



Energy
Transitions
Commission

ETC 2025 workplan: emerging key insights

*ETC Commissioners Meeting
20th March 2025*

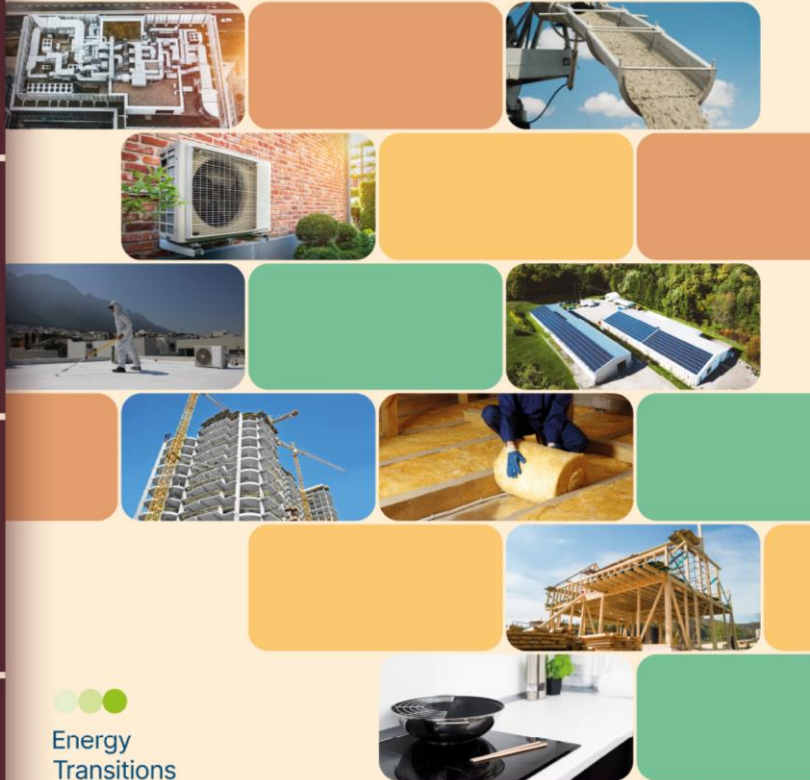


Energy
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Key insights from the latest ETC report on Buildings decarbonisation

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

February 2025 | Version 1.0




Energy
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1

The heating decarbonisation challenge

2

Increasing access to affordable cooling

3

Improving access to clean cooking

4

Efficient lighting and appliances

5

Decarbonising commercial buildings

6

Buildings within a clean energy system

7

The new build opportunity

Three sets of technologies required for zero-carbon buildings

Electric

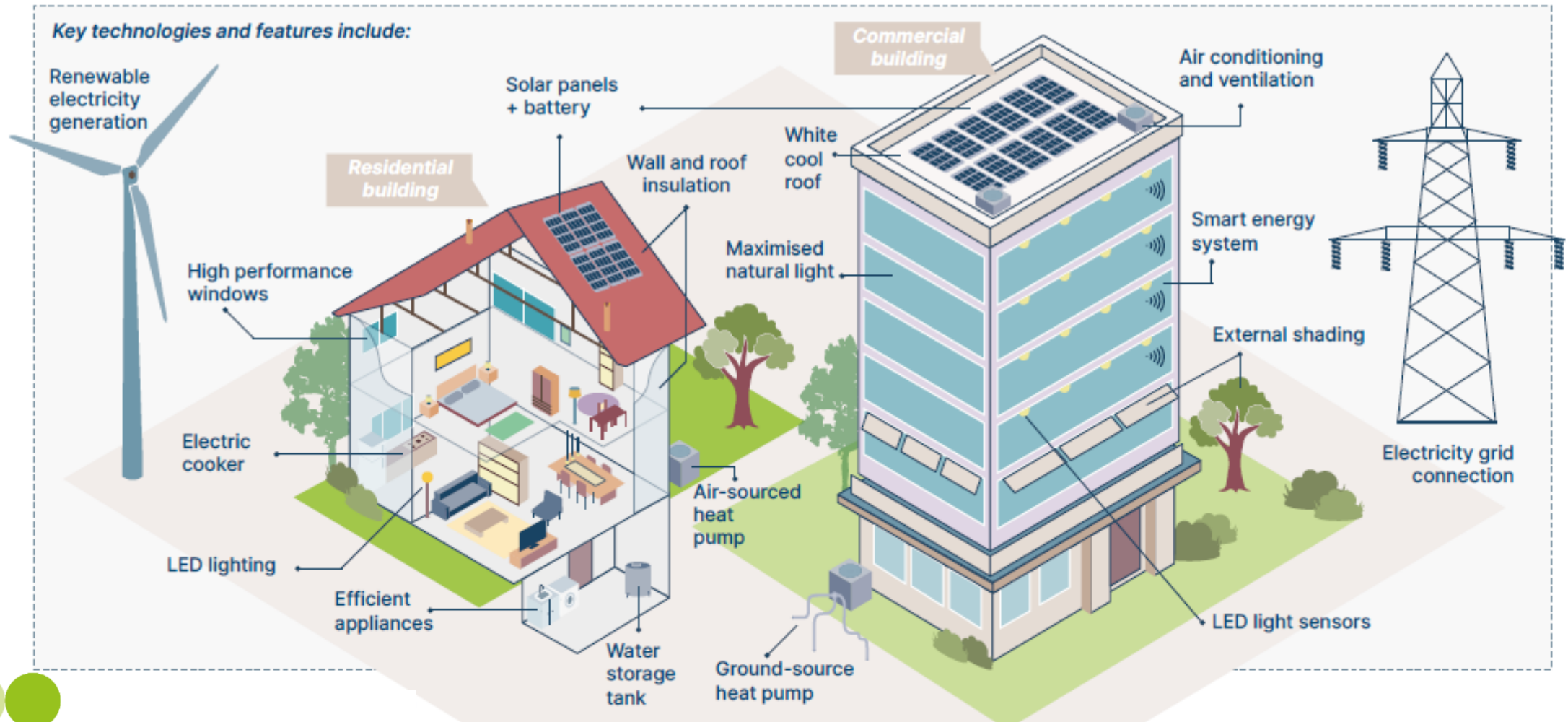
Clean heating technologies

Efficient

Technologies to reduce total energy consumption

Flexible

Technologies to shift energy consumption outside of peak times



Support the buildings decarbonisation campaign by sharing our work

1 x Main report

1 x Exec Summary

3 x Infographics

7 x Key messages

5 x Solution Toolkits

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

February 2025 | Version 1.0

Energy Transitions Commission

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

Executive Summary | February 2025 | Version 1.0

Energy Transitions Commission

DECARBONISING THE ENERGY USED IN RESIDENTIAL AND COMMERCIAL BUILDINGS

Achieving zero-carbon buildings: Electric, efficient and flexible

ANNUAL FINAL ENERGY CONSUMPTION USED IN BUILDINGS

GLOBAL CO₂ EMISSIONS TODAY

- 2.4 GtCO₂ (2019)
- 7.7 GtCO₂ (2050)
- 4.7 GtCO₂ (2050)
- 20% reduction in emissions

Key technologies and features include:

- Renewable electricity generation
- Solar panels + battery
- High performance windows
- LED lighting
- Electric lockers
- High performance doors
- High performance roof
- Maximized natural light
- Water storage tank
- Electric heating
- Heat pump
- Heat recovery
- LED light sensors
- External shading
- Solar energy system
- Electricity grid connection

Higher energy efficiency

- High-rise: High-rise → Mid-rise → Low-rise
- Mid-rise: High-rise → Mid-rise → Low-rise
- Low-rise: High-rise → Mid-rise → Low-rise

2 conditions for low-carbon materials to have near-zero life-cycle emissions:

- Sustainably sourced: Harvested at the right time and replanted
- Store carbon while in-building
- Deal with properly at end-of-life: Recycled or burnt with carbon capture

Low-cost finance and new financial products for retrofits, heat pumps, clean cooking and efficient AC

Early planning for location-specific and co-ordinated gas grid phase-down

Investments in improving the energy efficiency of social housing and implement minimum standards for rental properties

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The heating decarbonisation challenge: how electrification and cost-effective insulation can displace fossil fuels

Global emissions and energy use - residential and commercial space and water heating

Emissions today	Energy use today	Energy use in 2050	
4.1 GtCO ₂ 15% of global emissions	18,700 TWh 45% of total buildings energy use Of which, 2,600 TWh is electricity	+ 14,000-15,000 TWh Of which, 10,000 TWh is electricity	+ 8,000-10,000 TWh Of which, 4,000-6,000 TWh is electricity

But relies on strong policies and actions

The critical need to decarbonise building heating:

- 45% of the total energy consumed in buildings globally is used to heat homes and offices and provide hot water for bathing. Today, this is preliminarily achieved using gas or oil boilers, with heating accounting for 80% of direct fossil fuel use in buildings. While everyone around the world needs to heat water, most heating demand comes from space heating in buildings in northern temperate countries with cold winters.
- A whole-building approach is required to create zero-carbon buildings. This requires home and commercial building owners to adopt three types of technologies:
 - Clean heating technologies powered by clean electricity (e.g., heat pumps and electric radiators).
 - Insulating walls and windows.
 - Smart technologies that enable households and businesses to fix their energy use to different times of day (e.g., smart energy management systems, rooftop solar panels, and batteries).

Electrifying heating is effective and can be cost-effective relative to fossil fuel boilers:

- Building heating can and should be almost entirely electrified, primarily with heat pumps. In most circumstances, heat pumps can provide low-carbon heat at a total cost of ownership comparable, and in many cases lower, than fossil fuels. This is because, while heat pumps cost more than gas boilers upfront, they are 3-4 times more efficient than a gas boiler and will therefore have lower operating costs if electricity costs less than 3-4 times gas. There is, however, no one-size-fits-all solution. A range of technologies (including various district heat network solutions) will be needed to solve the challenges of specific building types and climate variations.
- In some countries, largely in Europe, hydrogen gas is being considered as an alternative to replace natural gas for heating. However, hydrogen is not a viable alternative to replace gas heating at scale. It is much less efficient (e.g., "green hydrogen" produced via electrolysis would require 3-4 times more electricity than heat pumps to produce equivalent heat input); and it would still require substantial retrofits to boilers and the gas network.

There is a huge opportunity for low-cost insulation improvements:

- Insulating the least efficient homes must be a priority, and combined with heat electrification can lower energy bills and improve comfort levels. For those at lower income levels government support is likely to be required. However, for the average home, deep retrofits is not a pre-requisite for installing a heat pump, as long as radiators and heat pumps are appropriately sized.

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Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

Achieving Zero-Carbon Buildings: Electric, Efficient and Flexible

Solution toolkit: Actions for energy and technology companies

Buildings decarbonisation relies on the deployment of a wider range of clean and efficient technologies and active support for their rollout.

Global emissions

- 9.7 GtCO₂ (2019)
- 2.6 GtCO₂ (2050)
- 4.7 GtCO₂ (2050)

Buildings decarbonisation relies on the deployment of a wider range of clean and efficient technologies and active support for their rollout.

- Heating
- Cooking
- Cooling
- Lighting and appliances
- Embedded carbon

Drive cost reductions and efficiency improvements

- Set commitments and targets for clean heating and cooking technologies to account for an increasing share of total sales.
- Invest in R&D to improve technologies:
 - Heat pumps: Focus on improving efficiency, reducing size and noise, and the ease of installation to drive down costs.
 - AC: Focus on improving efficiency and reducing the risk of refrigerant leakage.
 - Solar panels, batteries and other household appliances: Focus on improving efficiency, asset lifetimes and lowering costs.
- Engage in bulk procurement deals with national and local governments to support the decarbonisation of public buildings, social housing, and lower the costs of household appliances.
- Commitments to use refrigerants with a low global warming potential (GWP) in heat pumps and AC.
- Commitments to exceed regulated minimum energy performance standards.

Build infrastructure, skills and supply chains

- Conduct a full review and evaluate any constraints in national and local electricity networks and identify priority investments.
- Assist policymakers in developing street-by-street decarbonisation strategies, providing data and projections of supply demands and additional gas.
- Invest in training heating and cooling engineers and retrofit practitioners, participating in skills acceleration schemes and providing apprenticeships.
- Engage with policymakers on supply chain constraints and the importance of policy certainty.

