The Big Picture:
How well are we doing?

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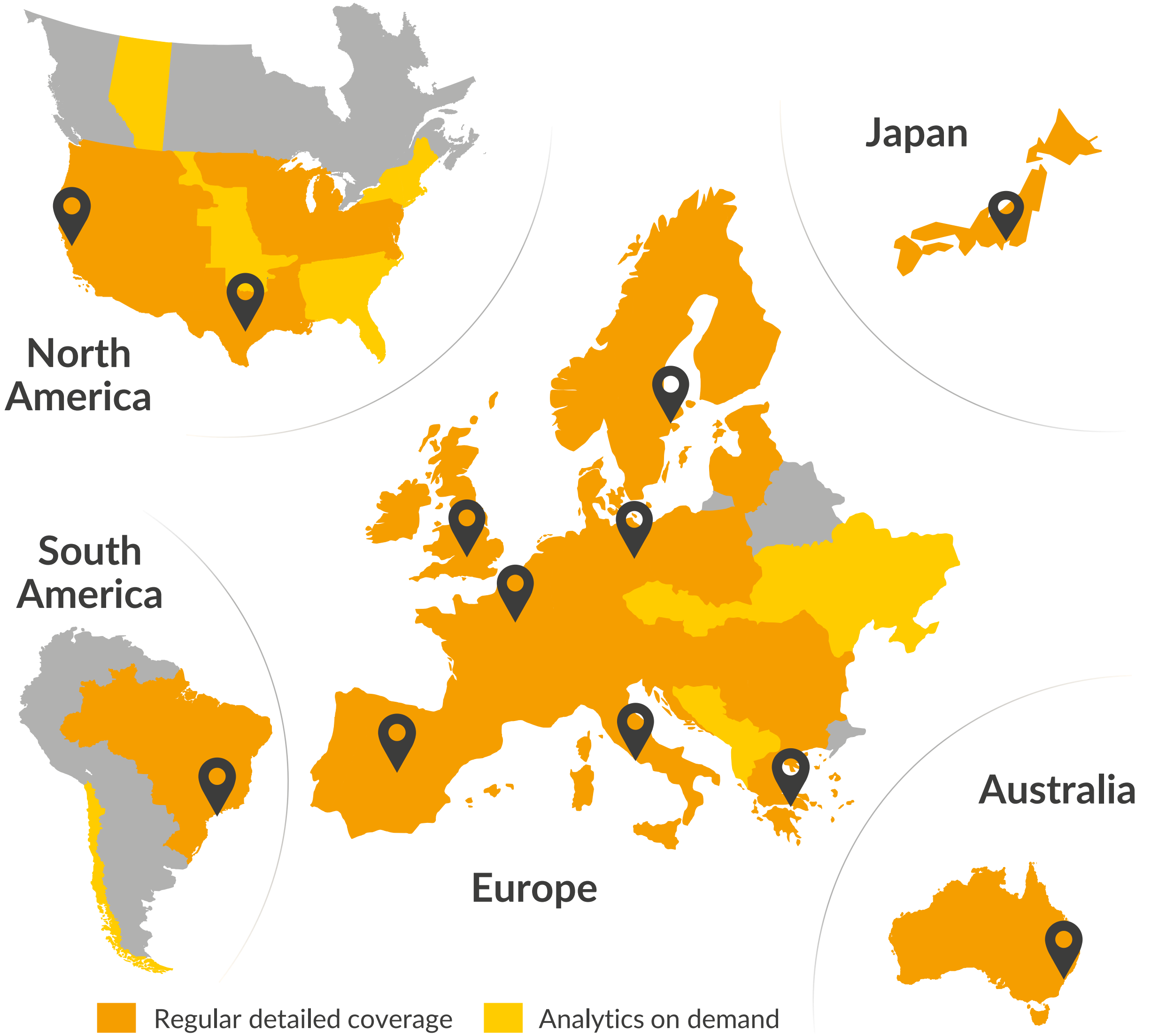

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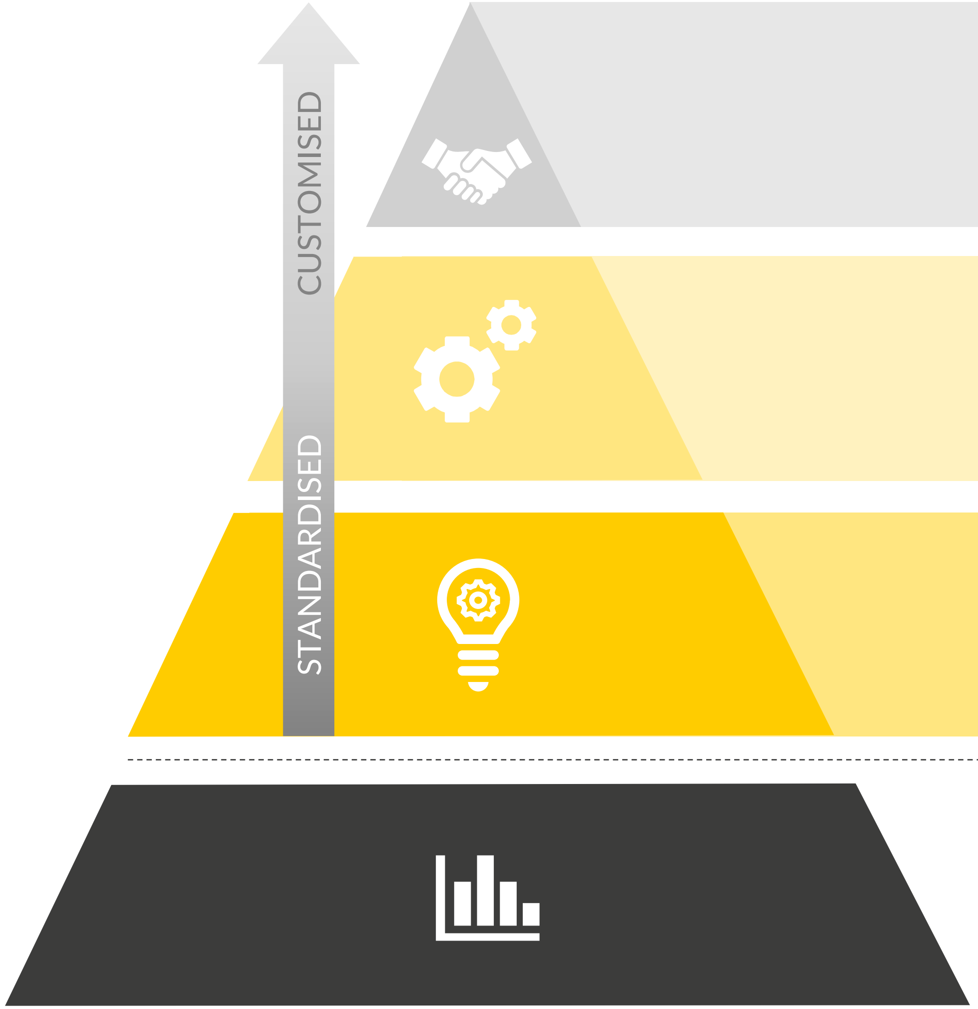

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Source: Aurora Energy Research

Agenda

Decarbonisation
How well are we *deploying* low carbon technologies?

Security of supply
How well are we *integrating* low carbon technologies

Affordability
Can we manage the costs of the transition?

In GB, electrification for heat, transport and hydrogen electrolysis will increase annual demand by 65% (to 498TWh) by 2050

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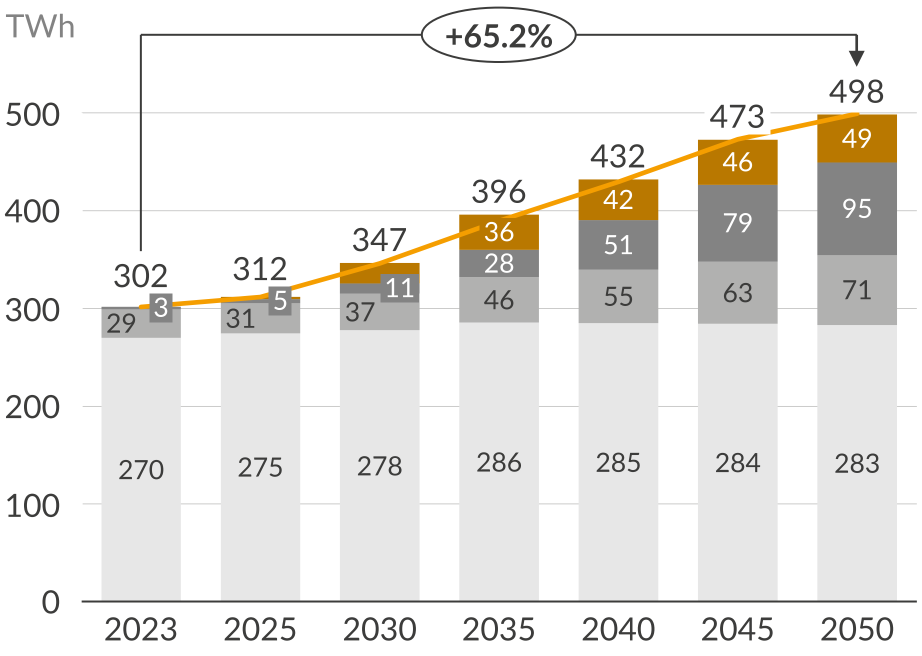
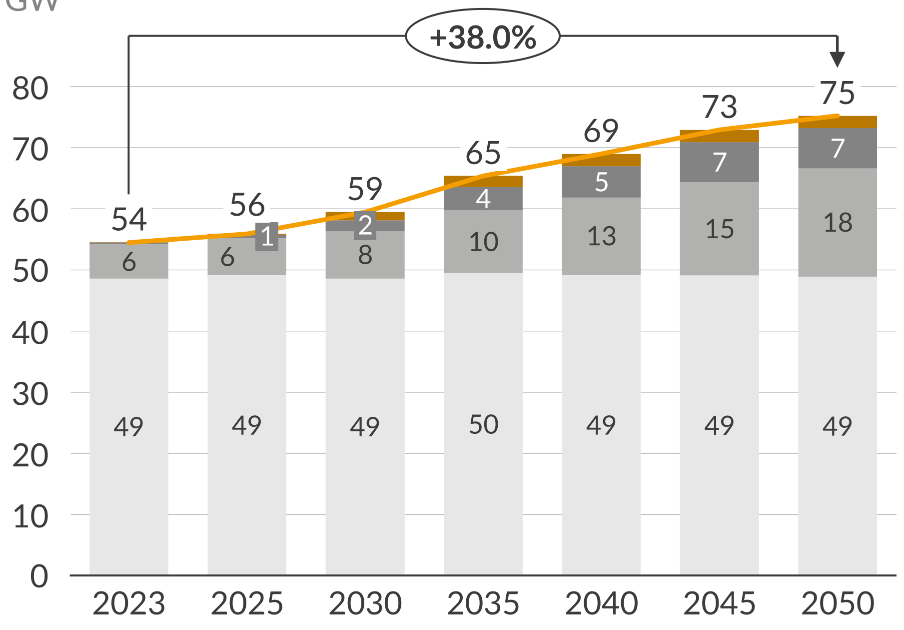
Annual Power Demand
TWh



