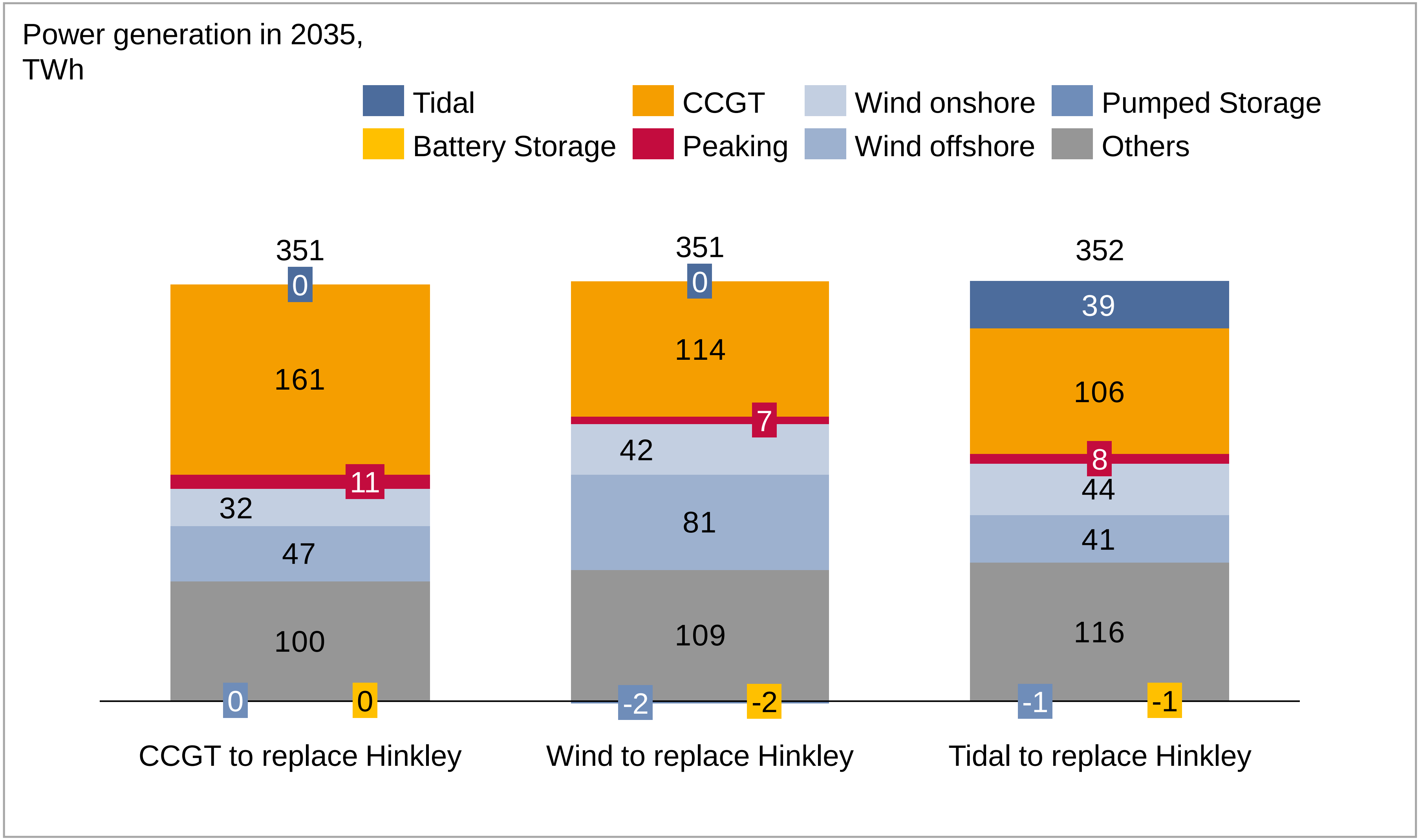
- Tidal provides significant amount of baseload generation, replacing the need for CCGT
- On the other hand, wind still requires large amount of CCGT to provide reliable baseload generation

1 Peaking includes both OCGT and reciprocating engines

2 Others include all other renewables (biomass, solar, hydro and marine), nuclear and interconnector

Source: Aurora Energy Research

Existing CCGTs also run fewer hours with more tidal and wind on the system



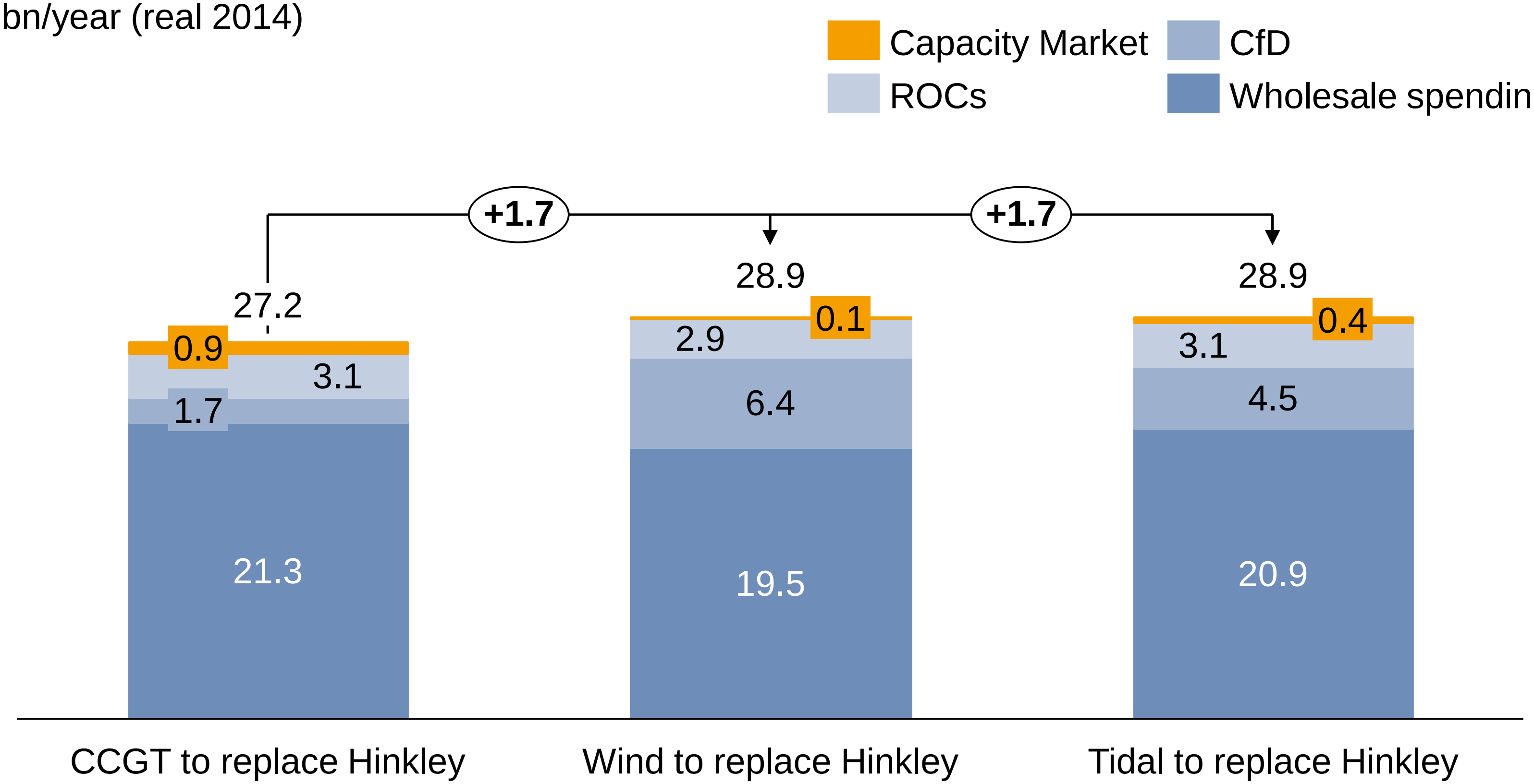
1 Peaking includes both OCGT and reciprocating engines