Drive the deployment of electric, smart and flexible technologies

- Build consumer trust in electric technologies through local pilots, one-stop advice services and consumer information campaigns.
- Commitments to rolling out smart metres to all customers without them.
- Introduce dynamic time-of-use tariffs, enabling consumers to benefit from smart heating, cooling and EV charging.
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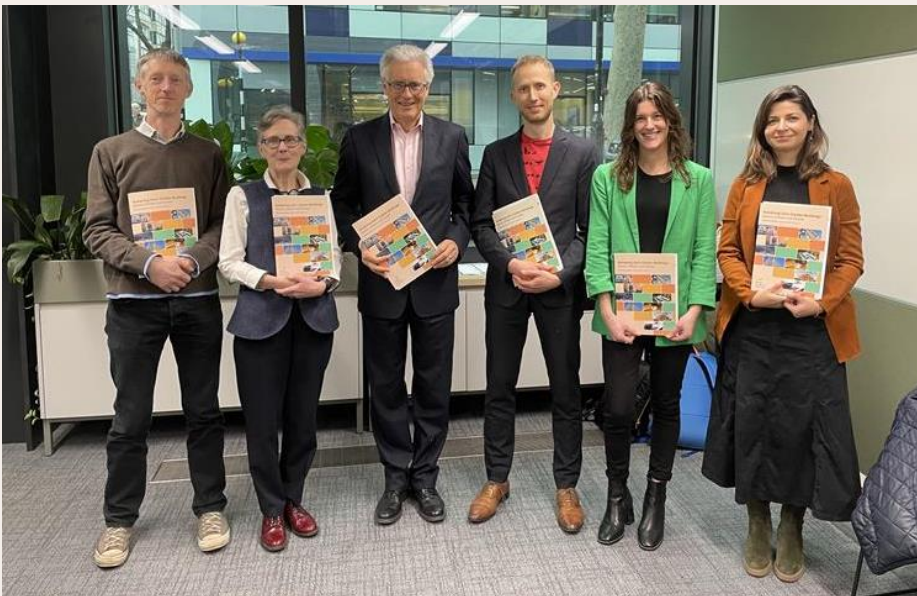
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All available to download on ETC's website and member portal



Achieving Low-Carbon Buildings: Launch Highlights

Our webinar in partnership with Arup drew around 300 attendees and featured speakers from Arup, World Green Building Council, World Resources Institute, and Octopus Energy



Press release newswire distribution to over 30 countries and embargoed briefings with journalists led to coverage with over 600 news stories



ETC members amplified our social media campaign, and our special issue newsletter reached over 24,000 people



Molly Walton • 2nd
Director, Energy at We Mean Business Coalition
1w • 🌐

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Sector by sector, clean energy is scaling and displacing fossil fuels. My colleague [Santeri Palomäki](#) has done an excellent rapid fire review of the [Energy Transitions Commission's](#) new report on Zero-Carbon Buildings.

ETC's report finds that a combination of electric, efficient, and flexible solutions can decarbonise buildings, improve standards of living, and reduce energy bills if supported by ambitious policy.

[#ZeroCarbonBuildings](#) [#Buildings](#)



Vincent Minier • 2nd
VP Energy Transition Research at Schneider Electric
1w • 🌐

+ Follow ...

A great piece from the ETC is out today. Very complete and depicting well what should be future-proof buildings! [#digitalbuildings](#) [#electrification](#) [#heatpumps](#) [#microgrid](#) [#batterystorage](#)

"Buildings are responsible for one-third of the world's carbon emissions. Harnessing the power of electrification, on-site generation, digital controls, IoT, big data and digital twins can make a net zero-carbon future in our built environment possible. Incorporating these technologies into new constructions or retrofitting existing buildings benefits the planet as well as the safety, resilience, and comfort of our buildings." Said Jean-Pascal Tricoire, Chairman of Schneider Electric.



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Potential for energy productivity improvement: integrated view of transport and industry

Agenda

- **Past energy productivity trends**
- Energy productivity opportunity to 2050
- Key policy priorities



Establishing a common language on energy efficiency is key to enable and coordinate action effectively

Defining key terms

Energy Productivity

The impact of reducing global energy consumption without compromising living standards (e.g. via using less/other goods, less/other materials)

Energy Efficiency

Part of productivity, focusing on energy input of production processes

How to measure progress?

- **Energy intensity:**
Energy input per unit of GDP

E.g. kWh/\$ GDP

- **Energy intensity improvement:**
Yearly change to energy intensity

$$\frac{\Delta \text{Energy intensity}}{\text{Energy intensity}_{t-1}} (\%)$$

Where we want action

Primary Energy

Energy before conversion, including losses during transformation and distribution

Energy consumed by end users, e.g. electricity or petrol

Final Energy

Energy to generate the desired output, e.g. move a vehicle

Useful Energy

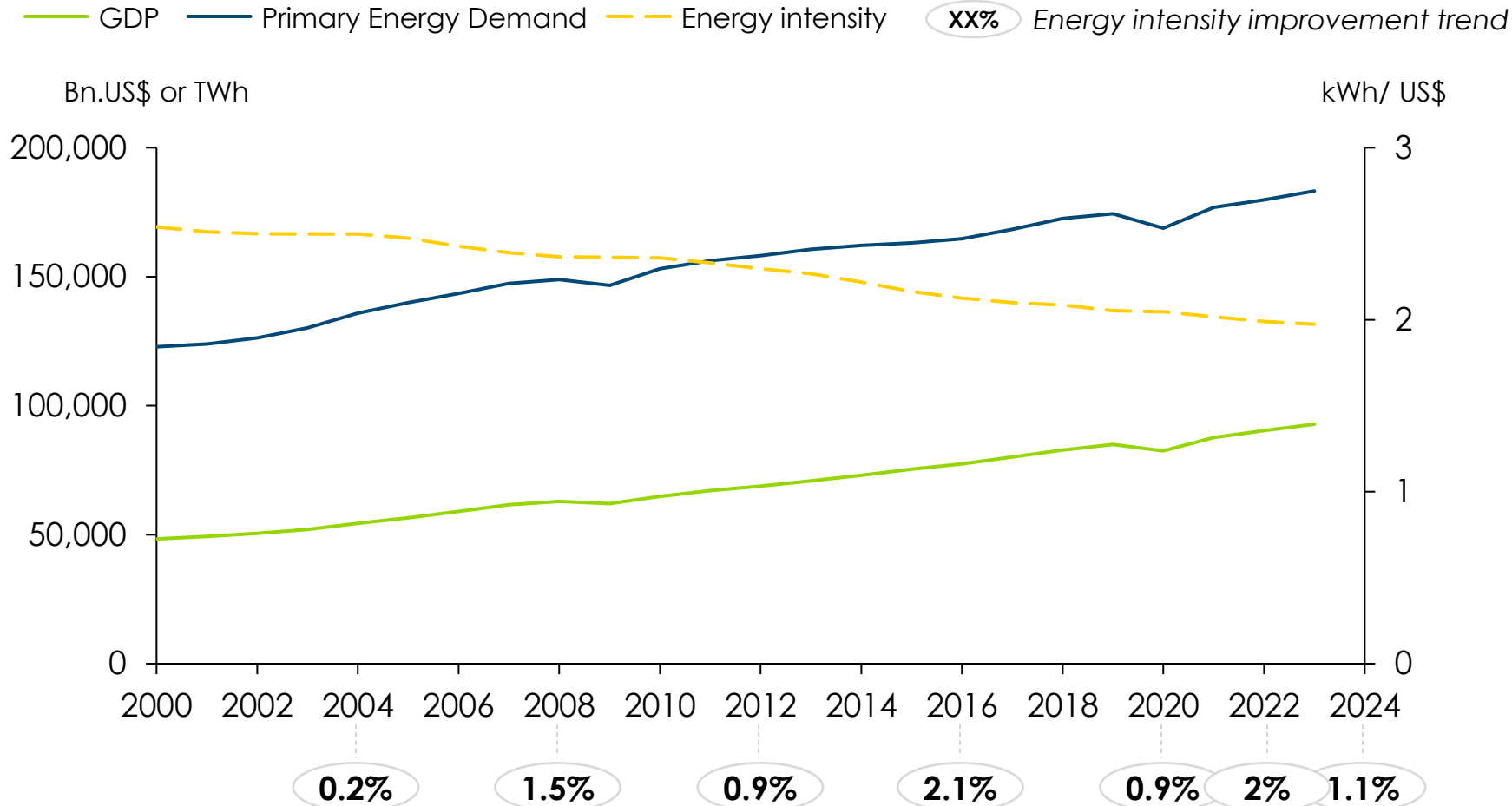


Despite improvements in energy intensity, primary energy demand still grows with GDP

Primary

Total GDP vs. Primary Energy Demand, 2000- 2023

GDP in constant 2015 Bn.US\$, Primary Energy Demand in TWh; Energy intensity in kWh/2015 US\$ GDP



- Energy productivity is a critical lever to **reduce energy costs and strengthen energy security**
- Energy intensity rates have improved over the last 20 years
- At COP 28, a commitment was made to collectively reach **a 4% improvement on the global average of energy intensity** to 2030, from a 2% improvement in 2022



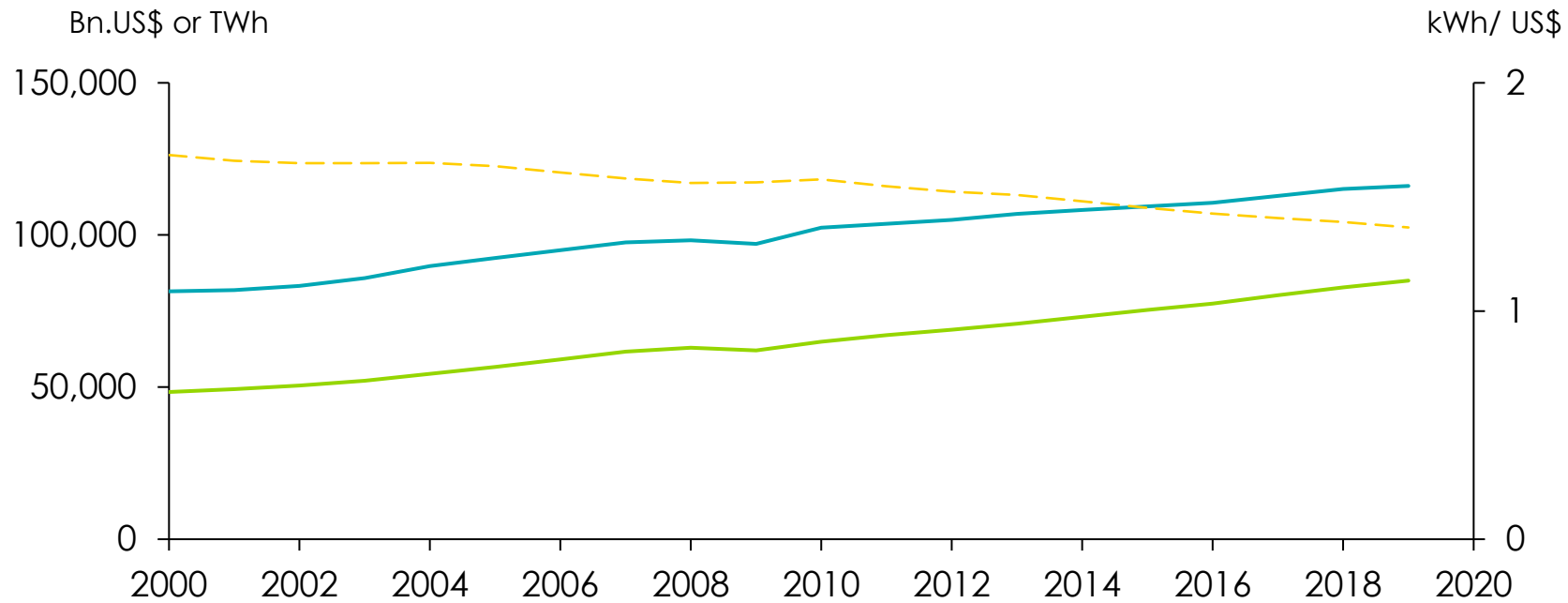
Final energy demand also grows with GDP, but there is a stronger intensity improvement trend



Total GDP vs. Final Energy Demand, 2000- 2019

GDP in constant 2015 Bn.US\$, Final Energy Demand in TWh; Energy intensity trend in constant kWh/2015 US\$

— GDP — Final Energy Demand - - - Energy intensity (XX%) Energy intensity improvement trend



Year	Final Energy Intensity Improvement (%)	Primary Energy Intensity Improvement (%)
2000-2004	0.2%	0.2%
2004-2008	1.5%	1.5%
2008-2012	0.9%	0.9%
2012-2016	1.8%	2.1%
2016-2020	2.2%	0.9%

- Final energy intensity has improved at a **faster pace** than that of **primary energy** in recent years



Agenda

- Past energy productivity trends
- **Energy productivity opportunity to 2050**
- Key policy priorities



Two challenges in energy productivity: reducing final energy demand while growing useful energy, and closing the gap between primary and final

Reducing final energy demand while growing useful energy

=

Using less energy per **building**, **transport** and **industry** while improving living standards

Closing the gap between primary and final energy demand

=

Reducing energy losses in the **power system** and **fuel production**



Two challenges in energy productivity: reducing final energy demand while growing useful energy, and closing the gap between primary and final

Reducing final energy demand while growing useful energy

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Using less energy per **building**, **transport** and **industry** while improving living standards

Closing the gap between primary and final energy demand

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Reducing energy losses in the **power system** and **fuel production**