ACS Peak Demand
GW



- In line with the Government's decarbonisation agenda and target of net-zero emissions by 2050, electrification of heat and transport and production of hydrogen through electrolysis will increase total power demand by 196TWh between 2023 and 2050
- Decarbonisation efforts are expected to accelerate faster post 2030, with Government initiatives including the 2035 ban[1] on internal combustion engine (ICE) vehicles and published hydrogen and heat pump targets
- Increases in ACS peak demand will be driven by the addition of EVs and heat pumps, while base peak demand remains stable due to energy efficiency gains

Hydrogen[2] Transport Heat Base power demand[3] Previous forecast

1) Delayed by Government in speech on 20th September 2023 by 5 years. 2) Demand for Green hydrogen production from electrolysis; 3) Underlying power demand excluding heat, hydrogen and transport.

Sources: Aurora Energy Research

Progress is being made within the transport sector with more than 23% of new cars registered in 2022 being either Battery EVs or plug-in hybrids

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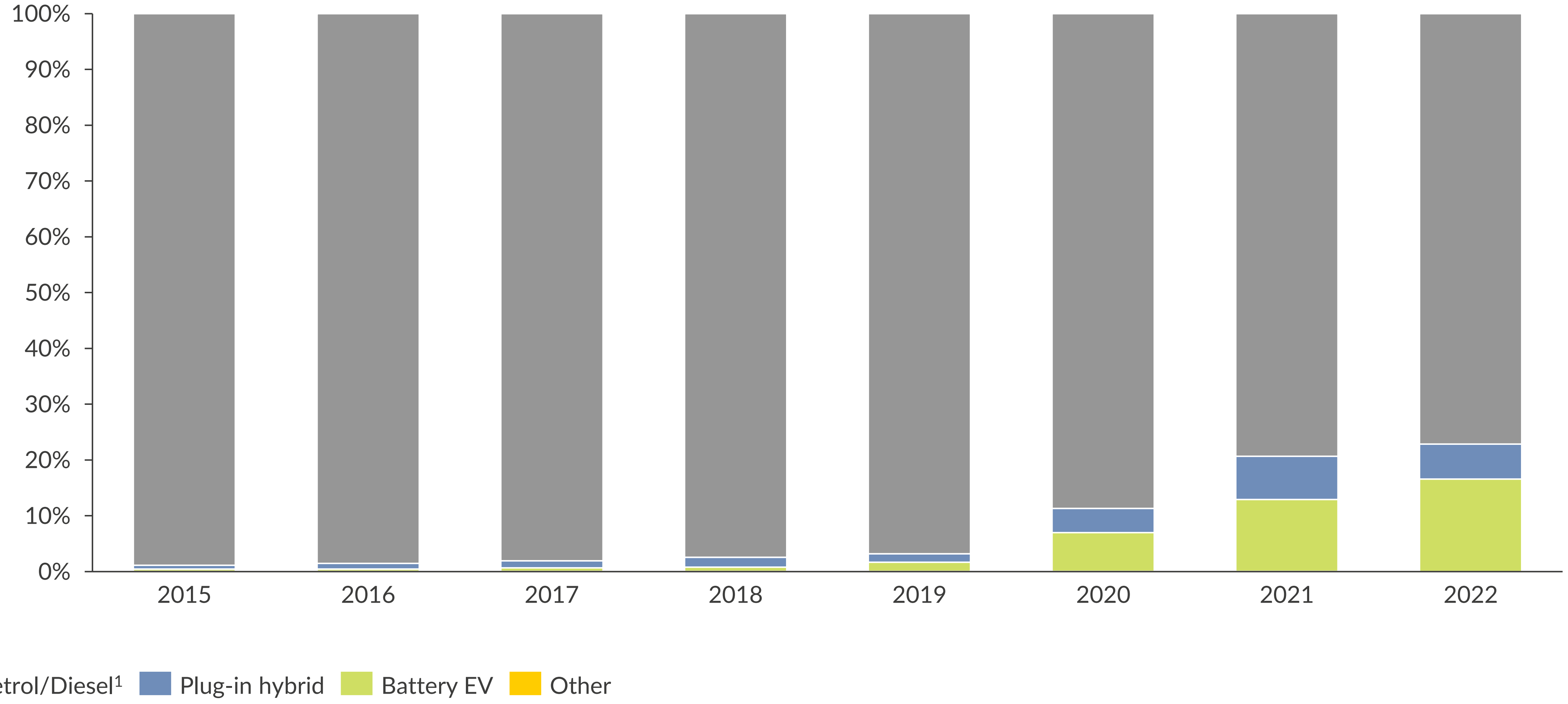
New car registrations by fuel type
%



1) Includes self charging hybrids with limited zero emissions electric only modes

Sources: BEIS, RAC

High heat pump deployment is likely the most cost effective decarbonisation pathway but a step change is needed in all scenarios

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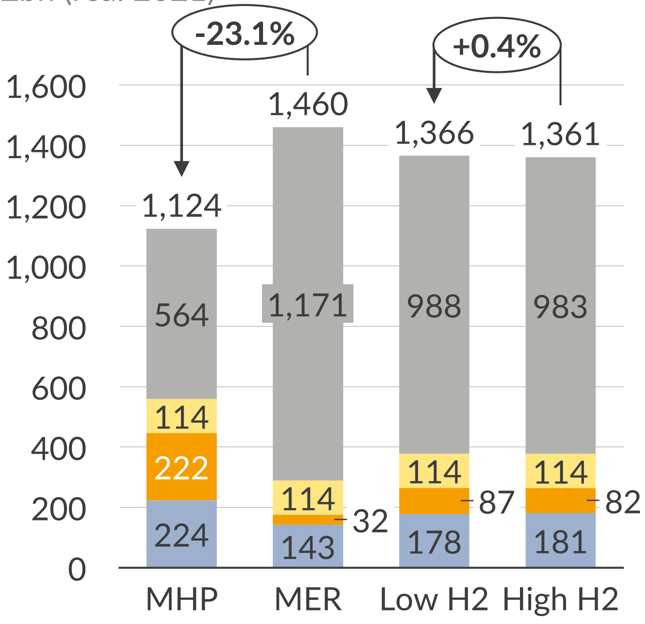
Total heat system costs, 2023-2050
£bn (real 2021)