2 Others include all other renewables (biomass, solar, hydro and marine), nuclear and interconnector

Source: Aurora Energy Research

Replacing Hinkley with wind or tidal both require an additional £1.7bn in system spending, compared to CCGT

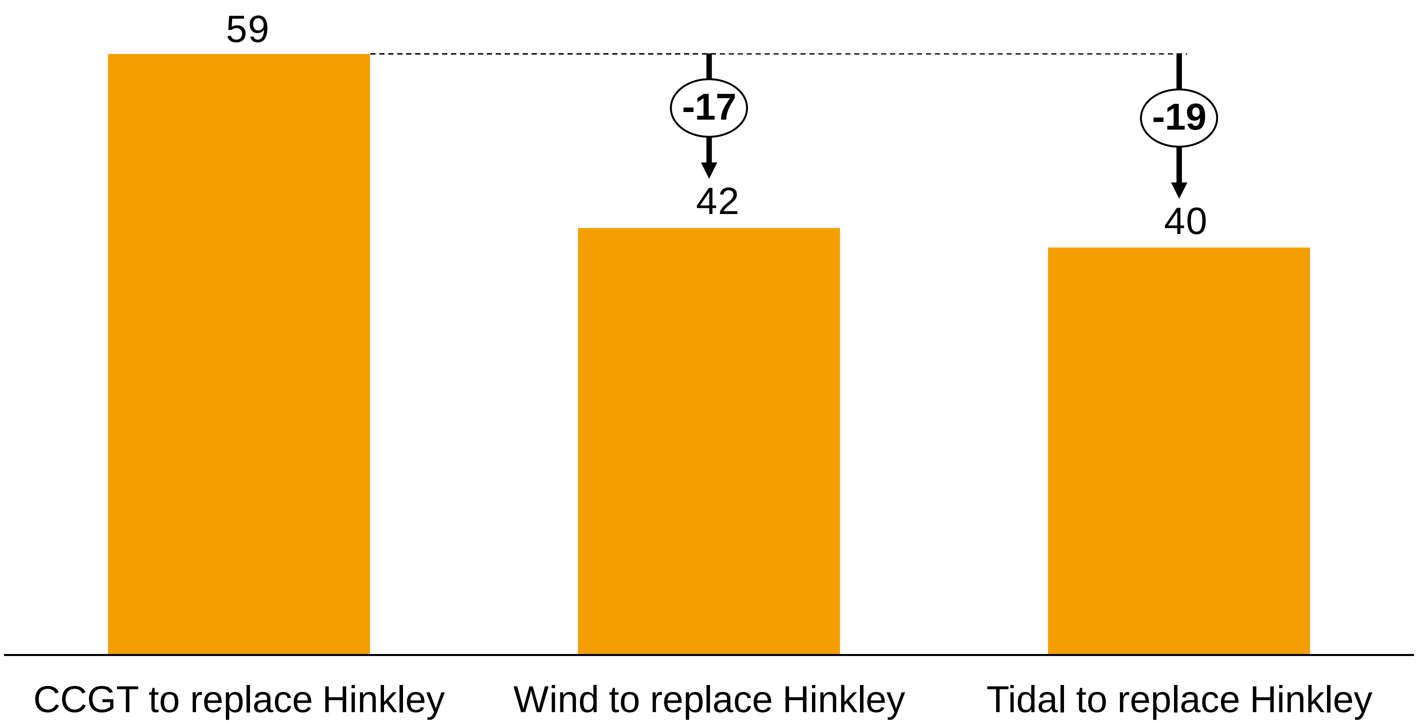
System spending[1], 2030-2040 average
£ bn/year (real 2014)



Source: Aurora Energy Research

Replacing Hinkley with tidal achieves a greater carbon reduction than replacing Hinkley with wind