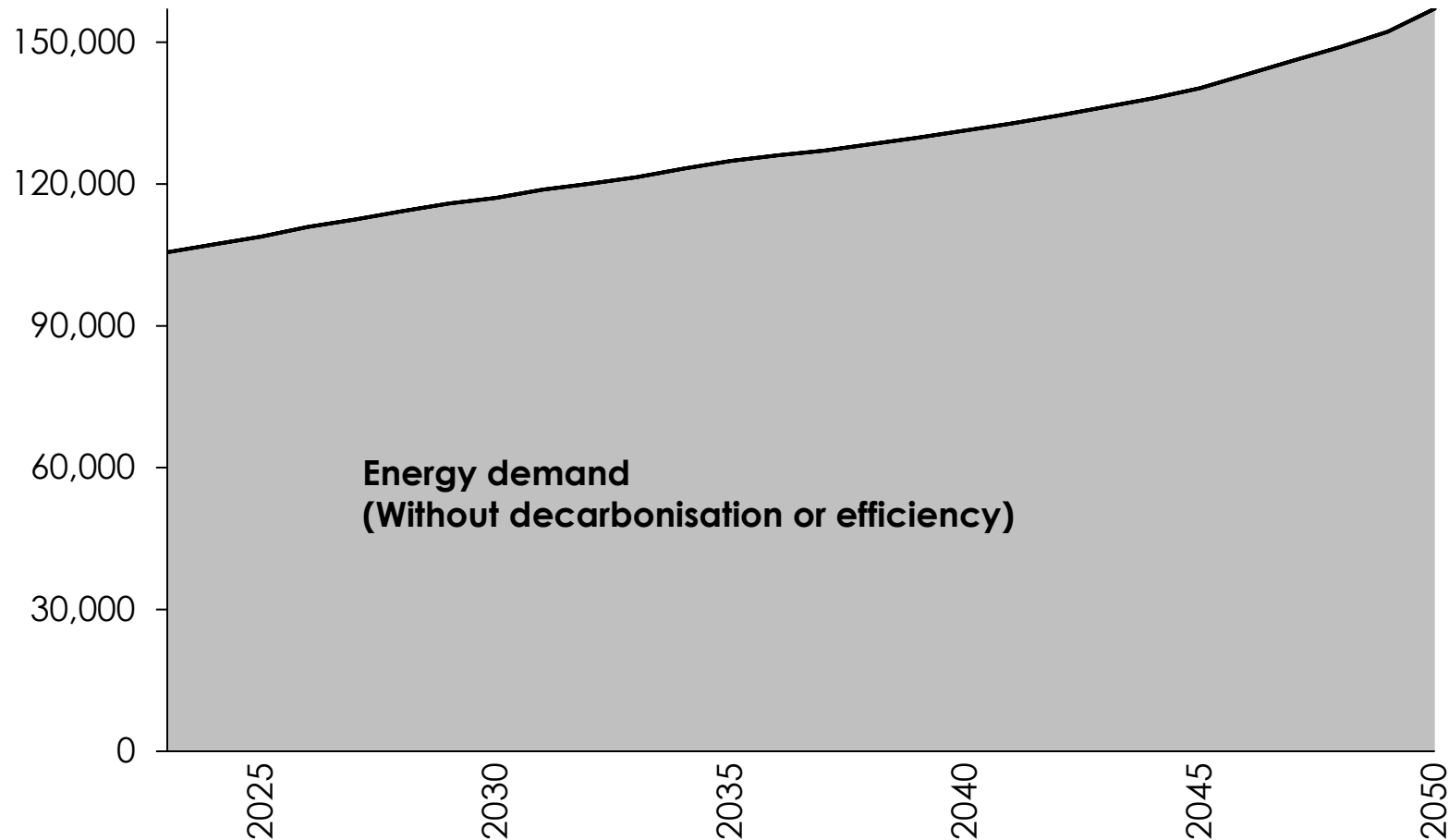
Baseline. Without any decarbonisation or productivity levers, rising energy demand

Preliminary

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation



**Energy demand
(Without decarbonisation or efficiency)**



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

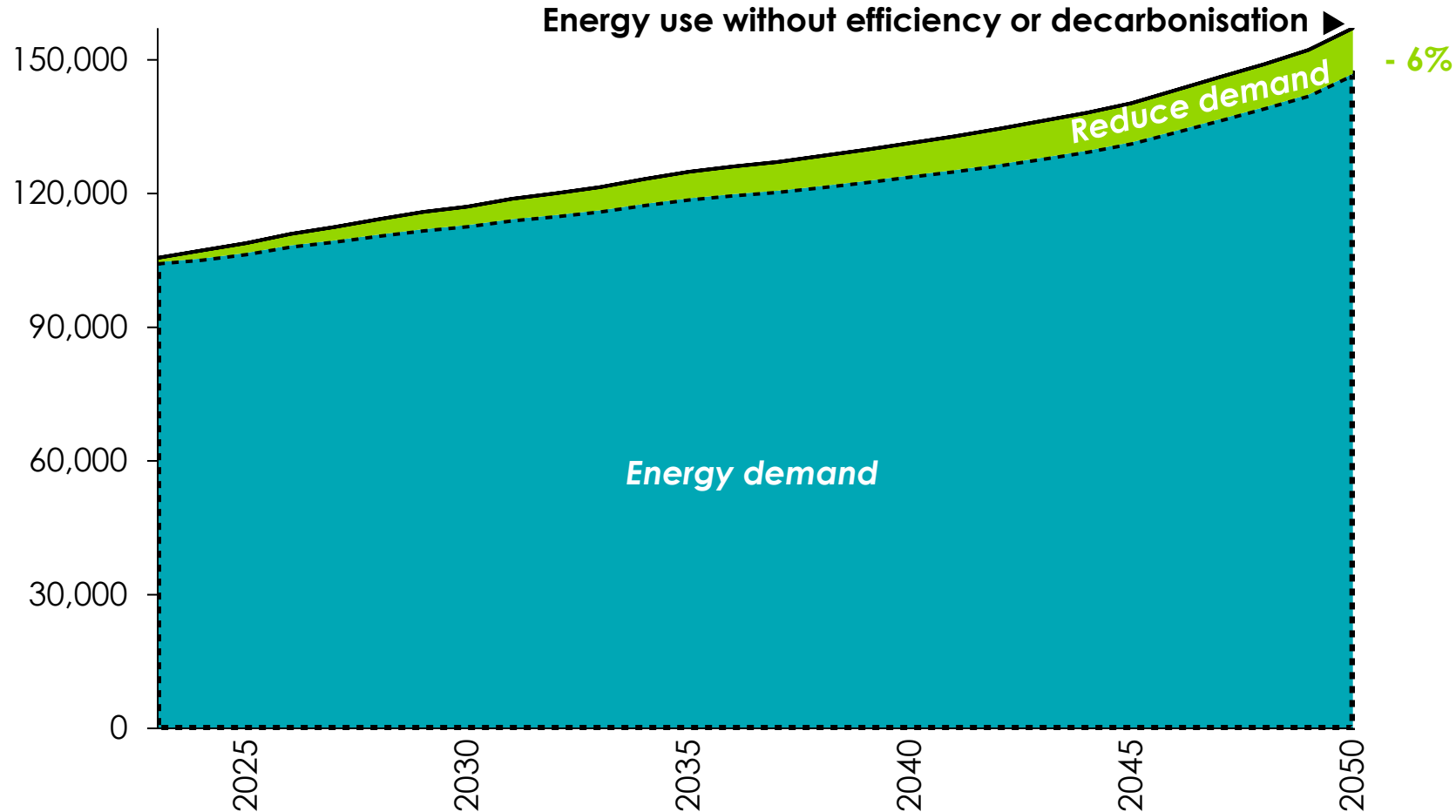
Reduce demand. 6% less energy could come from behavioural shifts and material efficiency

Preliminary

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation



Key actions

Demand reduction: services (e.g. public transport), using less materials (e.g. steel) and better operations (e.g. aviation and shipping)



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

Electrification = efficiency. 30% less energy can be consumed with electrification and demand reduction combined

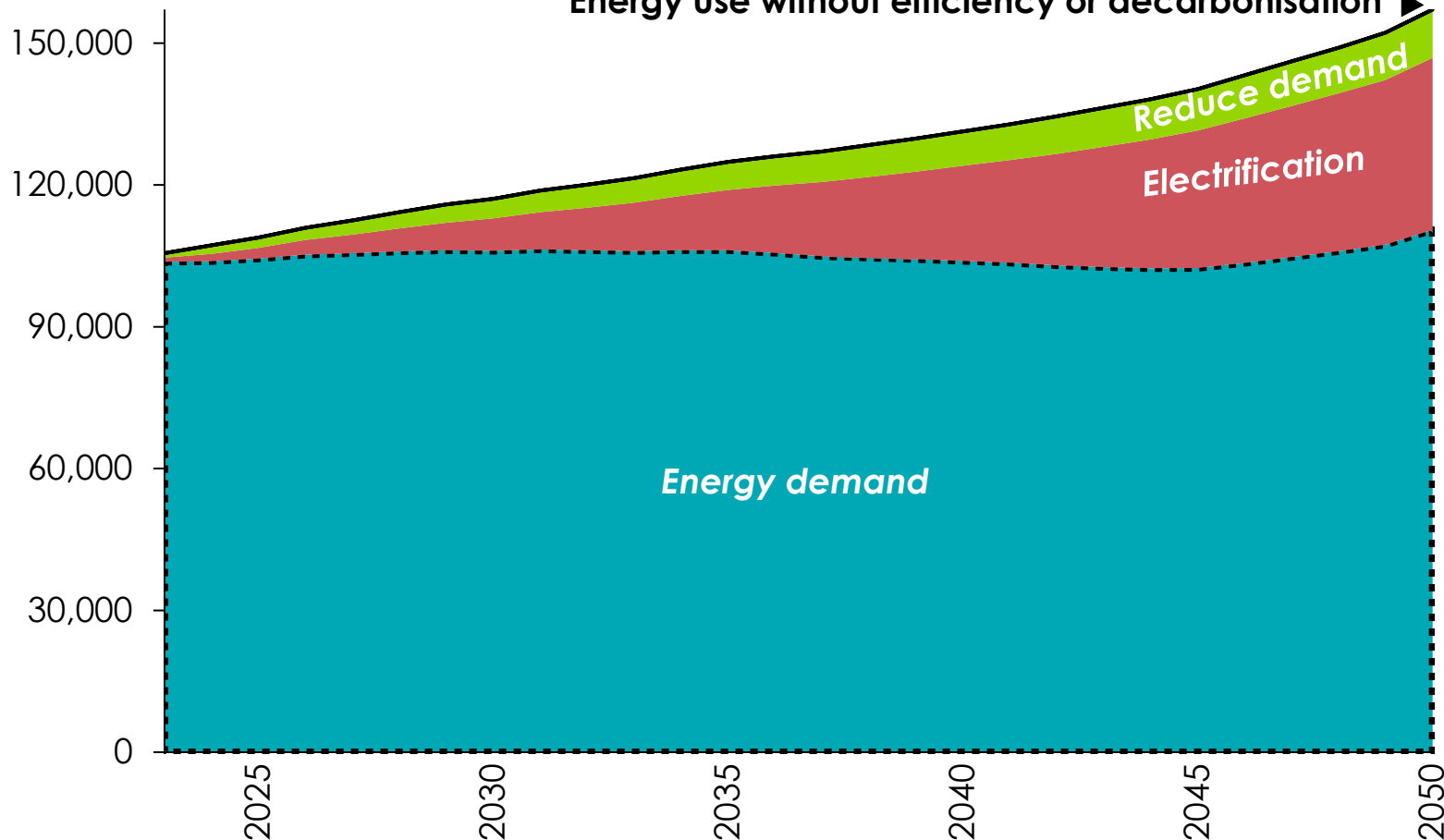
Preliminary

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation

Energy use without efficiency or decarbonisation



Key actions

Demand reduction: services (e.g. public transport), using less materials (e.g. steel) and better operations (e.g. aviation and shipping)