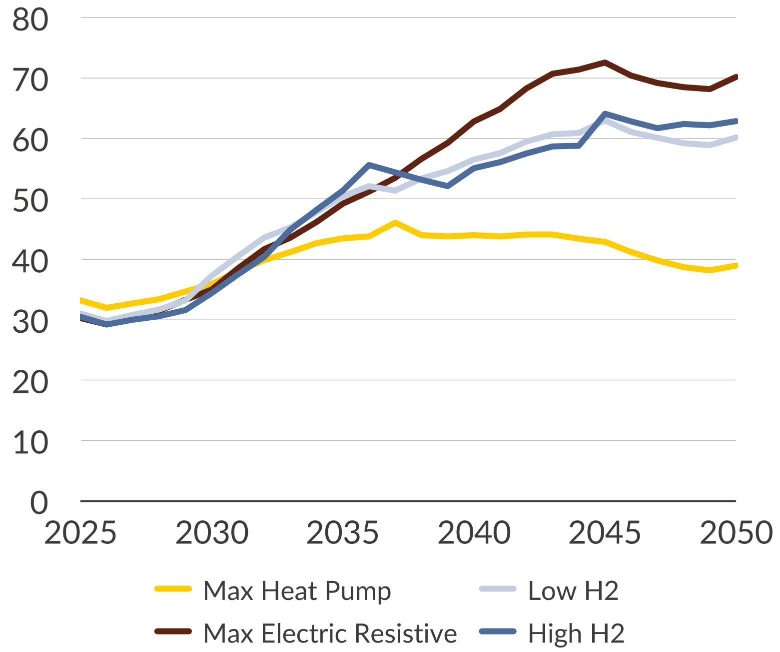
Fuel cost share of total costs, %

50% | 80% | 72% | 72%

CAPEX | Transition cost | OPEX | Fuel costs

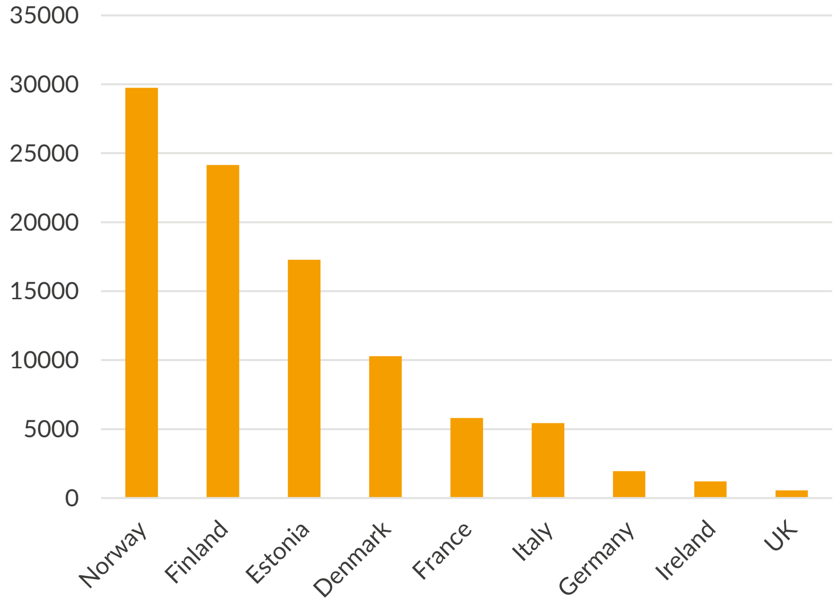
- Total heating costs are lowest in the Max Heat Pump scenario, and are 23% lower than the Max Electric Resistive scenario

Total annual heat system costs
£bn/year (real 2021)



- Total annual heating costs remain similar between scenarios before 2035, at £30-40bn/year
- After 2035, total costs diverge, with Max Heat Pump falling to £40bn/year by 2050, while other scenarios cost £60-70bn/year.

Heat pumps installed vs. 2035 requirement
Heat pumps per 100,000 of population, selected European countries



- GB requires 31-34% of homes to be fitted with heat pumps by 2035 across all scenarios
- In our scenarios, by 2050, heat pumps are deployed in 83% (High HP) and 46% (High H2) homes.
- 72,000 HPs installed in 2022 (0.26% of GB homes)

Sources: Aurora Energy Research for the National Infrastructure Commission, European Heat Pump Association (for current deployed heat pumps internationally)

Europe will see 448GW increase in variable renewables capacity by 2030 in a Central scenario, accounting for 48% of total generation

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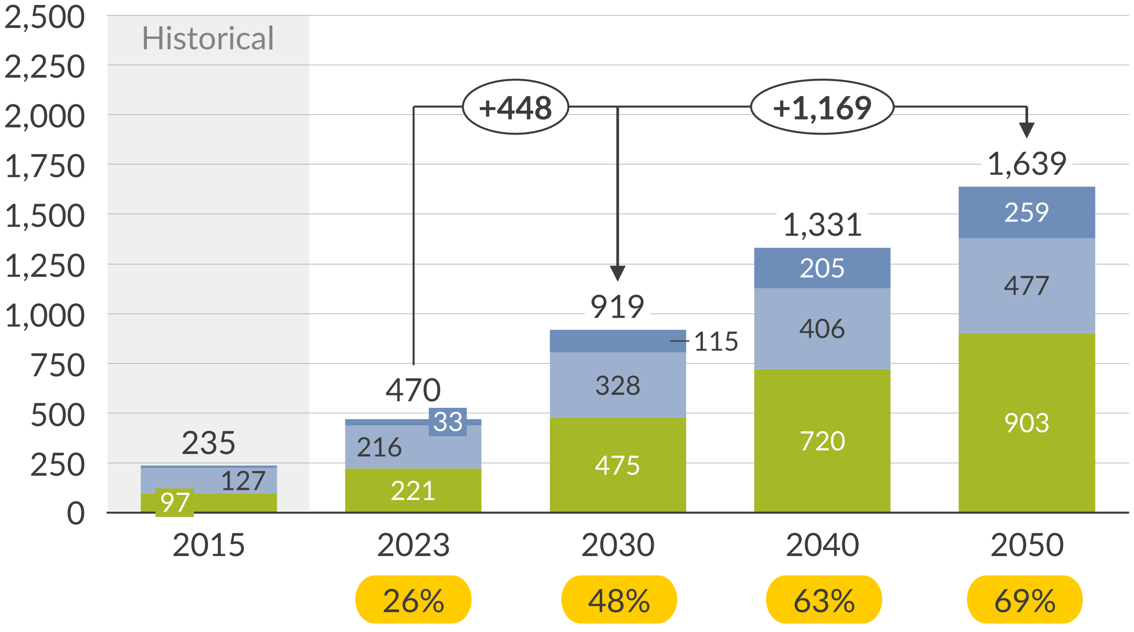
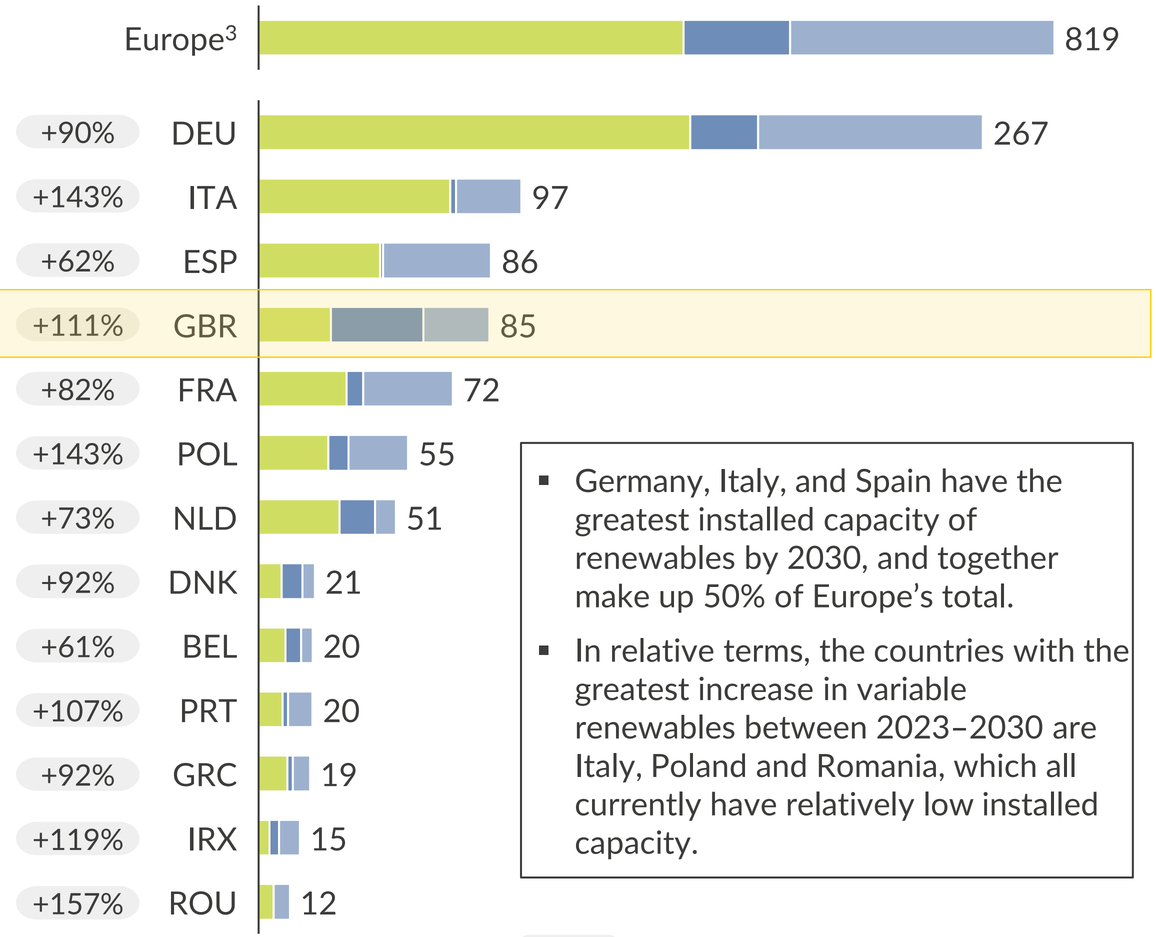
European installed variable renewable[1] capacity (Aurora Central scenario)
GW



- Europe's installed capacity of solar, onshore and offshore wind grows by 3.5 times between 2023–2050, in Aurora's Central scenario.
- The increasing penetration of renewables on the system results in an increase in the RES share of generation to 48% and 69% by 2030 and 2050.
- The increase in variable renewables will lead to more variability in generation, creating a need for flexible supply and demand technologies.