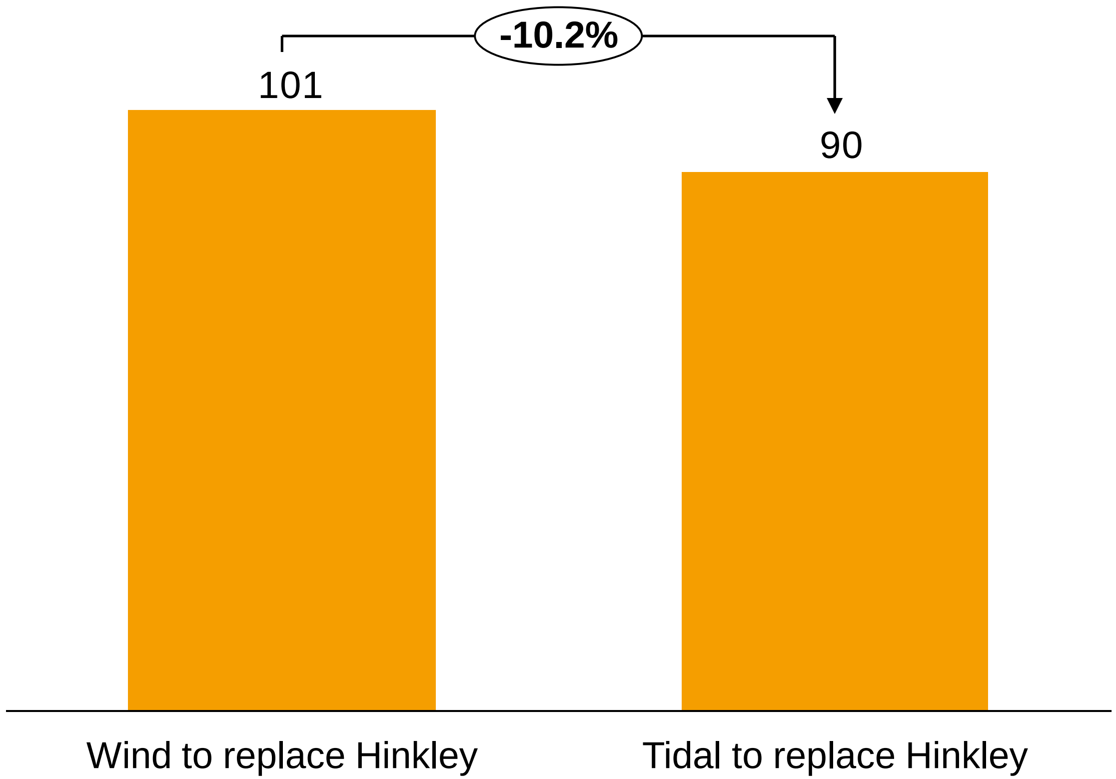
Average CO2 emission from 2030-2040 in UK power system, MtCO2 per year



Source: Aurora Energy Research

The cost of reducing carbon is thus £11/tonne cheaper with tidal replacing Hinkley, compared to wind

Average cost of carbon reduction from 2030-2040, £/tonne



Source: Aurora Energy Research

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To give a complete assessment of tidal's impact, we also consider the indirect costs

Direct costs to consumers	Indirect costs
Wholesale market spending	Balancing market spending
Capacity market spending	Intermittency costs
ROCs spending	
CfD spending	
1st Section	2nd Section

Source: Aurora Energy Research

In section 2, we ran three scenarios to compare the impact of tidal and wind on the system

Scenario	Description
Base case	Aurora's base case forecast (with Hinkley C) No tidal to enter
Tidal	25.3GW of tidal by 2030
Wind	15GW[1] of additional wind on the system by 2030

1. 25GW of tidal is required to achieve same annual production as 15GW of wind as tidal has an average load factor of 19% while wind has an average load factor of 30%

Source: Aurora Energy Research

Tidal does not contribute to imbalance, but 15GW of wind increases imbalance volumes by 35% on average

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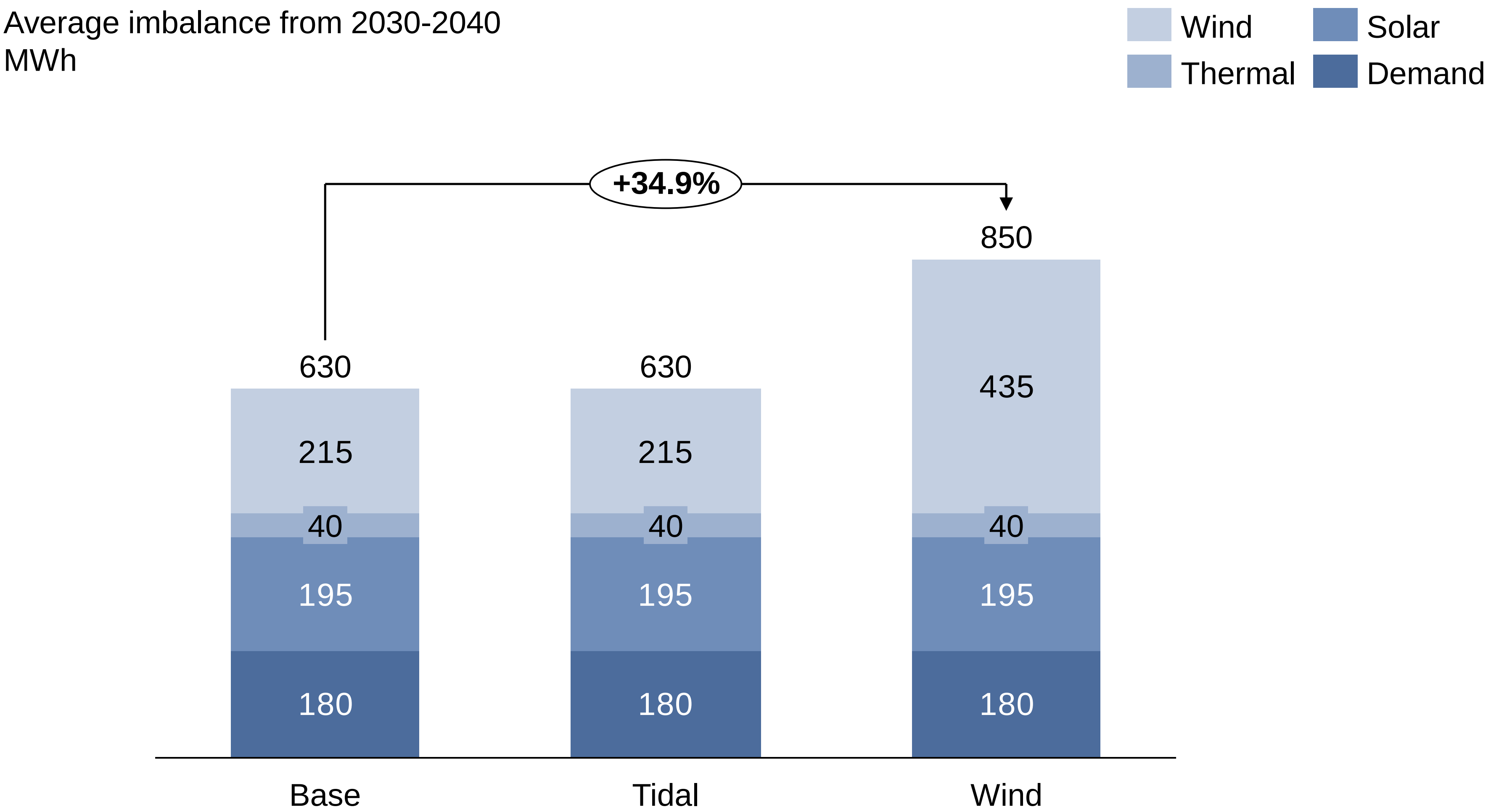