Electrification: switching to electric vehicles, electric heating and cooking

- 6%

- 24%

-30%



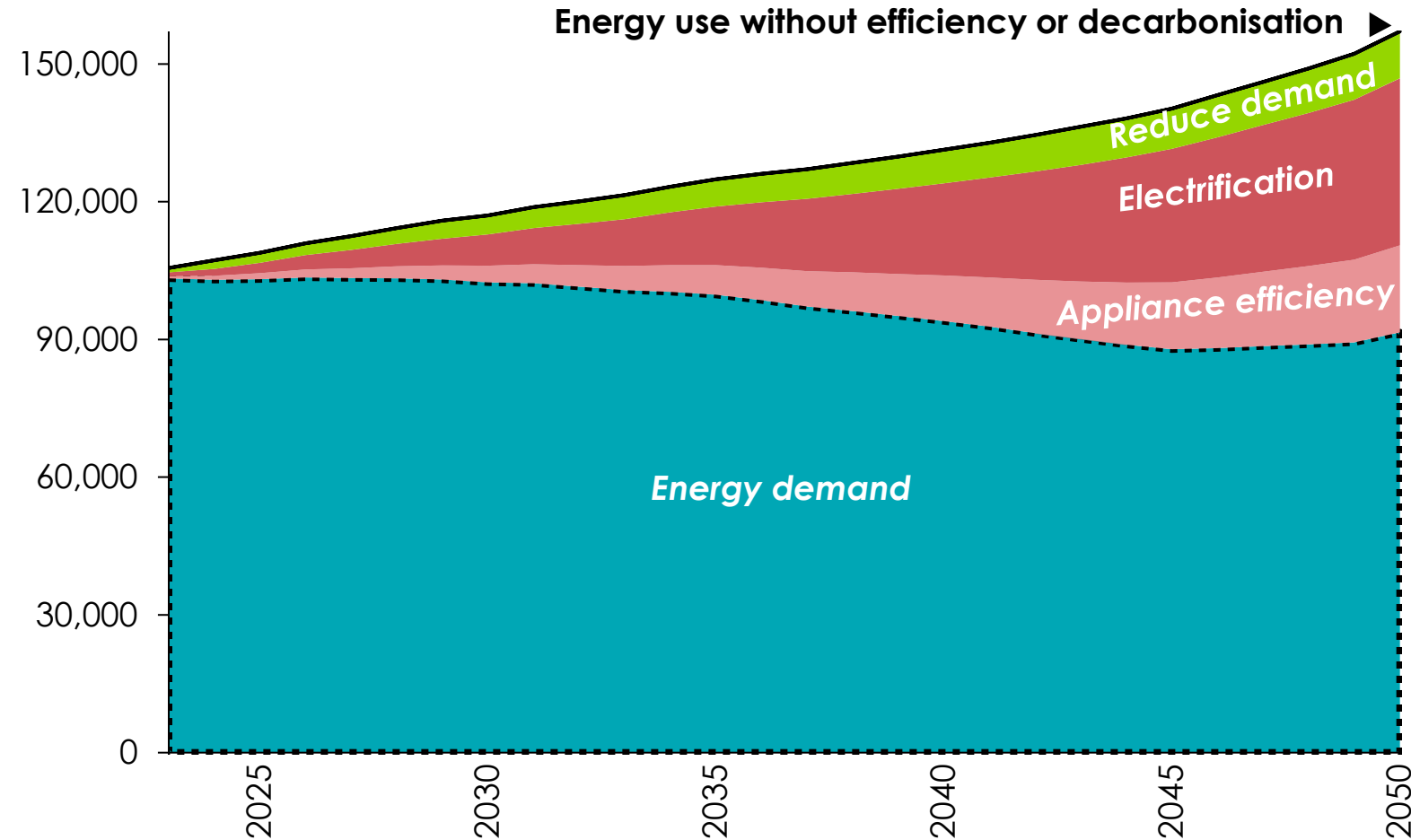
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

Improve electrical appliances and vehicles efficiency. 42% less energy is required with electrification, reduced demand and appliance improvements

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation



Key actions

Preliminary

Demand reduction: services (e.g. public transport), using less materials (e.g. steel) and better operations (e.g. aviation and shipping)

Electrification: switching to electric vehicles, electric heating and cooking

Improving efficiency of key electrical appliances: AC, heat pumps, EVs, lighting and other home appliances

Stock turnover will drive some of the potential for **electrification and appliance efficiency**

- 6%

- 24%

- 12%

-42%



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

Insulation. 45% less energy can be consumed, if combined with appliance efficiency, lower demand & better buildings insulation.

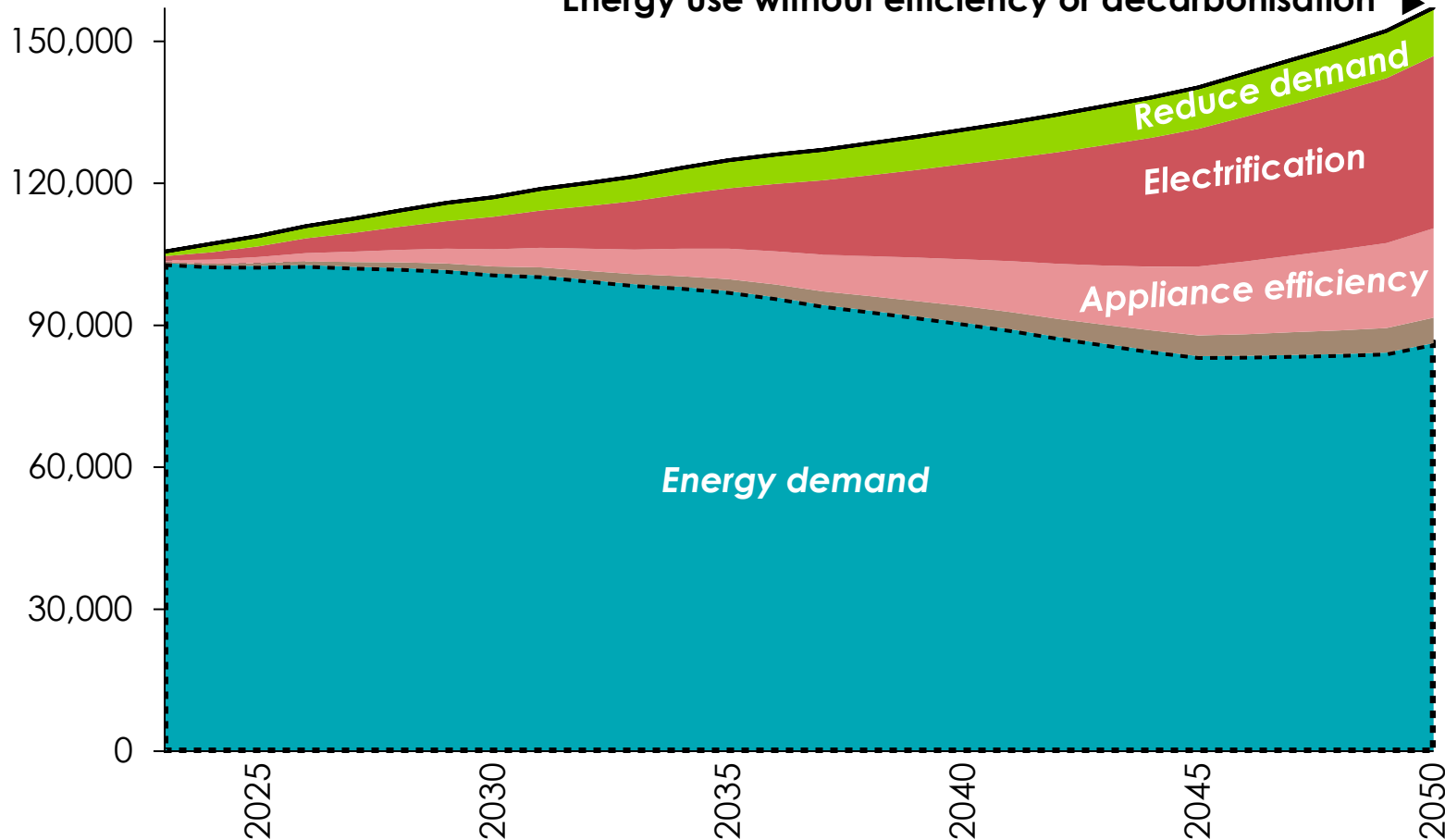
Preliminary

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation

Energy use without efficiency or decarbonisation



Key actions

Demand reduction: services (e.g. public transport), using less materials (e.g. steel) and better operations (e.g. aviation and shipping)

- 6%

Electrification: switching to electric vehicles, electric heating and cooking

- 24%

Improving efficiency of key electrical appliances: AC, heat pumps, EVs, lighting and other home appliances

- 12%

Better insulation in buildings: better buildings codes and fabric improvements

- 3%

-45%



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

Overall, ~50% less energy can be consumed, with all efficiency levers combined

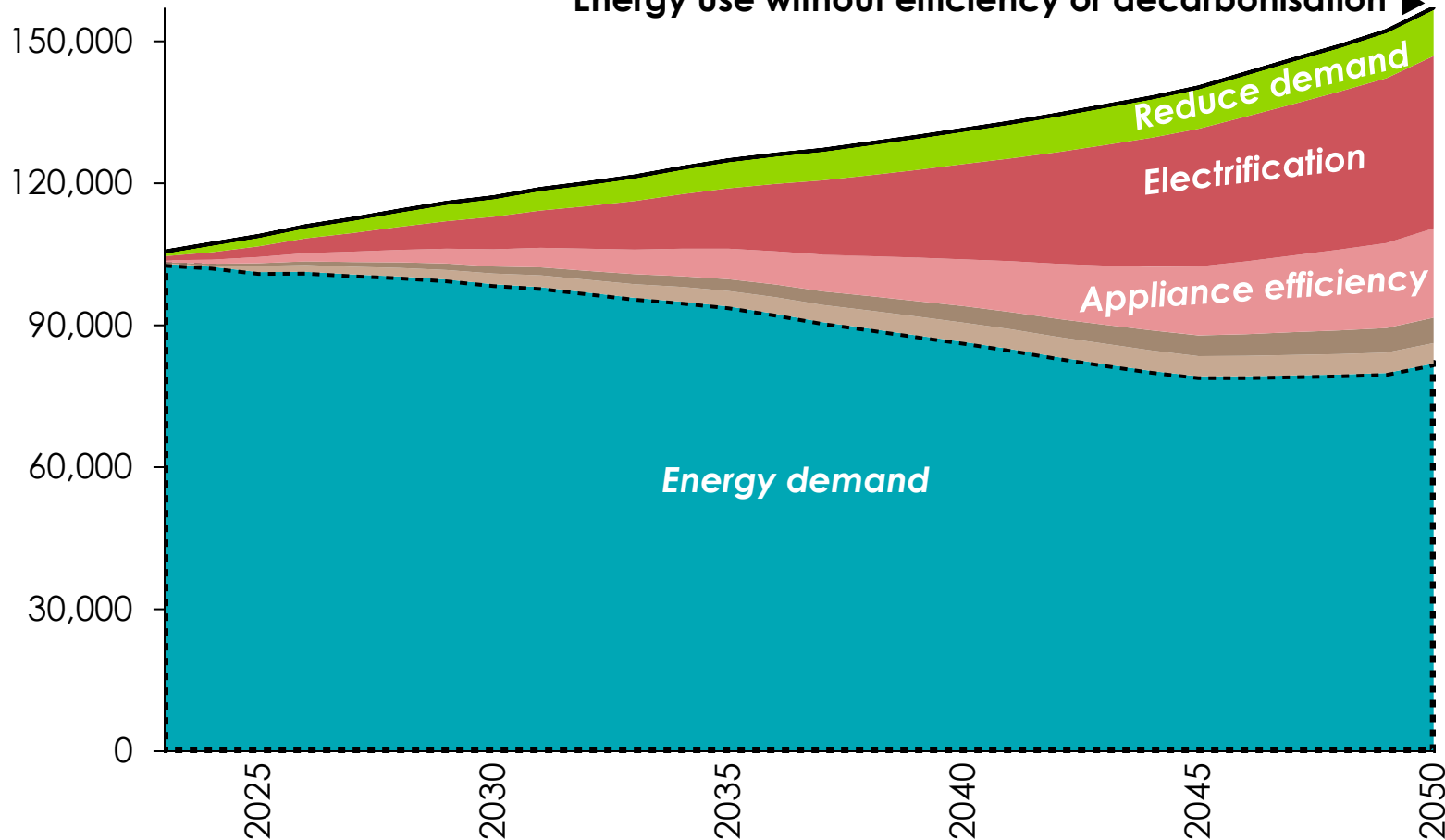
Preliminary

Final Energy demand vs. Productivity levers

TWh

% Reduction potential compared to 2050 Energy use without efficiency or decarbonisation

Energy use without efficiency or decarbonisation



Key actions

Demand reduction: services (e.g. public transport), using less materials (e.g. steel) and better operations (e.g. aviation and shipping)

- 6%

Electrification: switching to electric vehicles, electric heating and cooking

- 24%

Improving efficiency of key electrical appliances: AC, heat pumps, EVs, lighting and other home appliances