Offshore Wind[2] | Onshore Wind | Solar PV | xx% Variable renewables share of generation[3]

Installed variable renewable capacity in 2030 (Aurora Central scenario)
GW



- Germany, Italy, and Spain have the greatest installed capacity of renewables by 2030, and together make up 50% of Europe's total.
- In relative terms, the countries with the greatest increase in variable renewables between 2023–2030 are Italy, Poland and Romania, which all currently have relatively low installed capacity.

xx% Relative capacity additions 2023-30 (GW)

1) Defined as solar PV, solar CSP, onshore wind and offshore wind. EU27 plus UK and Norway, minus Malta and Cyprus; 2) Includes fixed bottom and floating offshore wind; 3) Considering all low carbon generation, we get to about 95% by 2050 (i.e. including hydro, nuclear, etc). 3) Total capacity of listed countries, not of the entire European Union.
Sources: Aurora Energy Research, Eurostat

These new capacity additions represent a potential cumulative investment opportunity in Europe of up to EUR464 bn

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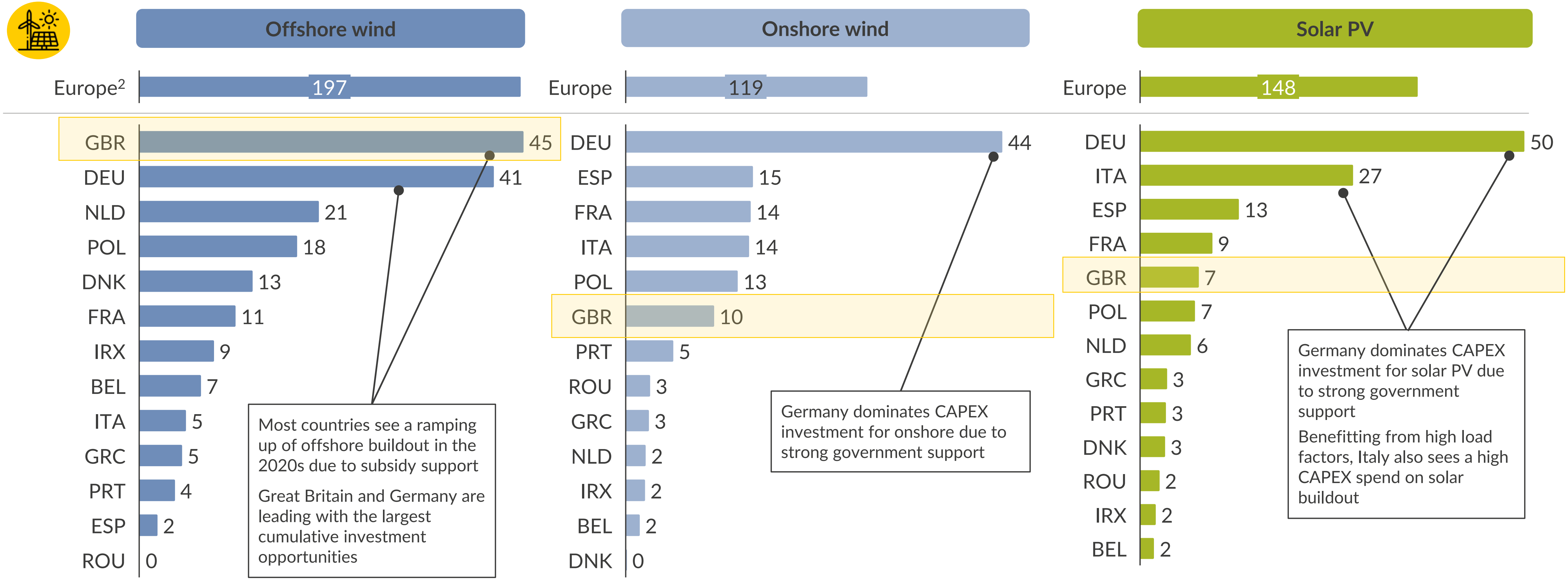
Total CAPEX[1] 2023 - 2030

€bn (real 2022)

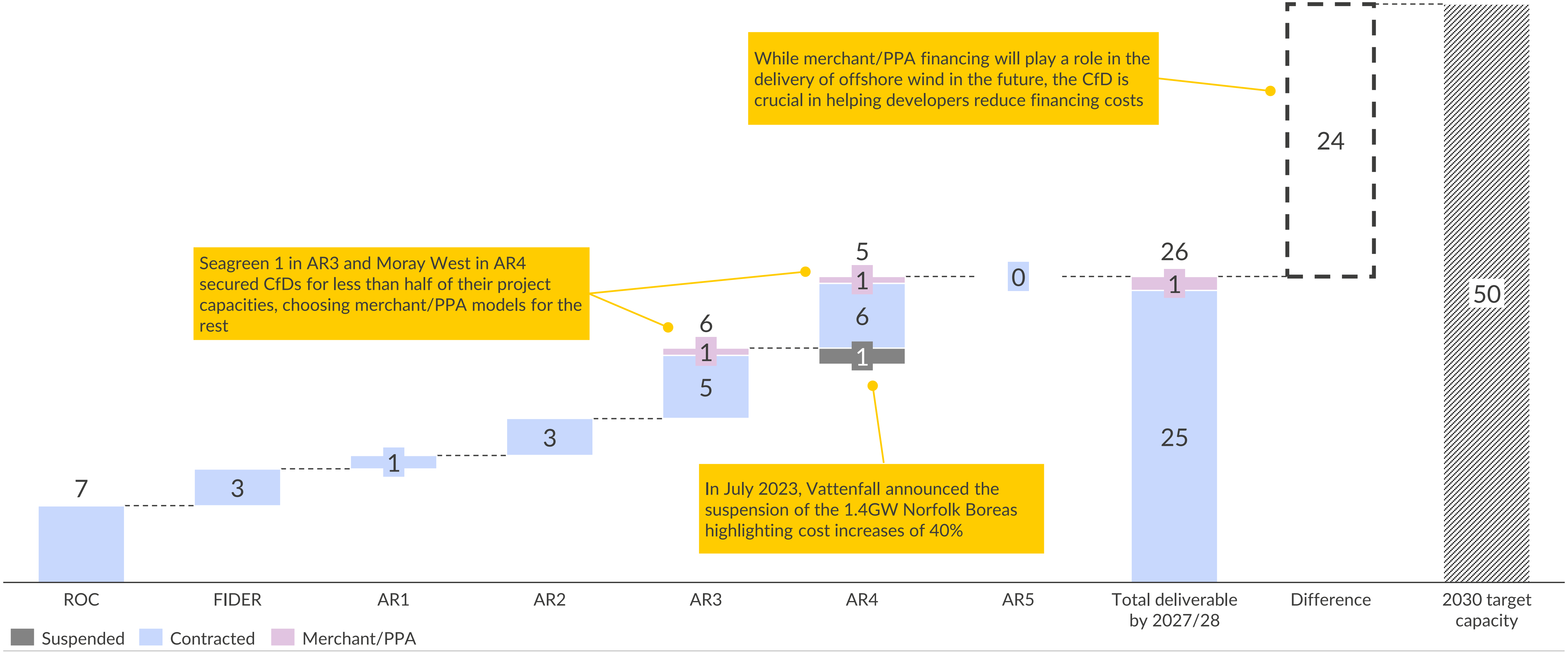


1) The figures represent net additions. 2) EU27 plus UK and Norway, minus Cyprus and Malta

Source: Aurora Energy Research

The ambition of 50GW offshore wind by 2030 is increasingly out of reach: after 2028, we need to build nearly as much capacity as we have built to date

Total offshore wind capacity procured versus 2030 government target
GW



Sources: Aurora Energy Research, DESNZ, LCCC

Takeaway 1: Despite recent policy missteps, deployment of renewables has been a GB success story. More progress is needed on electrification of transport and (especially) heat.

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The speed of the energy transition in Europe is threatened by an increasingly constrained grid, requiring significant investment

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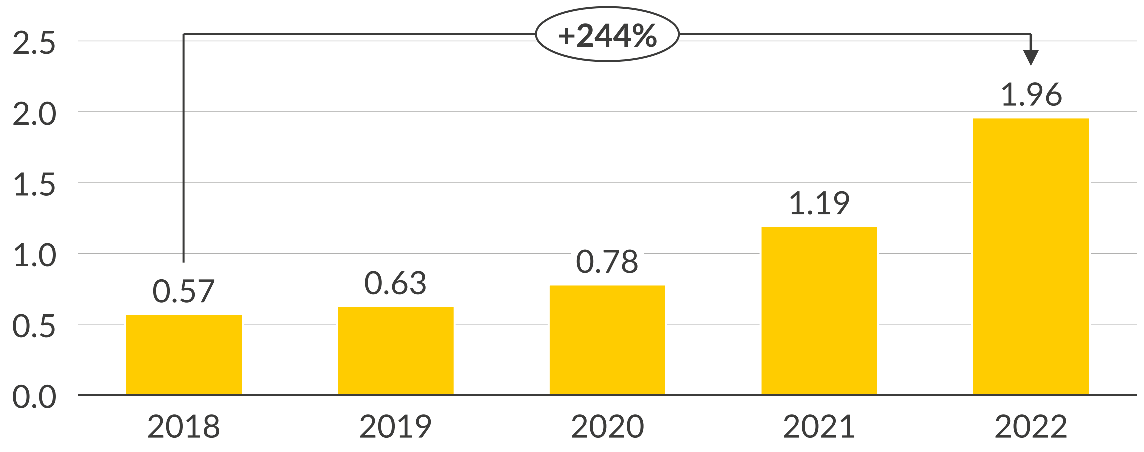
The volume of wind curtailed due to thermal constraints is growing with RES deployment, leading to the cost of managing the transmission network system to increase substantially over recent years

Annual cost of constraint management[1]
£bn (real 2022)