Source: Aurora Energy Research

25GW of tidal requires on average £266million/year less BM spending, compared to having 15GW of wind

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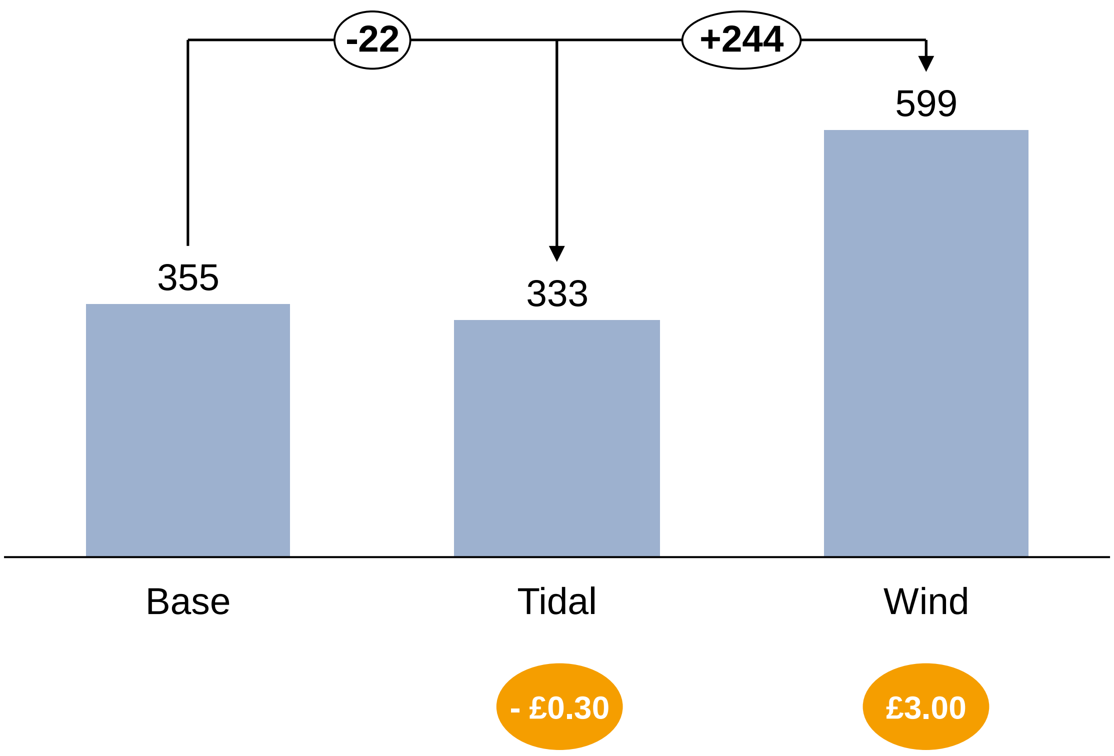
System spending on balancing market, 2030-2040 average
£ million/year (real 2014)

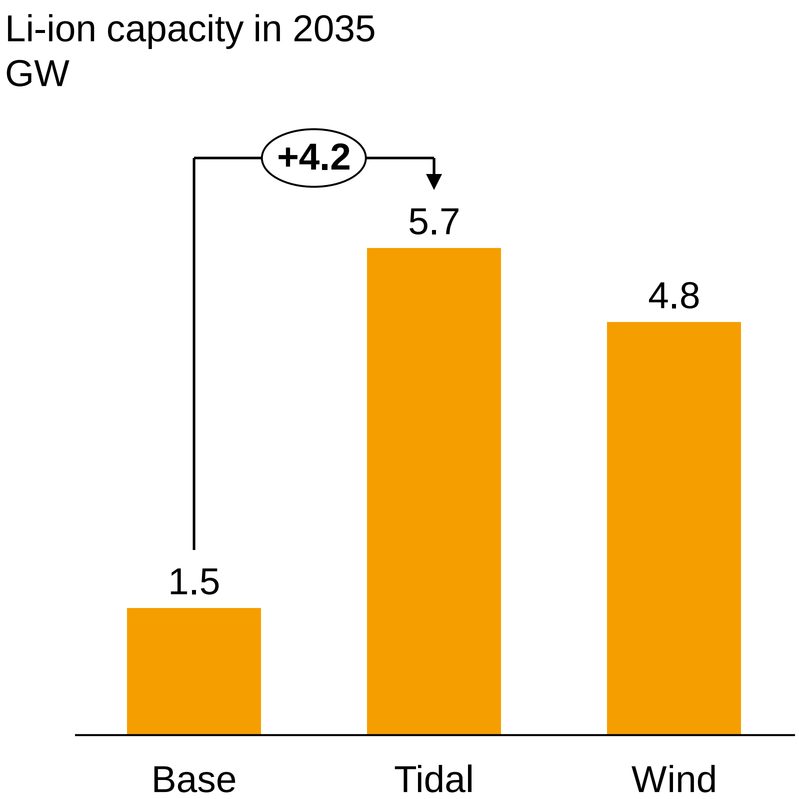
Additional cost to annual household electricity bill[1]