- 12%

Better insulation in buildings: better buildings codes and fabric improvements

- 3%

Everything else – sector-specific interventions

- 3%

-48%



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

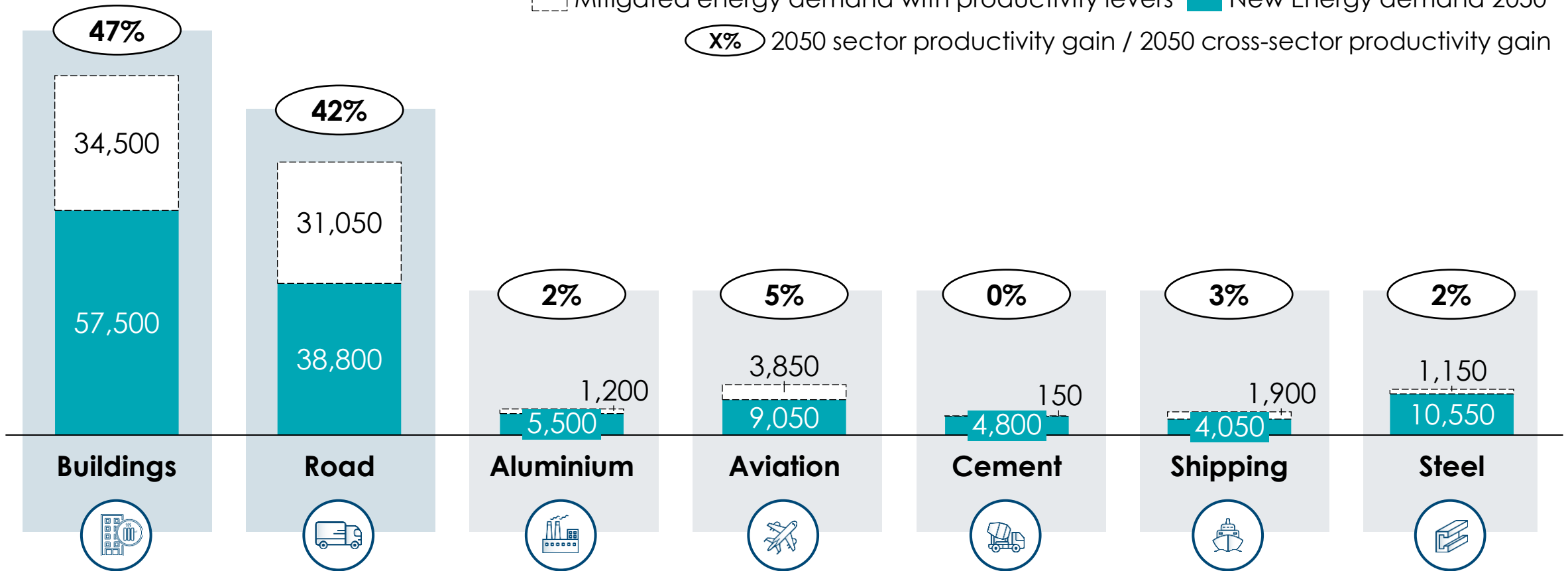
Buildings and road transportation hold the biggest opportunity: together they hold 89% of the potential productivity gain in final energy demand

Preliminary

Final energy demand in 2050

TWh

 Mitigated energy demand with productivity levers
 New Energy demand 2050
X% 2050 sector productivity gain / 2050 cross-sector productivity gain



Note: Aluminum include captive generation;
 Source: Building Report (ETC), Road Report (ETC), STS (MPP)

Two challenges in energy productivity: reducing final energy demand while growing useful energy, and closing the gap between primary and final

Reducing final energy demand while growing useful energy

=

Using less energy per **building**, **transport** and **industry** while improving living standards

Closing the gap between primary and final energy demand

=

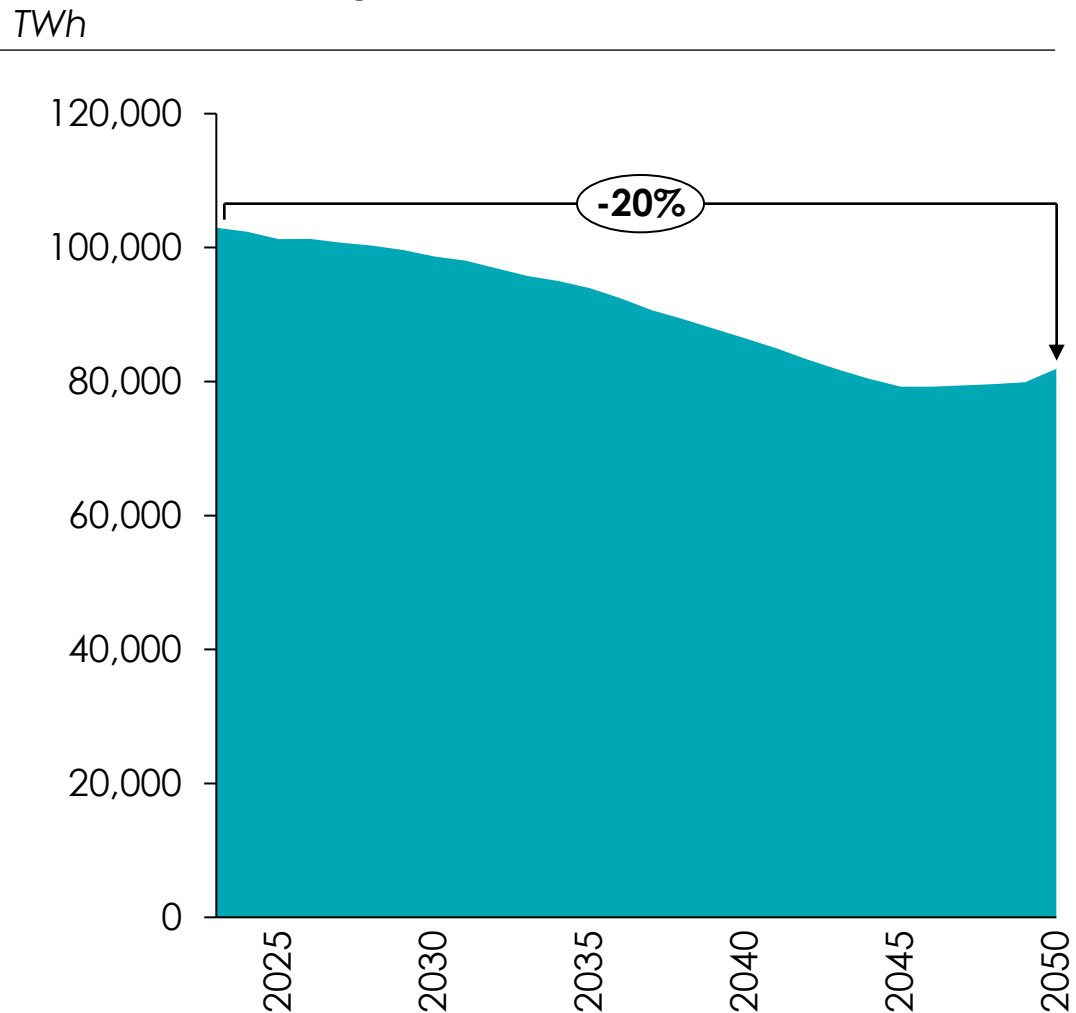
Reducing energy losses in the **power system** and **fuel production**



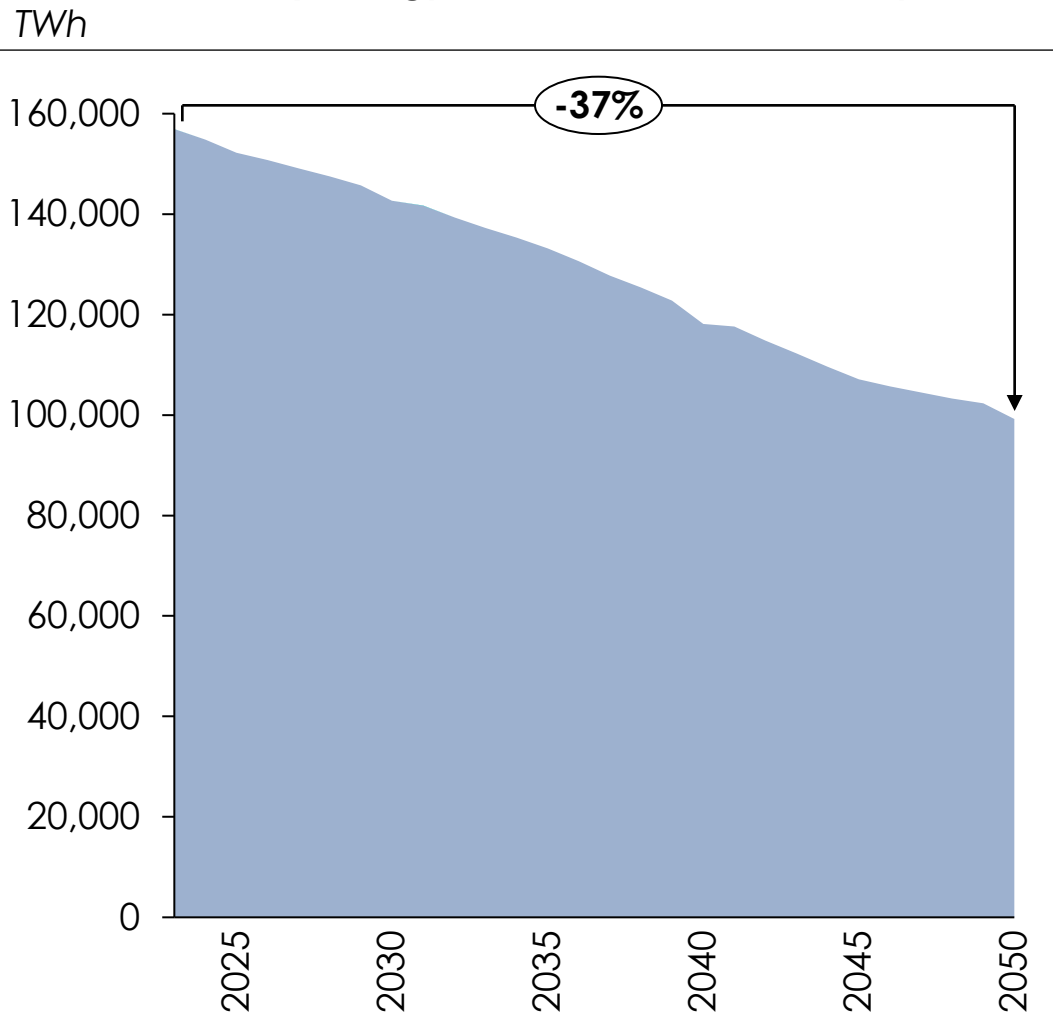
Primary energy demand decreases even more drastically than final energy demand due to clean electrification

Preliminary

Net Zero Final Energy with Productivity levers



Net Zero Primary Energy demand with Productivity levers

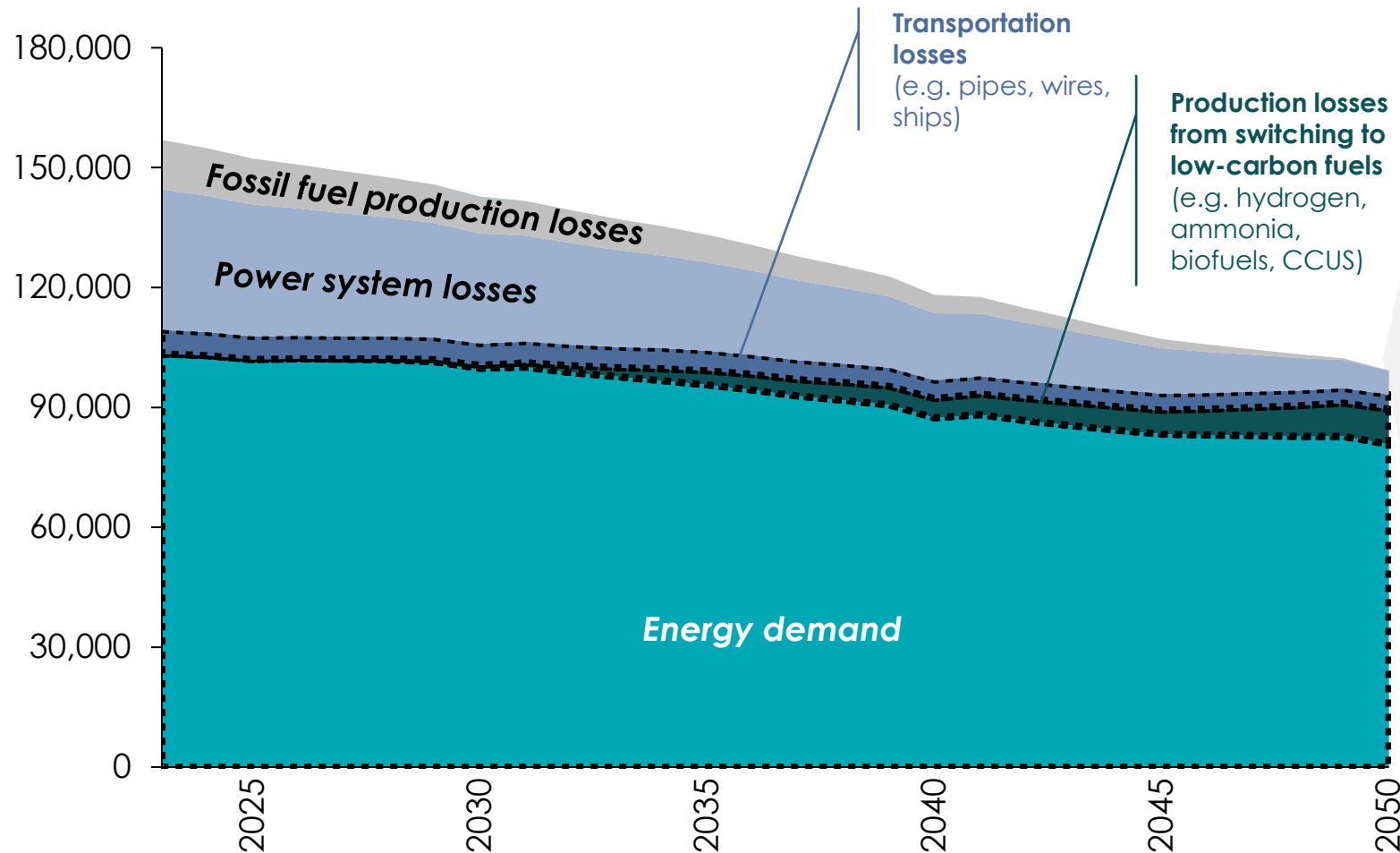


Note: Does not include Chemical levers, Road to be adjusted
Source: Systemiq analysis for ETC;