Annual cost of constraint management
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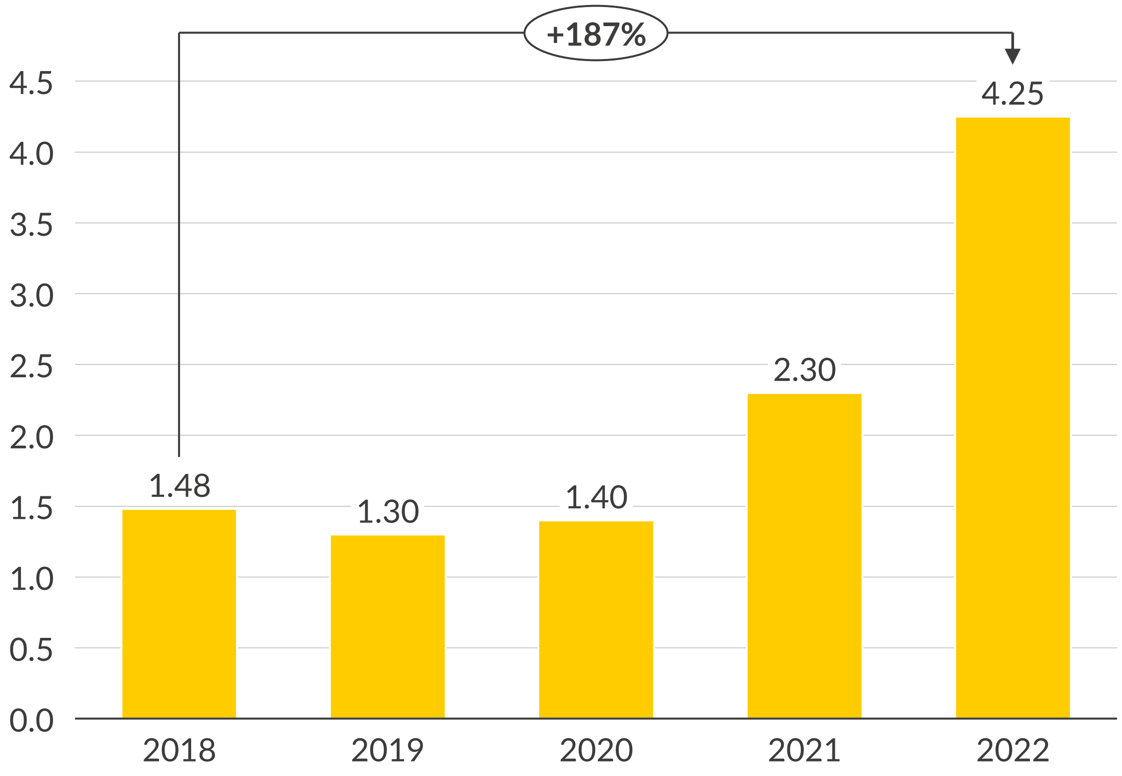

1) Covers any actions taken due to limitations on transmission network, whether for thermal, voltage or stability reasons.

Source: Aurora Energy Research

Expanding transfer capacities will require at least 300% more new infrastructure to be built in 2023-2033 compared to 2012-2022

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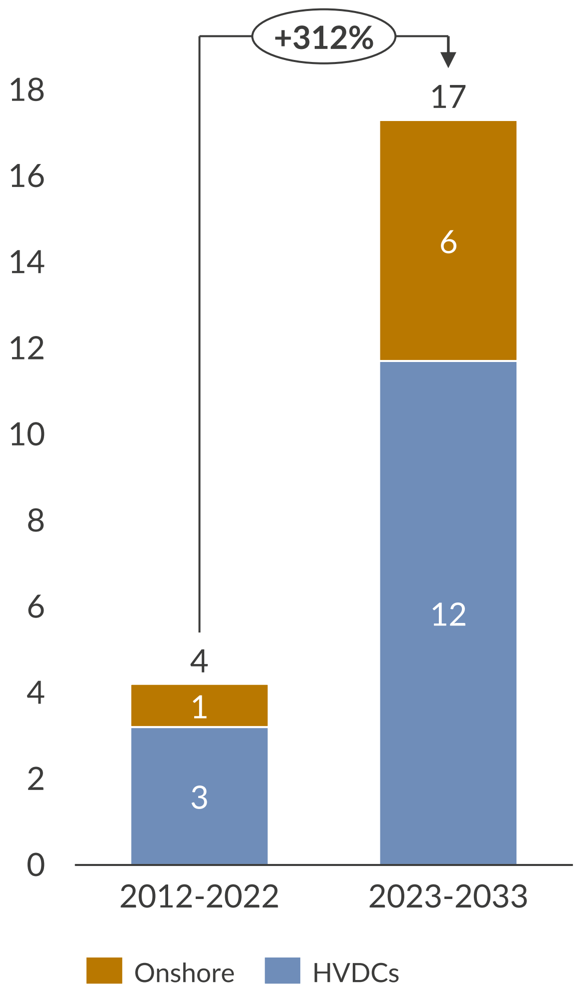
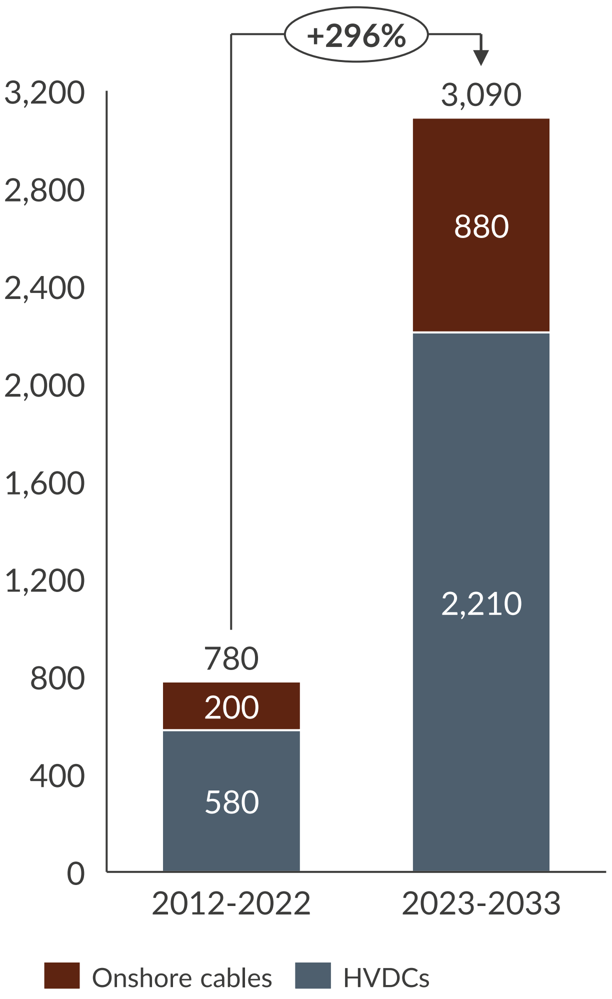
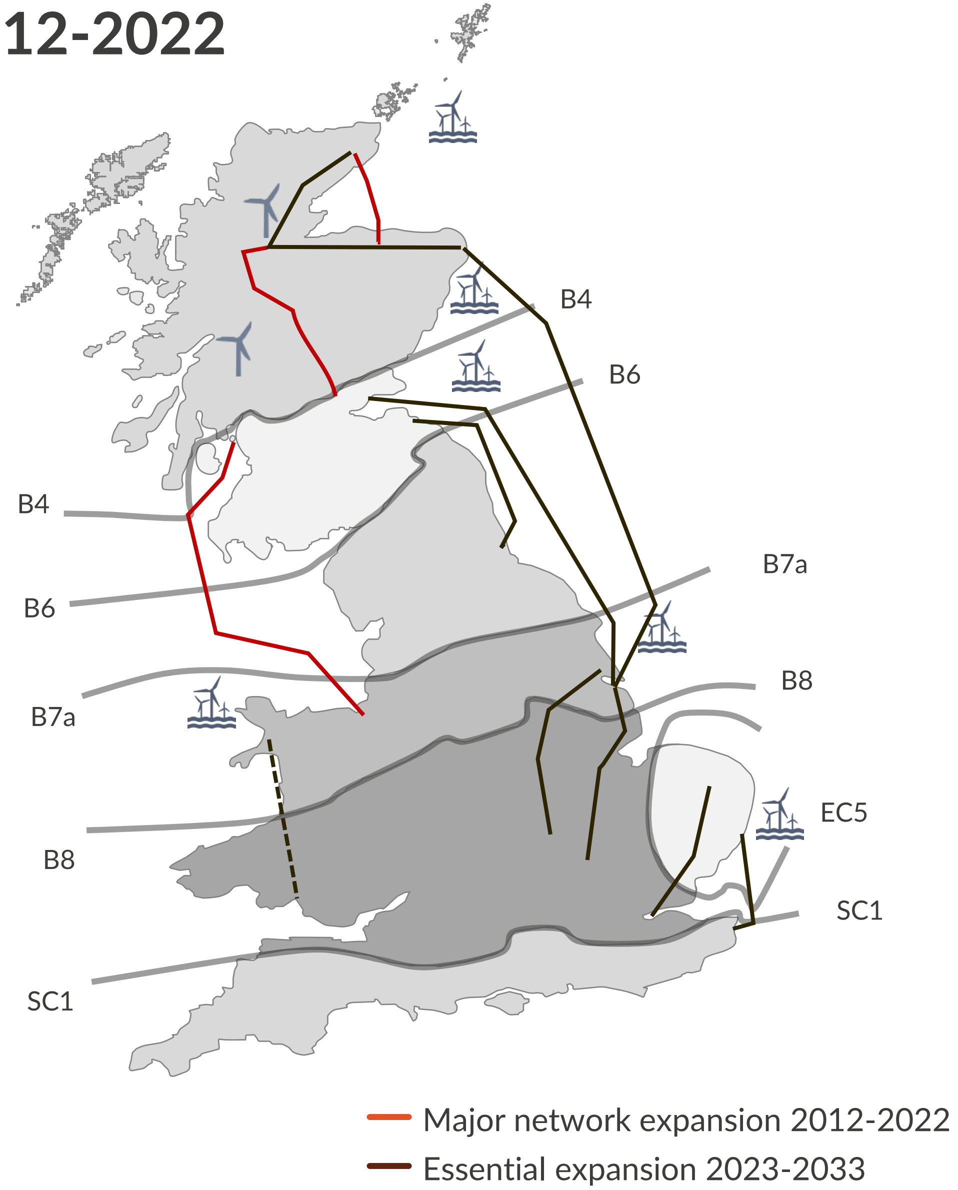
Transfer capacity from major new build
GW