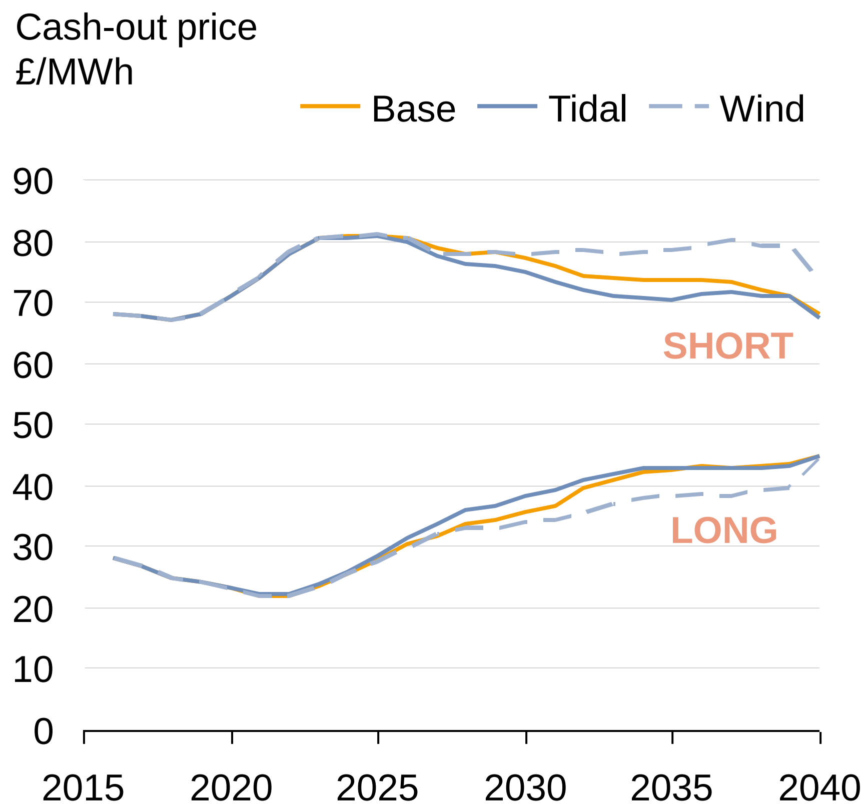


1 assuming all balancing costs are passed onto consumers and spread evenly across all units of consumption; calculated based on the following assumptions: 27 million households in UK by 2035 and 30% of total power consumption comes from domestic sector

Source: Aurora Energy Research

More batteries enter with tidal on the system, flattening cash-out prices





- An additional 4.2GW of li-ion enters under the tidal scenario

- Li-ion provides cheap balancing capacity and flattens the cash-out prices

Source: Aurora Energy Research

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To calculate the cost of intermittency, we look at the following 3 drivers

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The cost of intermittency – the additional costs imposed on the energy system resulting from the timing and predictability of a given generation technology's power output relative to a case where the same number of MWhs are generated evenly over every hour of the year

Poorly-timed power

Intermittent generators may produce electricity at periods of low demand instead of when consumers would really benefit from it (Note: this incorporates 'spill' costs)

Need for backup

Intermittent generators cannot be relied upon during the winter peaks and so additional backup is needed from the capacity market

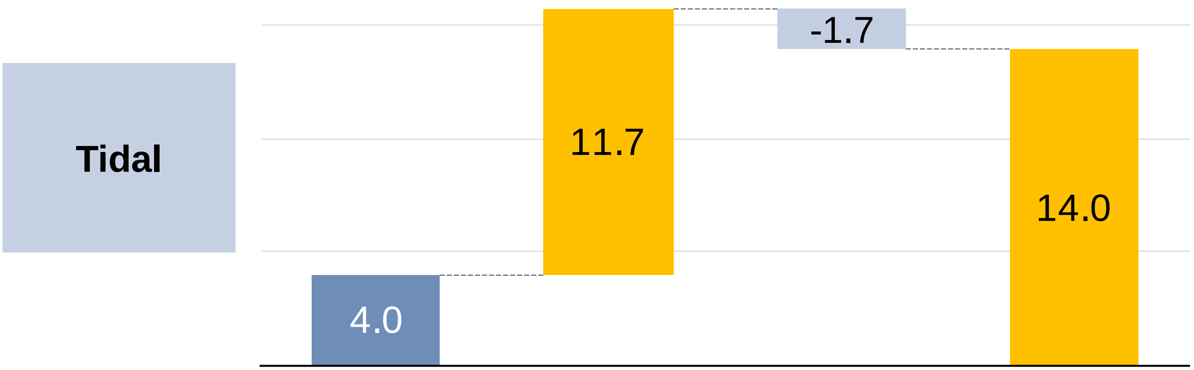
Consumer imbalance cost

Intermittent generators create imbalance which pushes up the cost of demand (i.e. consumer) imbalance

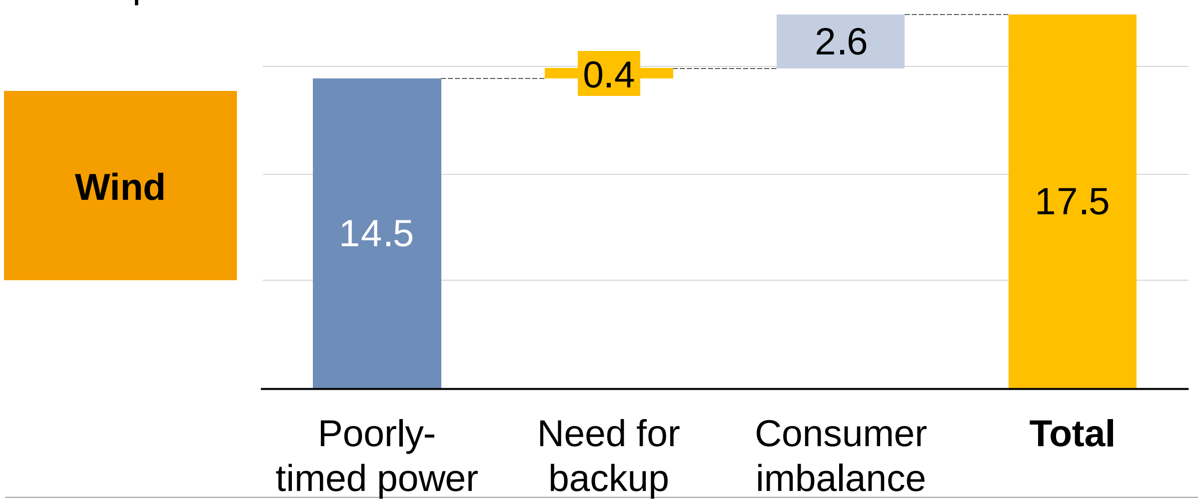
Source: Aurora Energy Research

Wind has a higher cost of intermittency than tidal, driven by its power coming at worse times