Growth of the power system as fossil consumption phases down, along with power decarbonisation, is main driver to reduce primary energy demand

Preliminary

Primary energy demand
TWh



- **Growth of the power system** as direct fossil use is displaced via electrification decreases primary losses, due to electricity being 20 to 60% more efficient than fossil fuel combustion
- Further reductions on primary losses are possible as **power system decarbonises and grid emissions declines**



Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP), RMI (2024) The Incredible Inefficiency of the Fossil Energy System

Agenda

- Past energy productivity trends
- Energy productivity opportunity to 2050
- **Key policy priorities**



Priority actions to drive energy productivity

	Main productivity levers	Key actions
Final Energy	1 Electrification	<ul style="list-style-type: none">• Set and uphold full ICE sales bans by 2035• Expand charging infrastructure by investing in fast chargers and coordinating network upgrades
	2 Improvements in the efficiency of electrical appliances and vehicles	<ul style="list-style-type: none">• Set ambitious efficiency standards on new vehicles, main household appliances (e.g. refrigerators, air conditioning), and overall buildings performance• Roll out scrappage schemes for the oldest appliances/vehicles targeted to lower income households
Primary Energy	3 Grid decarbonisation	<ul style="list-style-type: none">• Establish specific goals to reduce grid carbon emissions, set renewable deployment capacity + coal phase out targets• Planning for grid expansion + deployment of storage and flexibility
Cross cutting	4 Integrated and sector specific interventions	<ul style="list-style-type: none">• Pursue sector specific efficiency gains, e.g. vehicle lightweighting, new tyres• Seek integrative design intervention to improve efficiency, alongside electrification (e.g. reduce friction in pipes when installing heat tech, add cycling lanes when opening roads to install charging infrastructure, etc.)





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Transforming power systems: summary, key enablers and market design

Power report structured in 5 chapters

1	Introduction	Clean electrification is critical to net-zero, power demand will grow by 3x by 2050; decarbonisation in many locations will be primarily via wind and solar
2	System Balancing	System balancing varies by region, set of technologies exist to deliver balancing at low cost
3	Grid build and optimisation	Grids will need to grow by 50% to 2050 to support clean electrification, requiring significant investment and higher grid costs in the short-medium term; critical opportunity to optimise networks, increasing efficiency and reducing costs
4	Costs	Clean power systems based on wind and solar can be cost competitive with today's systems
5	Enablers	Several key enablers around market design, grid regulation, and system capabilities must be deployed to ensure systems can transform at low cost



Agenda

- **Introduction: Power system decarbonisation is technically feasible and can be achieved at low cost**
- Systems balancing: set of solutions exist
- Grid build and optimisation: grid will need to expand massively
- Clean power systems can be competitive with today's costs
- Key enablers to deliver future systems
- Future work: consumers in the transition

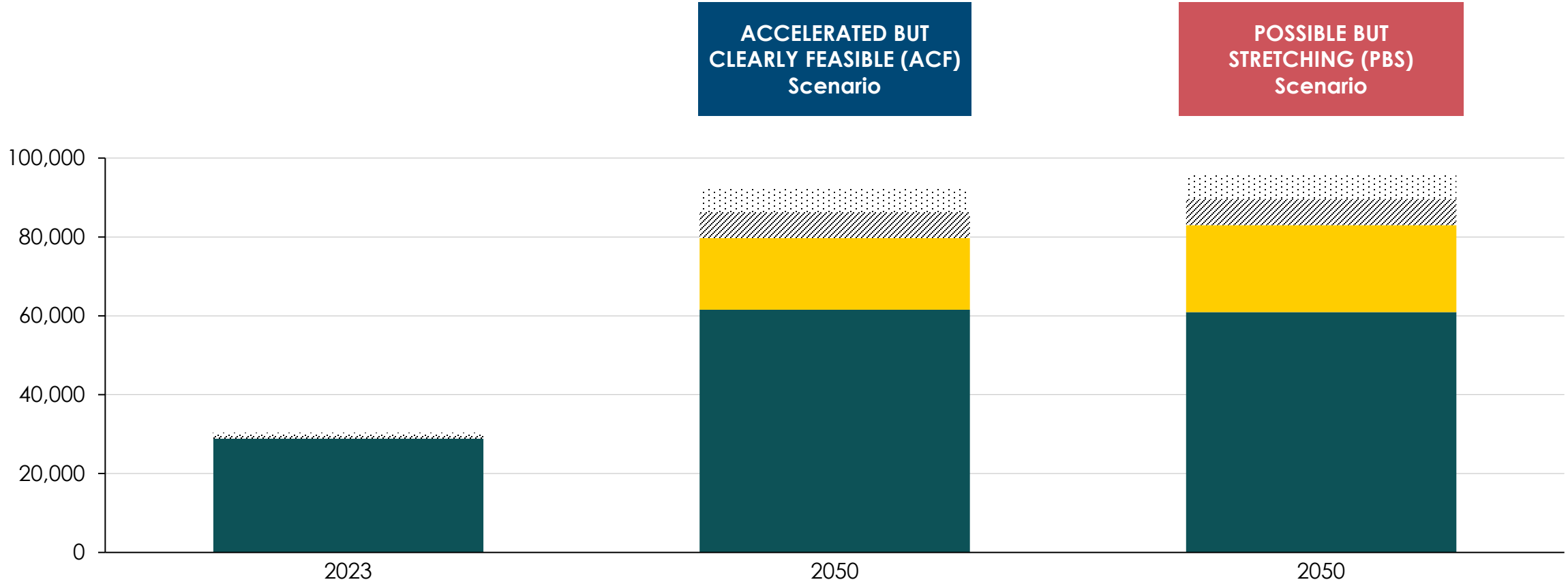


1 ETC updated scenarios show clean power generation grows x3 to 2050

Annual electricity generation, updated scenario

TWh

- Transmission losses
- Storage losses
- Indirect power for H2 production
- Direct power



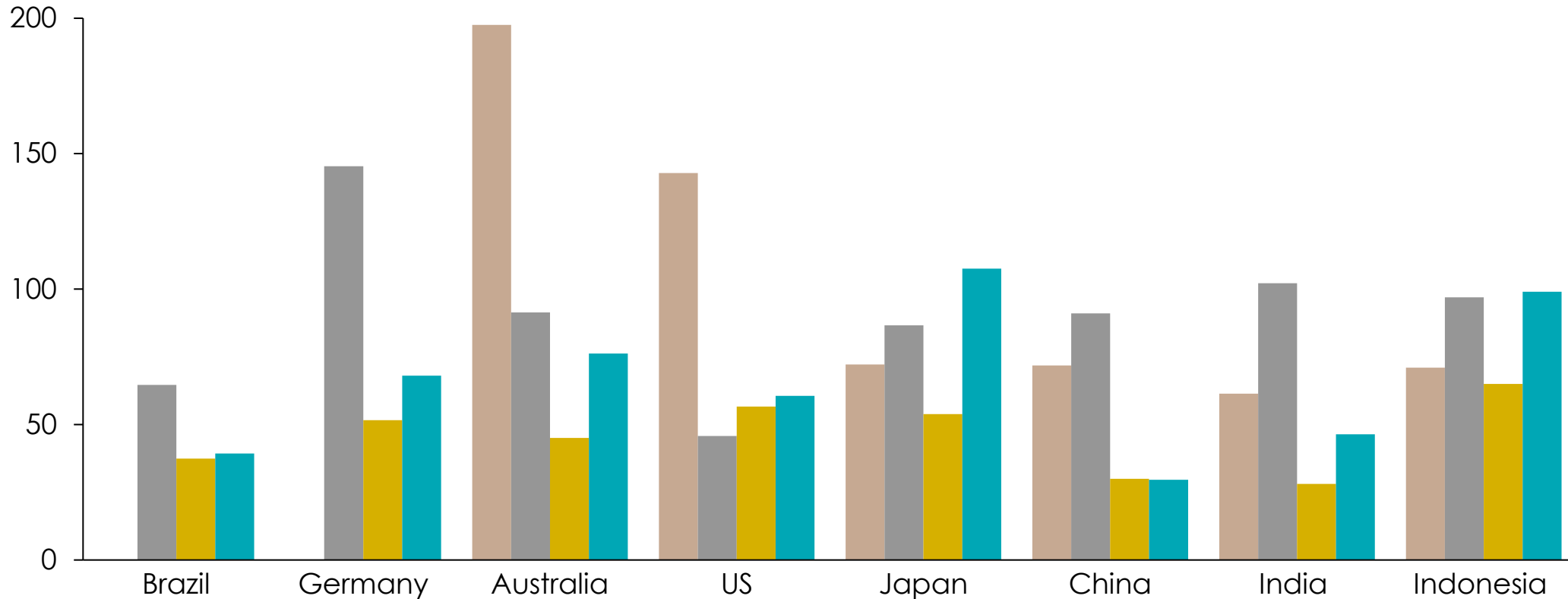
Source: Ember, Systemiq analysis for the ETC (2024)

1 Solar and wind are cost-competitive in many regions

New bulk generation LCOE costs in selected markets (BNEF)

\$ per megawatt-hour (real 2024)

Coal Gas Solar Onshore wind



Note: All LCOE calculations are unsubsidized. Project size is at utility scale. Capacity factors for wind are P50. PV capex is in \$/MW(DC). In countries where carbon schemes exist, the LCOEs and marginal cost of generation estimates of fossil fuel power plants include a carbon price. The LCOE range represents a range of capacity factors and project costs. For each market, we apply the standard corporate tax rate and an inflation rate from International Monetary Fund's (IMF) forecast consumer price index (CPI) annual rate for that market. Currency exchange-rate assumptions are based on a three-month average preceding the start of the analysis. Source: BNEF (2025) Levelised Cost of Electricity Update 2025.

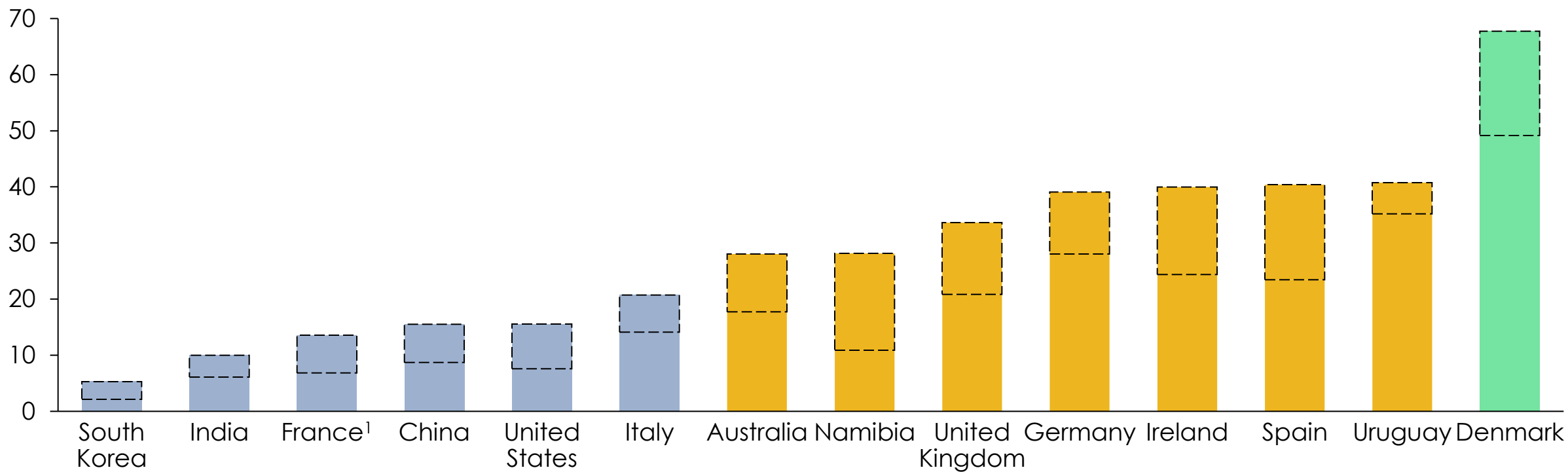


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This has led to the share of renewables being already significant in many countries