Major new build line length
km





Sources: Aurora Energy Research, NGESO

Locational pricing offers theoretical solutions to grid congestion; both GB and Germany are currently looking into either zonal or nodal pricing

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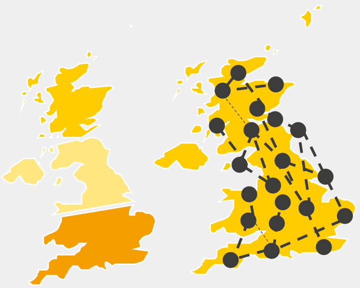
Nodal Pricing
- Prices and dispatch determined at the nodes for generators
- No European country has nodal pricing systems, However, outside of Europe it is established in the **CAISO, PJM, ERCOT** and **Singaporean** power markets.

Zonal Pricing
- Generators and retailers settle prices at an aggregate, or marginal, bid in the entire zone.
- Currently, bidding zones in Europe are mostly defined by national borders, the exception being Sweden and Italy that have intra-national zonal pricing

GB is debating the benefits of zonal versus nodal pricing zones

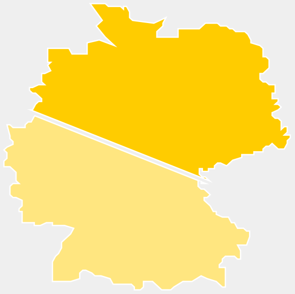
- The Department of Energy Security and Net Zero (DESNZ) called for a consultation with important stakeholders to review current electricity market arrangements (**REMA**).
- The results, published in March 2023 indicate that the government will consider introducing nodal or zonal pricing zones.
- However, respondents were divided as to which market policy is best suited to GB needs. **Both options are going to be evaluated in the coming months.**



Potential zonal and nodal splits

Germany is considering introducing a zonal price split

- The EU Agency **ACER** has given **the TSOs of France, Germany, Italy, the Netherlands and Sweden** until end of 2023 to conduct a bidding zone review
- In Germany, the possible introduction of zonal price zones leads to **political resistance**: While northern Germany, has much cheap wind power, southern Germany is the power-reliant industrial center
- Particularly Bavaria is worried about increasing power prices in the case of a price zone split



Potential zonal split

Source: Aurora Energy Research

Renewables historically brought to market by subsidy schemes. However, policy-makers now seeking to balance deployment with market integration

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Routes to market for solar PV and onshore wind projects

Subsidy Schemes

Feed-in Premium

- A feed-in premium (FiP) is paid to the generator to top up wholesale revenues

Contracts for Difference

- Increasingly, countries move towards CfDs, "top-up" payments equal to the difference between an awarded strike price and market reference price

Power Purchase Agreements

- PPAs are long-term contracts during which time the power purchaser buys energy at a pre-negotiated price.
- There is a loss of some capture price upside due to the off-taker price discount, however this is compensated for by having a lower hurdle rate, or WACC (typically 3-6% lower, depending on the structure of the offtake agreement)

Merchant projects

- Fully merchant projects experience higher risks and financing costs compared to subsidized or PPA-assets.
- Currently, we only see substantial merchant projects in GB. However, developers may hedge against some merchant risks with innovative set-ups such as **solar-battery co-located projects**

CfDs and PPAs are increasingly dominating the markets, with merchant projects failing to clear the hurdle rate in most countries and FiPs schemes being increasingly phased-out

Capacity-based CfDs?

- Some reform options combine a capacity-based subsidy with merchant/PPA prices for generation

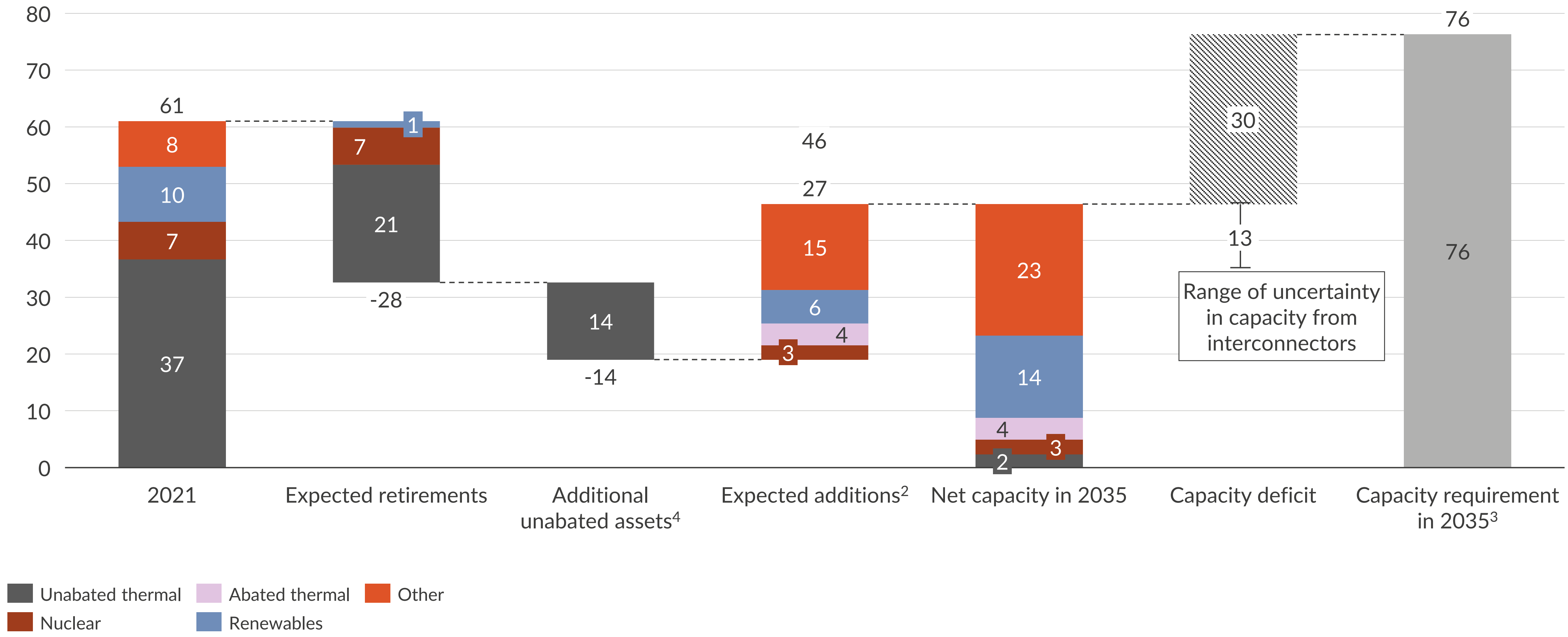
Unlevered cost of capital for solar and onshore wind at FiD, pre-tax, real[1]

5.5 - 6.5% | 7.0 – 8.0% | 10.0 – 11.0%+

1) Representative for GB.

Net Zero power by 2035 could also result in a 30 GW (de-rated) undersupply of firm capacity, putting security of supply at risk

Expected capacity retirements and additions by 2035[1]
GW, de-rated



1) Expected retirements reflect publicly announced dates for nuclear plant closures, policy mandated closure of coal assets and retirements of existing CCGTs based on a 30 year technical lifetime. 2) Reflects expected and potential additions based on confirmed and announced projects in the GB pipeline. 3) Estimated capacity requirement in 2035 (de-rated) based on Aurora's Net Zero scenario. 4) Unabated assets that will need to close or be converted to meet 2035 Net Zero targets.

Sources: Aurora Energy Research, REPD, EDF, Drax

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Takeaway 2: There is a pivotal debate now about the extent to which system integration can be most efficiently and speedily achieved through central planning or market design

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How well are we *deploying* low carbon technologies?