Cost of intermittency (average 2025-2040), £/MWh production



Cost of intermittency (average 2025-2040), £/MWh production



- Tidal has a smaller cost of intermittency due to poor timing as it oscillates at a reasonably constant frequency and seems to have some seasonal variation that matches with the electricity price
- Intermittency cost from consumer imbalance is also smaller as tidal is more predictable
- However, tidal has a larger CM cost of intermittency as:
  1. It procures more flexible capacity
  2. It runs during the peaks and so decrease the profitability of CM participants and raises their CM bids

Source: Aurora Energy Research

Appendix - methodology

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In practise we quantify the cost of intermittency by comparing intermittents to a baseload equivalent

Our power market model allows us to calculate the system wide effects of removing the intermittency of wind and tidal, by running two scenarios

Intermittent generation

System has an additional

- 25[1] GW of tidal compared to today's levels
- 15[1] GW of wind compared today's levels

Baseload equivalent

- System has same annual production from the additional renewables
- However, the MWh are spread evenly throughout year like nuclear

Our model forecasts the electricity, capacity and balancing markets in an internally consistent way

Electricity market

- Half-hourly electricity prices
- Consumer electricity spending out until 2040

Capacity market

- Annual generation mix
- Capacity market prices and bids consistent with other two markets

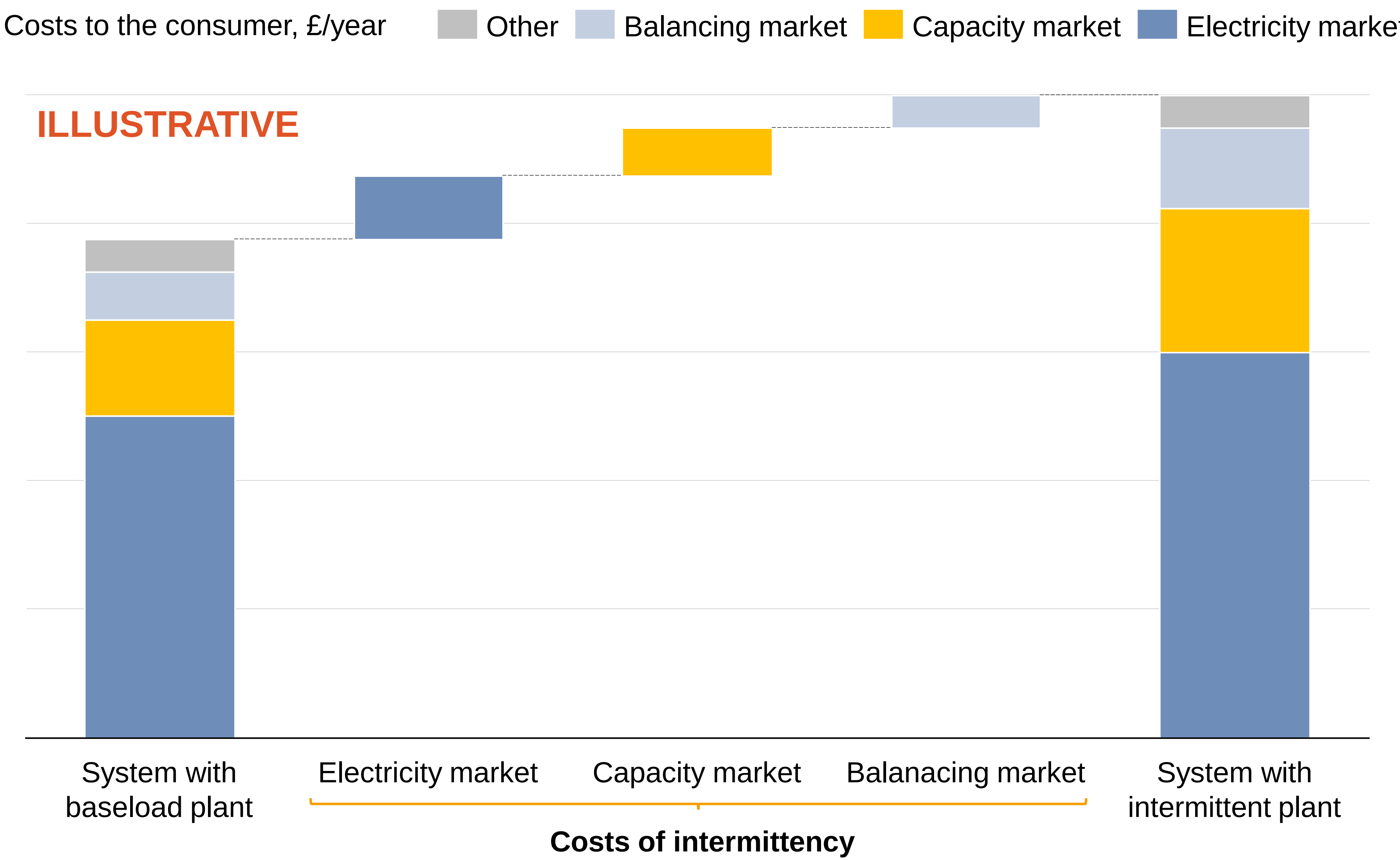
Balancing market

- Half-hourly cash-out prices
- Charges for all imbalance producing parties
- Profits for thermal plants taking part in the BM

1. 25GW of tidal is required to achieve same annual production as 15GW of wind as tidal has an average load factor of 19% while wind has an average load factor of 30%

Source: Aurora Energy Research

We can compare the differences in consumer spending across the markets to calculate these costs



Source: Aurora Energy Research

Aurora has developed a comprehensive and internally consistent model for these markets

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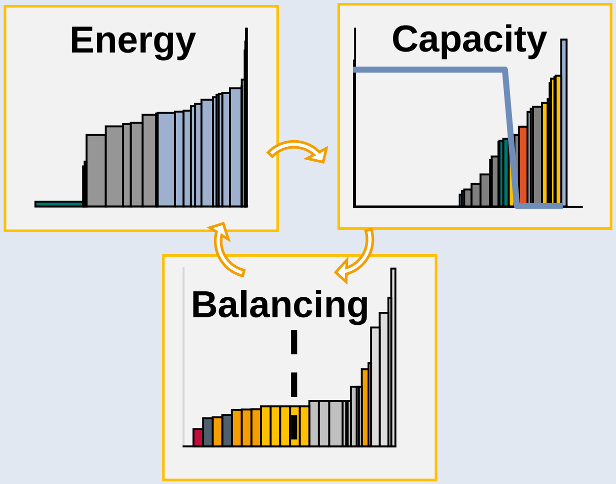
Input assumptions
- **Technology** (capex, performance, learning rates)
- **Policy** (changes to existing regulation, renewables build out, nuclear)
- Fuel prices