Annual wind and solar share and corresponding system integration phase in selected countries

% Wind and solar annual electricity generation, 2018, 2023



This points to three phases of system operation:

- Initial steps to bring in renewables
- Renewables start to make up almost all generation in some periods
- Renewables dominate generation

 2023
 2018



¹France's wind and solar share dropped from 14% in 2023 to 12% in 2024 due to increased nuclear and hydro contributions to the electricity generation mix in 2024.
 Source: Ember (2024), Electricity Data Explorer, featuring latest available data (2024 for European countries, 2023 for others); BloombergNEF: New Energy Outlook (2024), 1H 2024 South Korea Energy Transition Market Outlook (2025),

1

To address these, ETC has focused this year on key challenges of running expanded and decarbonised power systems

System Balancing

A systems balancing challenge arises as the penetration of wind and solar grows






Grid build and optimisation

Grids will need increase 2-3 times in size to support demand growth and new generation locations

Costs

Managing customer support for the energy transition is crucial as bills continue to increase

5 key technologies are critical to building and managing grids of the future

				
Innovative grid technologies	Flexible dispatch generation	Long-distance interconnection	Energy storage	Demand-side flexibility



Agenda

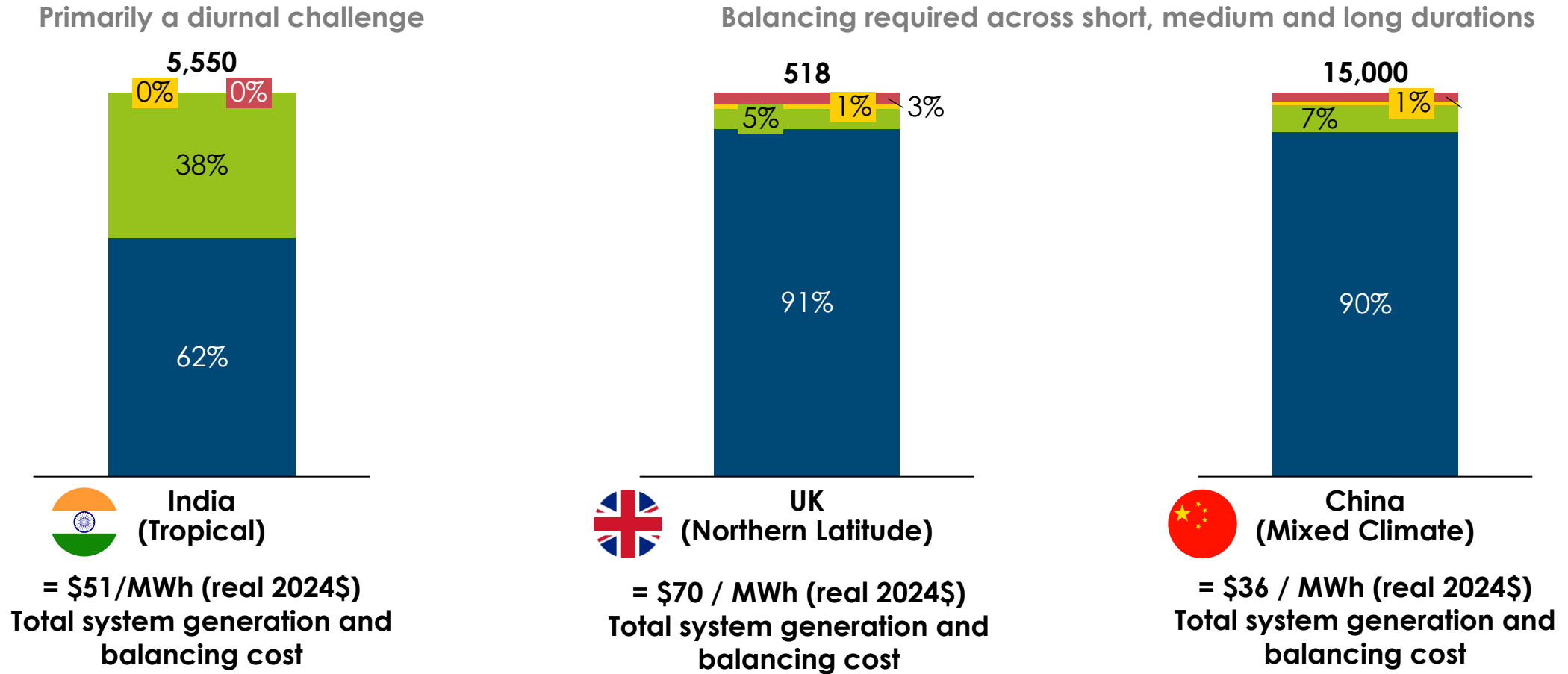
- Introduction: Power system decarbonisation is technically feasible and can be achieved at low cost
- **Systems balancing: set of solutions exist**
- Grid build and optimisation: grid will need to expand massively
- Clean power systems can be competitive with today's costs
- Key enablers to deliver future systems
- Future work: consumers in the transition



2 The balancing challenge differs across regions

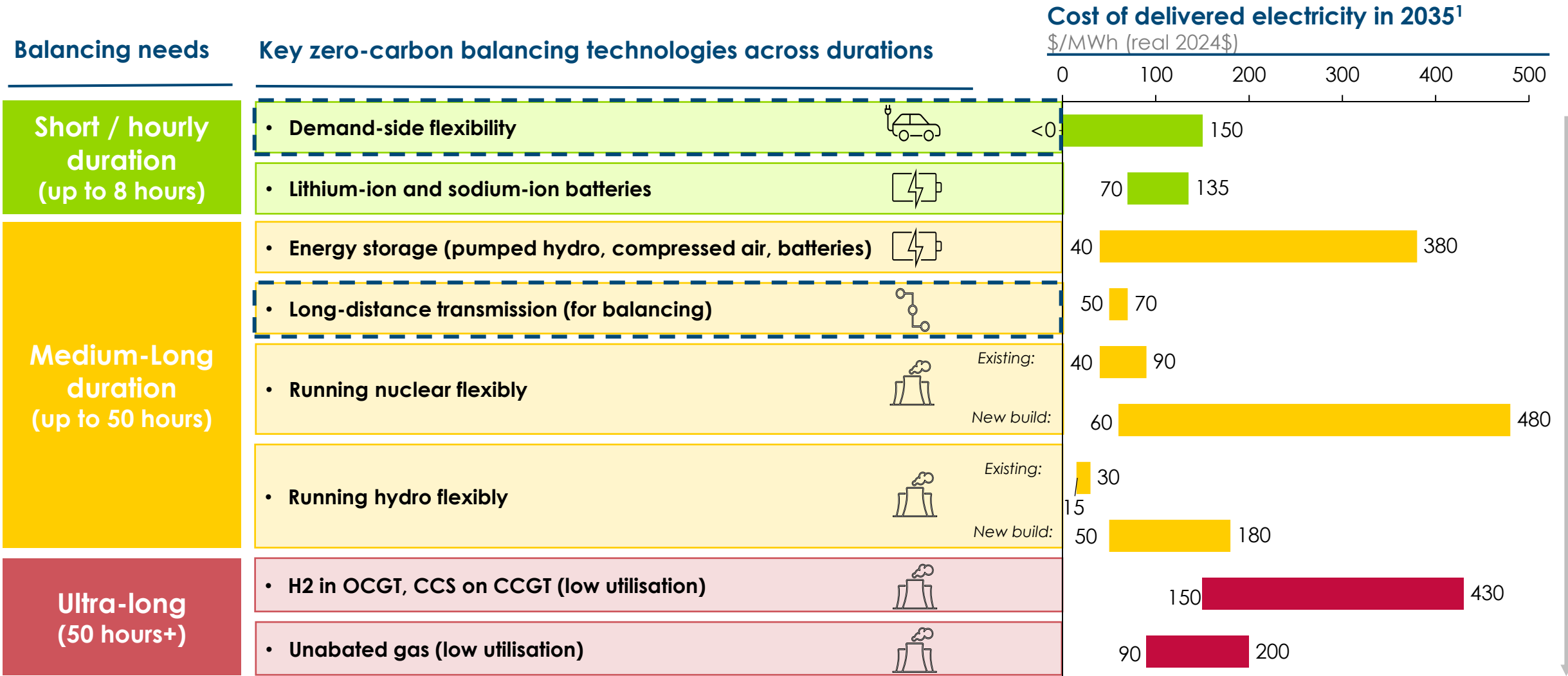
Balancing variability for India, UK, and China

% of TWh of annual demand provided by specified generation/storage ■ Ultra-long storage ■ Medium-long storage ■ Short storage ■ Concurrent



Source: Systemiq Analytiq analysis for ETC (2024) using supply data from; ECMWH (2024) ERA5 weather data; UK Government (2023) 'Untapped potential' of commercial buildings could revolutionise UK solar power; TERI (2024) India's Electricity Transition Pathways to 2050: Scenarios and Insights. Demand data from UK ESO (2022) FES 2022; India - The Energy Resources Institute (TERI) (2024) India's Electricity Transition Pathways to 2050: Scenarios and Insights; China - Li, M et al. (2024), The role of dispatchability in China's power system decarbonisation; Spain - AFRY (2025)

2 The costs associated with different balancing solutions vary significantly



[1] The DSF range includes thermal heat storage and assumes that DSF can reduce total system costs at the lower end (through reducing overall demand) and that upgrades to smart, DSF-capable systems incurs a net cost at the upper end. LCOS calculations assume electricity input cost of \$0.06/kWh. All batteries are full LCOS calculations including cost of electricity usage. Heat storage source based on Rondo heat battery LCOS and BNEF thermal LCOS figures for solid state and molten salt storage. Other figures are based on ETC analysis. OCGT = Open-cycle gas turbine, CCGT = combined-cycle gas turbine.

2 Short-duration flexibility “ladder” highlights key opportunities

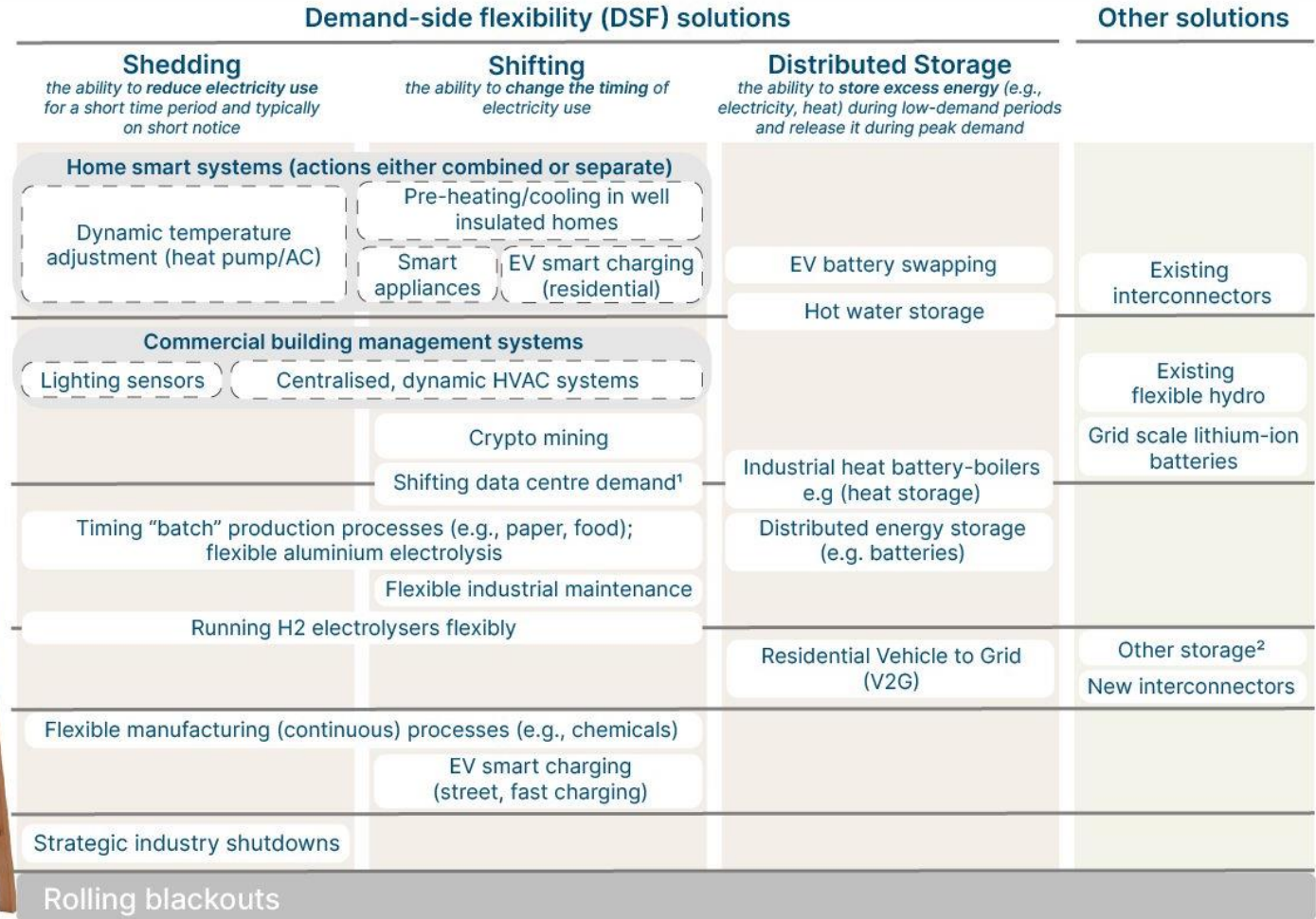
High Priority

Low cost, low barriers, high efficiency, potential for automation



Low Priority/Undesirable

High cost, high barriers



Note: This DSF ladder infographic is published under CC-BY 4.0 and the ladder concept has been adapted from Michael Liebreich/Liebreich Associates, [Clean Hydrogen Ladder, Version 5.0, 2023](#). Original Concept credit: Adrian Hiel, Energy Cities.