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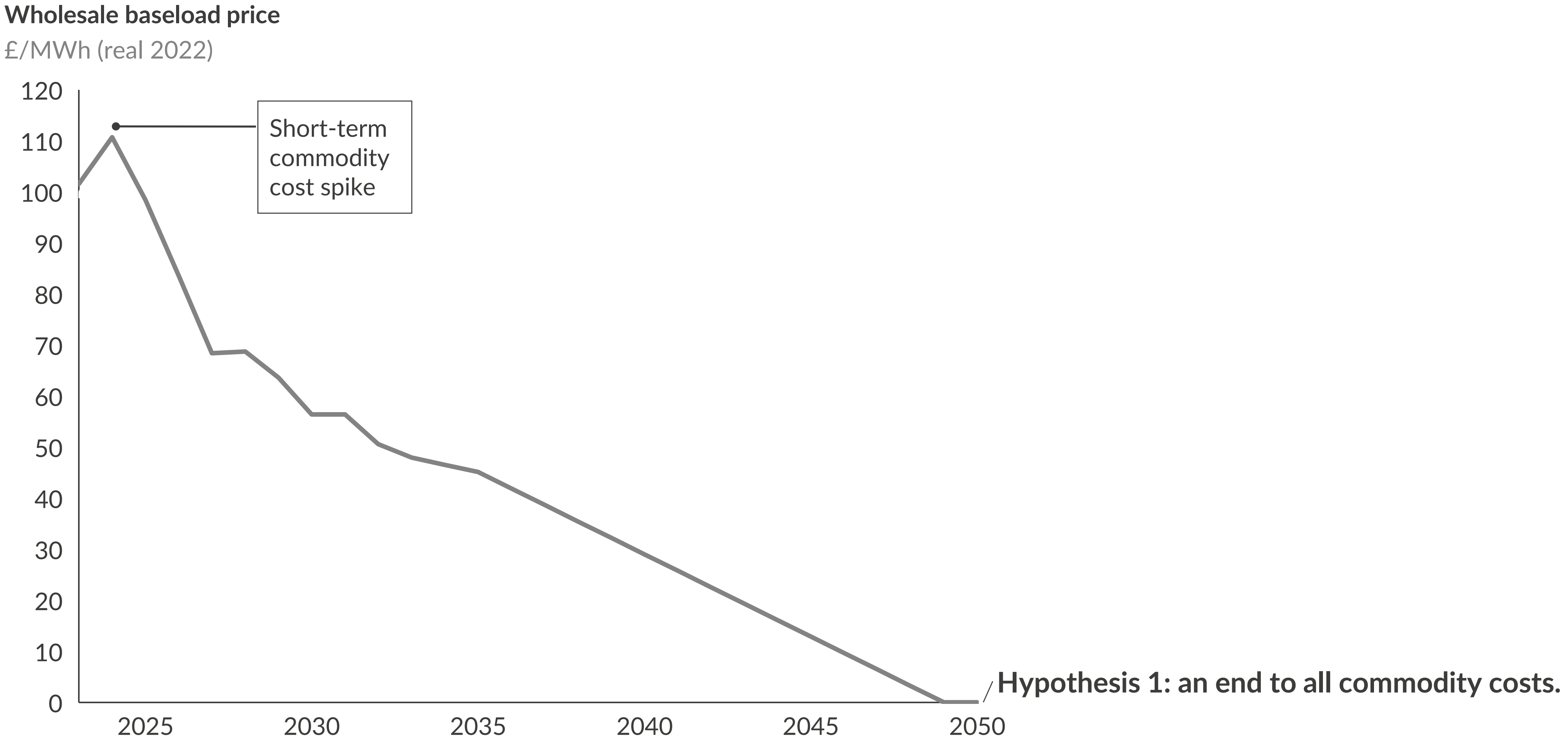
Affordability
Can we manage the costs of the transition?

Is wholesale price going to drop to the floor in a Net Zero world?



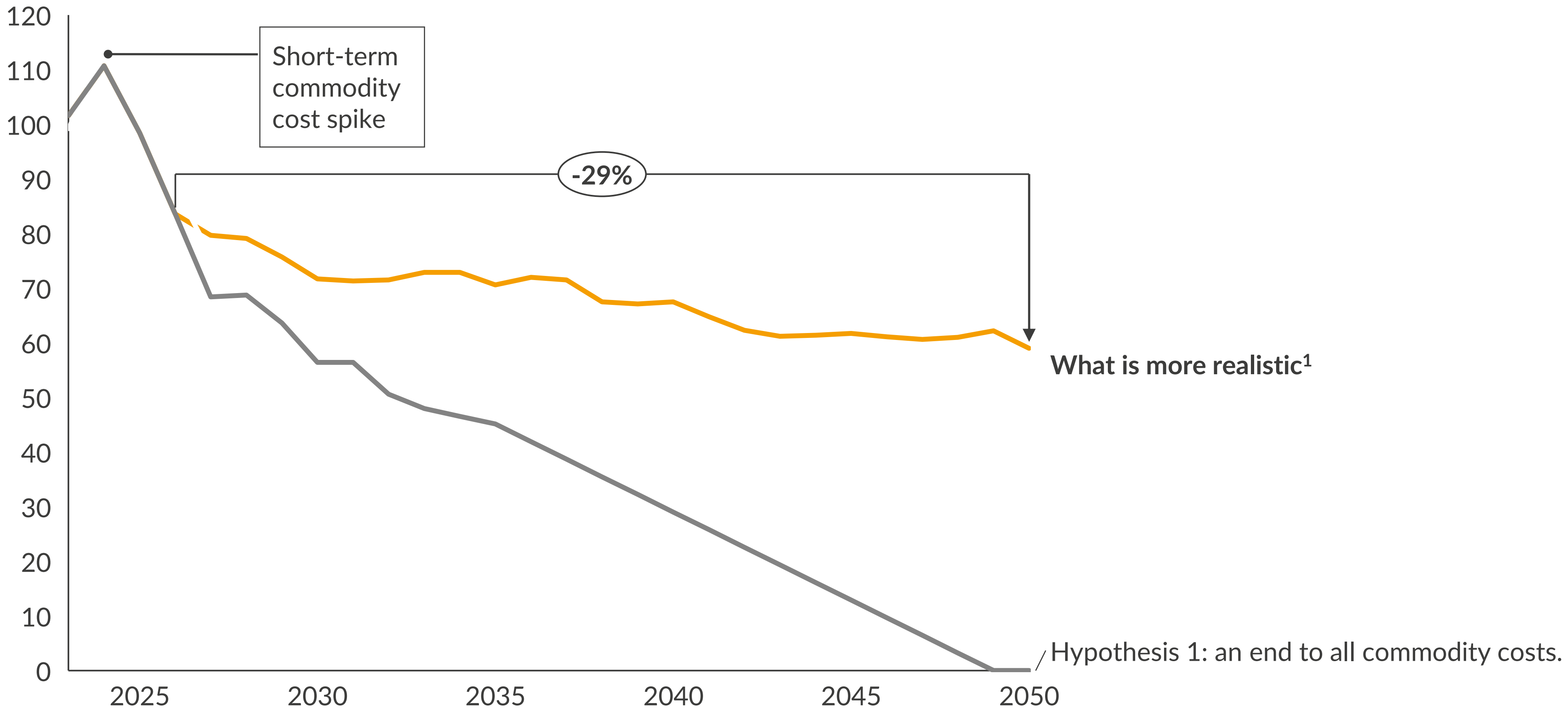
1) Aurora Central scenario forecast, October 2023 publication cycle. 2) Aurora Net Zero scenario forecast, October 2023 publication cycle.

Source: Aurora Energy Research

Is wholesale price going to drop to the floor in a Net Zero world?

Wholesale baseload price

£/MWh (real 2022)



1) Aurora Central scenario forecast, October 2023 publication cycle. 2) Aurora Net Zero scenario forecast, October 2023 publication cycle.

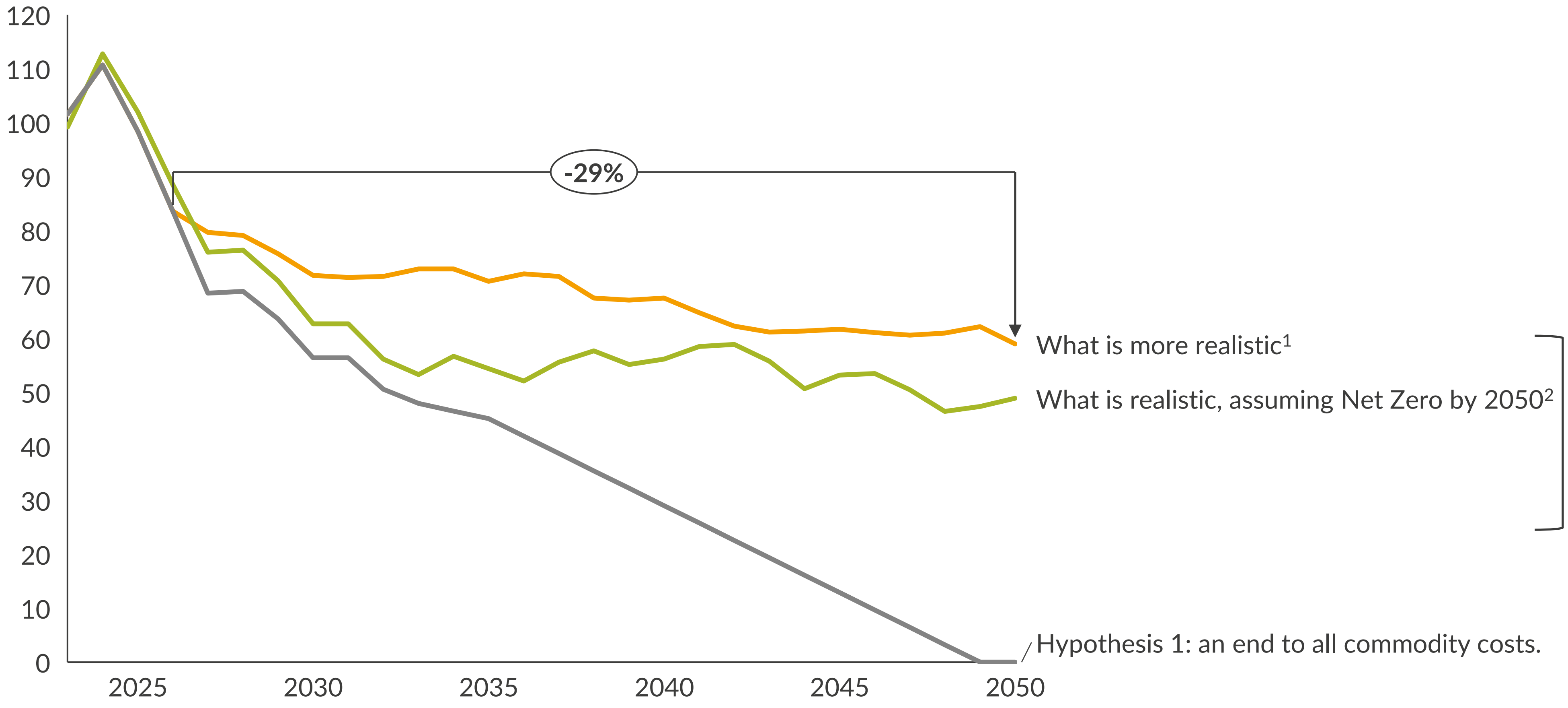
Source: Aurora Energy Research

Is wholesale price going to drop to the floor in a Net Zero world?