Inside of model



- Recalculated thousands of times to produce internally consistent solution
- Forecasts rational investor behaviour for correct entry and exit of plants
- Decisions in each market affect all others correctly

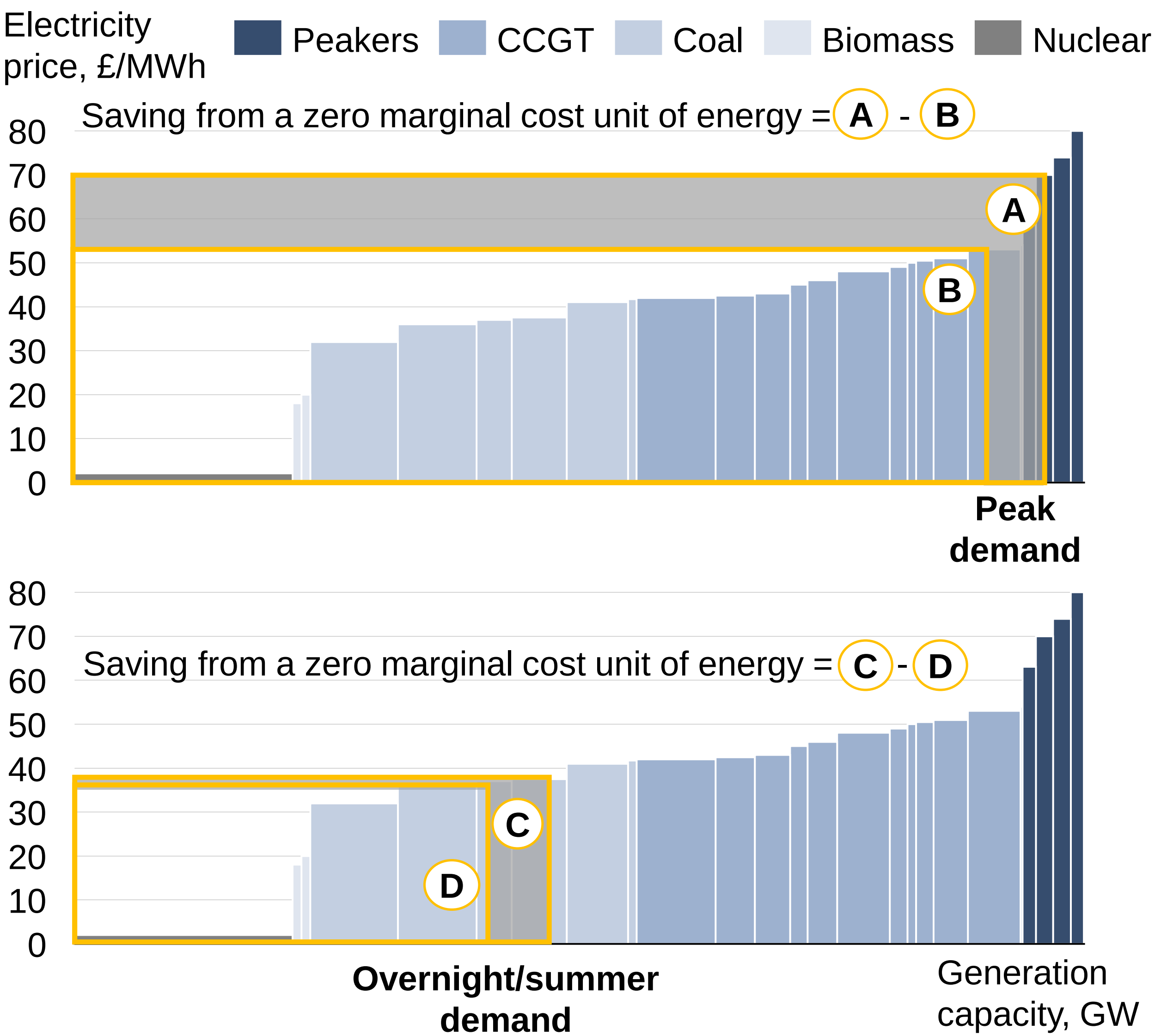
Entry and exit of every technology calculated, not assumed

- Peaking plants
  - OCGTs
  - Gas recips
    - Embedded
    - Centralised
  - Diesel recips
- DSR
  - Common process
  - Manufacturing processes
- Storage
  - Lithium ion
    - Paired with intermittent
    - Paired with domestic solar
    - Paired with industry
    - Paired with dispatchable
  - CAES
- CCGT
- Coal

Market outcomes
- New build entry and existing decisions and levels
- Half hourly electricity and cash-out prices
- Yearly capacity market prices
- Plant level revenues

Source: Aurora Energy Research

There is cost of intermittency in the EM due to the steepness of the merit order at high demand levels



- Intermittent generation tends to occur in low demand periods (either overnight or during summer)
- Baseload however hits both peak and off-peak periods equally
- The cost of intermittency is this potential savings loss from these poorly placed MWhs

Cost of intermittency =

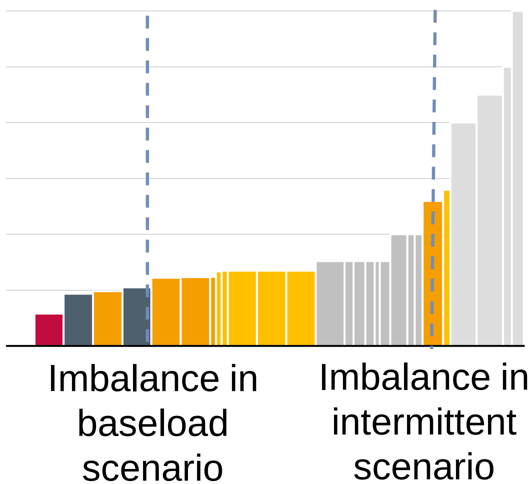
(A – B) – (C – D)

Source: Aurora Energy Research

The cost of intermittency for the BM arises as intermittents raise the cash-out price for everyone else as well

- Intermittents create imbalance, increasing the need for balancing services…

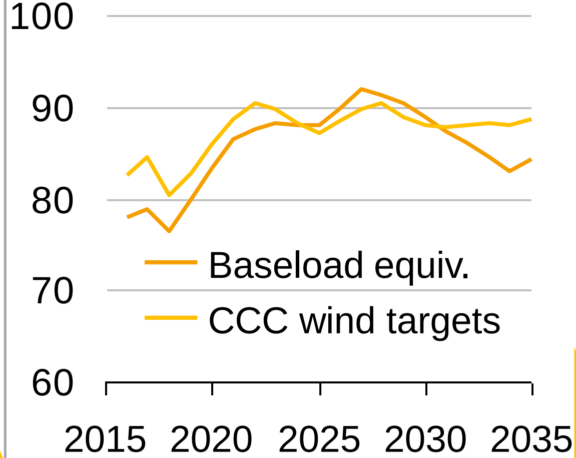
Balancing offers, £/MWh



- The extra imbalance in this half hour means more expensive balancing offers need to be taken
- All imbalance is charged at the clearing price (cash-out price)

- …which raises cash-out prices above what they otherwise would have been…

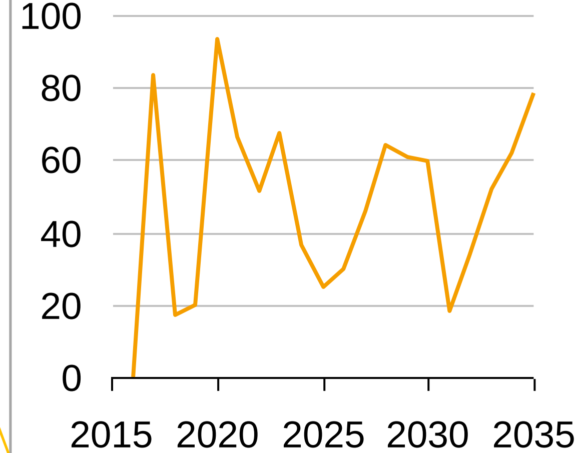
Cash-out price (short), £/MWh



- In early years, the system doesn't have chance to adjust to the increased balancing revenues available
- Cash out prices are therefore higher on average

- …increasing the cost of imbalance for everyone else (so raising consumer bills)

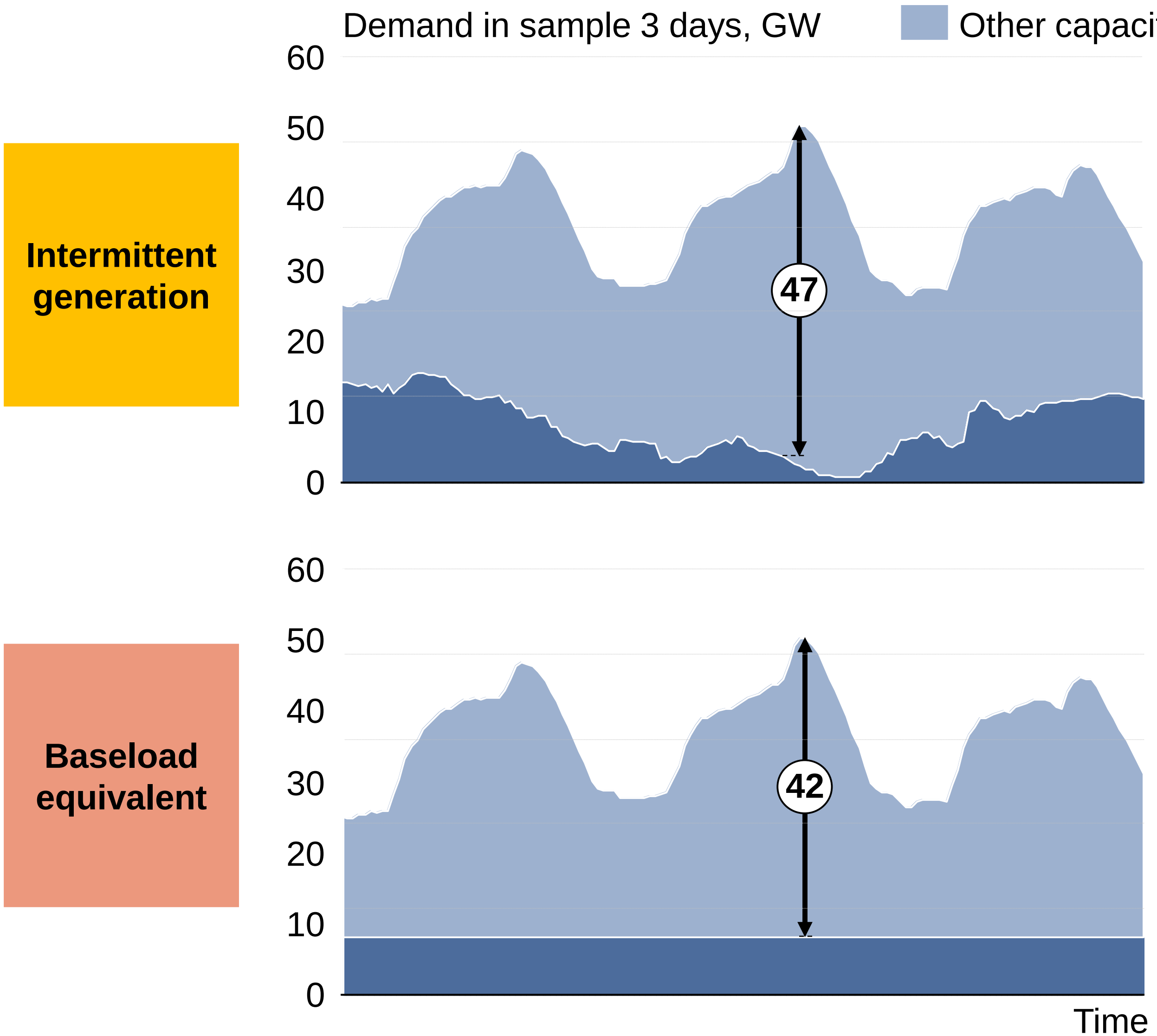
Additional balancing spend, £m



- Every MWh of imbalance from demand forecasting error was previously at lower cash-out prices
- The additional imbalance from intermittents may increase this

Source: Aurora Energy Research

The intermittent plant has the same load factor as its baseload equivalent, but needs more CM backup



- While both plants have the same load factor, the baseload equivalent is de-rated at its load factor, but the intermittent plant far less
- This means more CM capacity needs to be procured for the intermittent case
- This extra spending is a cost of intermittency

Source: Aurora Energy Research

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