No – commodities continue to set the price more than half the time

Wholesale baseload price

£/MWh (real 2022)



What explains this difference?

1. Rising demand
2. Stable /rising long-run commodity prices

1) Aurora Central scenario forecast, October 2023 publication cycle. 2) Aurora Net Zero scenario forecast, October 2023 publication cycle.

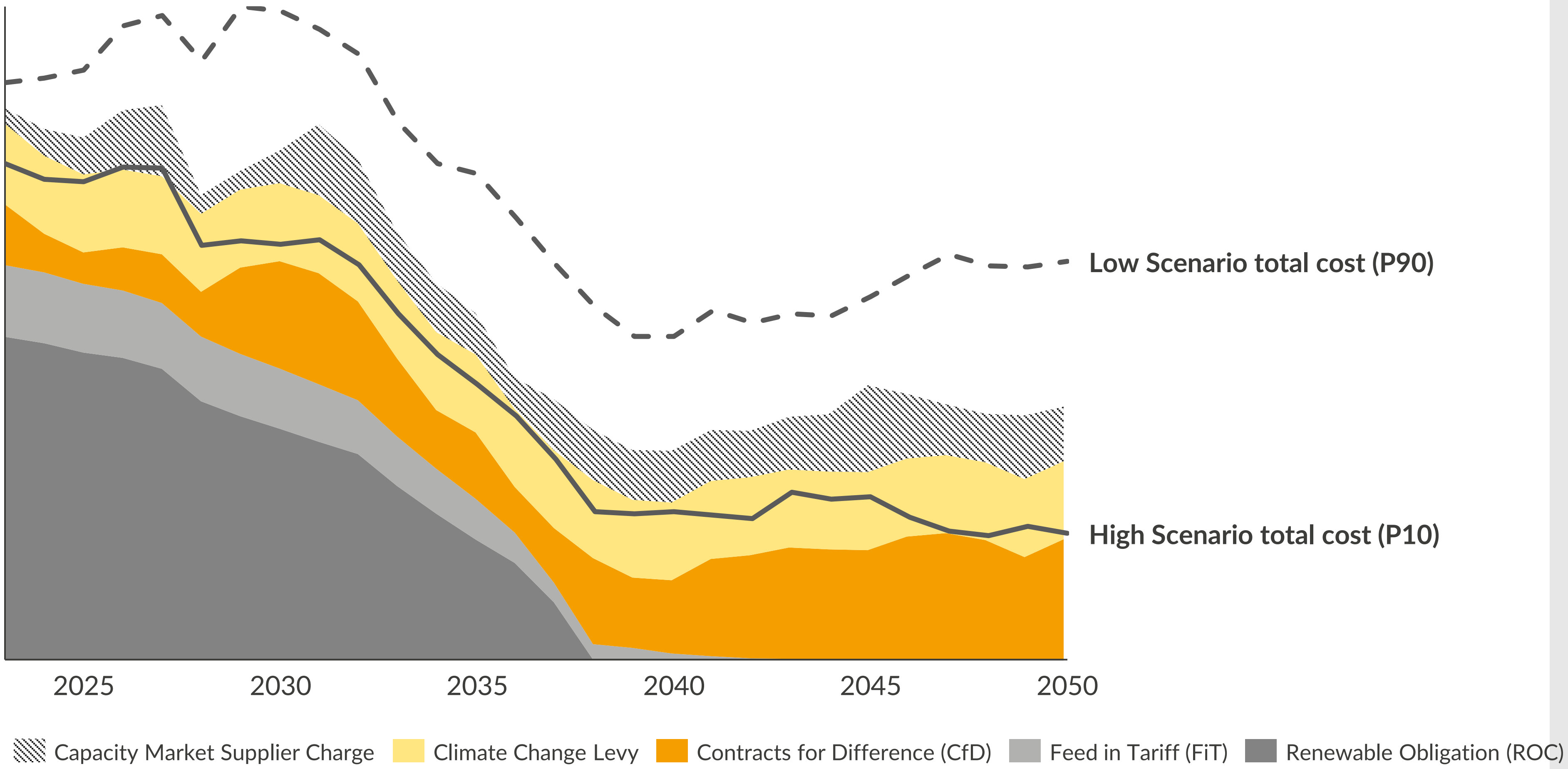
Source: Aurora Energy Research

Are policy costs inexorably rising?

No – although many important policy choices remain

Illustrative policy costs breakdown for suppliers– Aurora Central[1]

£/MWh (real 2022)

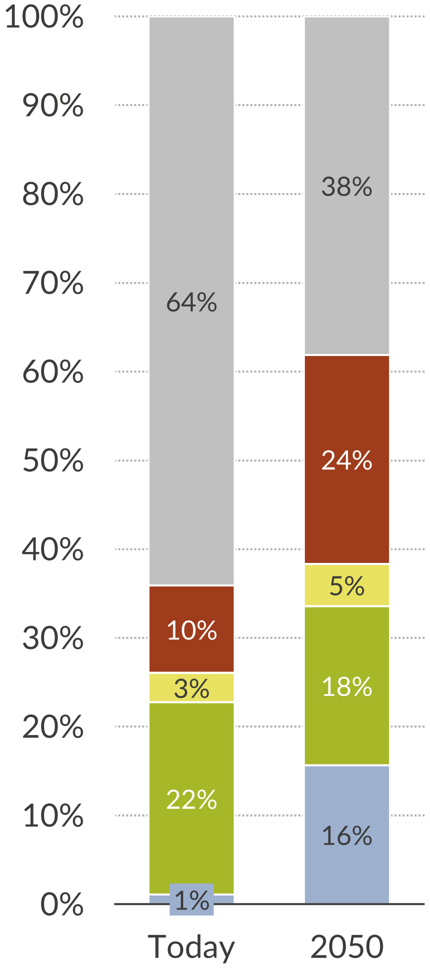


Efficiency

- Move expensive early renewables fully amortised by mid-2030s.
- A net zero power system requires an addition 38GW low carbon generation capacity on top of the already expected 50GW wind and solar.
- Further policy choices could make the power system more or less efficient
  1. How efficient the future system will be at integrating renewables?
  2. Optimising heat decarbonisation can make a ~£20/MWh difference
  3. Where do the costs of industrial decarbonisation fall?

The bigger debate around affordability is not whether we can afford to decarbonise but how best to allocate costs

Total system cost components shares, %



Cost elements	Costs to be recovered by 2050	Direction of travel to 2050	Current Time of Use Dependency
Wholesale Costs	£554 – 614bn	Increasing penetration of low marginal cost power will reduce wholesale costs	
Network Costs	£174 – 201bn	Installed capacities are expected too more than double towards 2050 which will require significant expansion of the network	
Balancing Costs	£59 – 61bn	With increased intermittency, lower inertia and voltage control, the cost of balancing the system is set to grow significantly increasing	
Low Carbon Subsidies	£155 – 188bn	To meet the net zero goals increasing amount of renewables will come online, which will depress their capture prices	
Capacity Market	£29 – 108bn	As LRMCs fail to be recovered through wholesale costs, the missing money increases. In addition, retiring existing assets necessitate higher prices to finance new-build capacity	

Wholesale costs Network costs Balancing Costs Low Carbon Subsidies Capacity Market

Fairness

- Recovery of capital costs through levies, rather than wholesale power costs, will be a majority of power system costs
- Very little attention yet given to how costs are charged to domestic consumers with both efficiency and fairness effects
- Major gains for early adopters of flexibility (who also make the system more efficient overall)
  - ~10% lower average household wholesale costs for smart user in dumb world
  - Only marginal gains once everyone is smart
  - Enabling infrastructure, like distribution network upgrades, paid by everyone

Sources: Aurora Energy Research

Takeaway 3: Consumer costs are not bound to rise inexorably. There are real choices about efficiency and fairness that will determine the costs of the transition and who bears them.

Key takeaways

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Renewable capacity is expected to grow substantially across Europe, driven by decarbonization targets and rising commodity prices, with new capacity additions representing a potential cumulative investment opportunity of up to 464 billion €. But we are well behind the pace elsewhere, especially heat decarbonisation.

The speed of the energy transition in Europe is threatened by an increasingly constrained grid, with the cost of managing grid constraints increasing alongside renewables deployment and curtailment. Policy has to take a whole system approach to both deployment and integration.

There is nothing inevitable about inexorably rising consumer energy bills but policy costs now will make a material difference to the efficiency, fairness and therefore public acceptability of the transition.

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