¹Non-critical data processes, such as AI training, can be **postponed or shifted** to low-demand periods without real-time constraints. Flexibility also exists when companies run computing centres across different countries / regions to allow **load shifts over geographies**.

²Medium-duration storage (including pumped hydro) is **less competitive for short-duration balancing** than batteries, driven by the higher round-trip efficiency of batteries.



2 ETC analysis on long-distance transmission links highlights high potential



Long distance transmission can help to deliver:

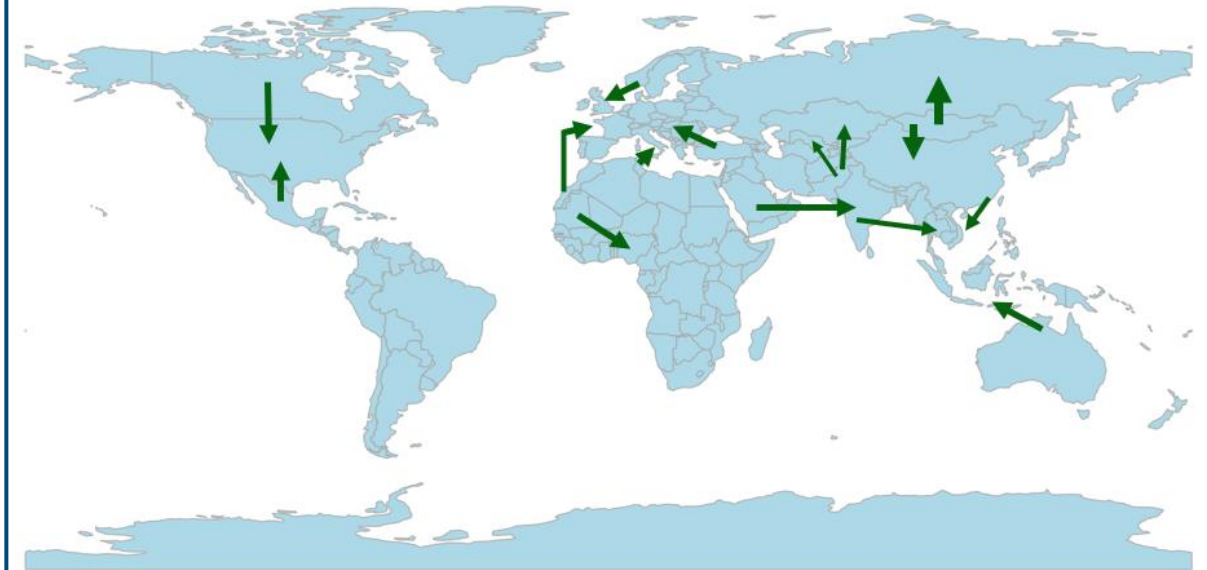
- Low-cost clean generation, from a low cost/high availability geography
- Balancing, Using non-correlated weather and demand including with storage at the export site



Overall the modelling results suggest very large global technical potential for cross border interconnection, with a small number of high potential links having potential to deliver by 2050:

- **15%** of 2024 global power demand
- **1.8 Gt** per annum carbon reductions (equal to 13% of global power sector emissions)
- **\$100bn** dollars of savings per year

Overall modelling results: top 15 lines show potential for network 'megaprojects' such as Morocco and Australia as export hubs



Agenda

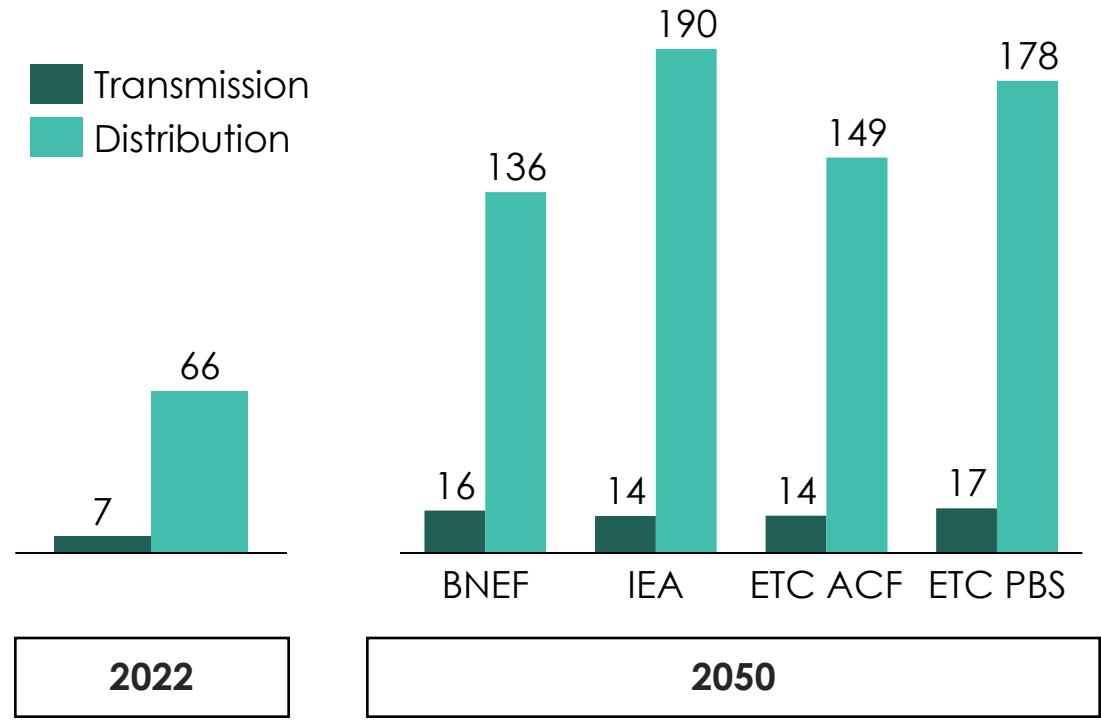
- Introduction: Power system decarbonisation is technically feasible and can be achieved at low cost
- Systems balancing: set of solutions exist
- **Grid build and optimisation: grid will need to expand massively**
- Clean power systems can be competitive with today's costs
- Key enablers to deliver future systems
- Future work: consumers in the transition



3 Transmission and distribution network build will have to increase drastically across regions

Estimated wires required under assumptions

Million km



- Grid growth should aim to optimise the system, reducing total build required by deploying:
 - 1) Innovative grid technologies that increase the efficiency of power flows
 - 2) increasing storage and flexibility and
 - 3) use of long-distance interconnectors

- However, even full deployment of all optimisation routes will not eliminate the need to build new grids

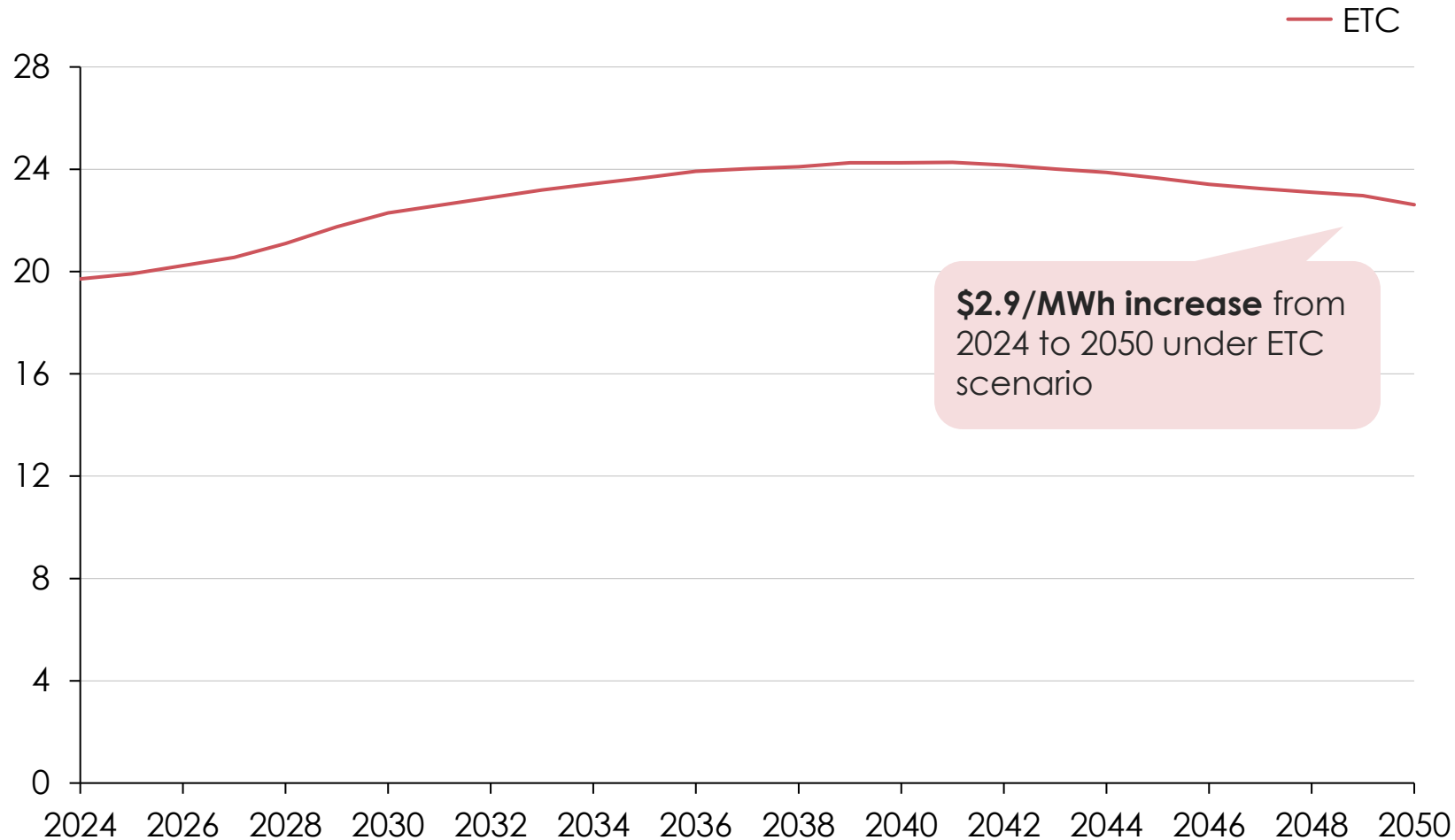


Notes: *Over the short term, billpayers may have to compensate for a lack investment in grids over the past decade with increased spending, though this shouldn't entirely be attributed to net zero costs. Historical grid spend from 2014-2020 taken from IEA and compared with BNEF time series of additional TWh 3 years in the future (2017-2023). Source: BNEF (2023) NEO grids; BNEF (October 2023) NEO data viewer; IEA (2023) Electricity Grids and Secure Energy Transitions; IEA (2023) Electricity Grids and Secure Energy Transitions; Systemiq analysis for the ETC (2024)

3 Grid costs per MWh will only increase slightly to 2050, but can be reduced if we maximise flexibility

Grid Capex costs (transmission & distribution) per demand unit, global, 2024–2050

\$/MWh (real 2024\$) for payments per electricity demand; interest rate = 5%; 30-year repayment timeline



- The **initial increase in cost per unit of demand** is due to the upfront investments needed to build and reinforce the grid infrastructure in line with rising electricity demand.
- **The grid cost per unit of demand then decreases** because the fixed costs are spread over a larger volume of electricity consumption.
- **Grid optimization measures could further reduce** the need for additional grid build, lowering overall costs.

Source: Systemiq analysis for the ETC (2025), BNEF (2024) *New Energy Outlook 2024*

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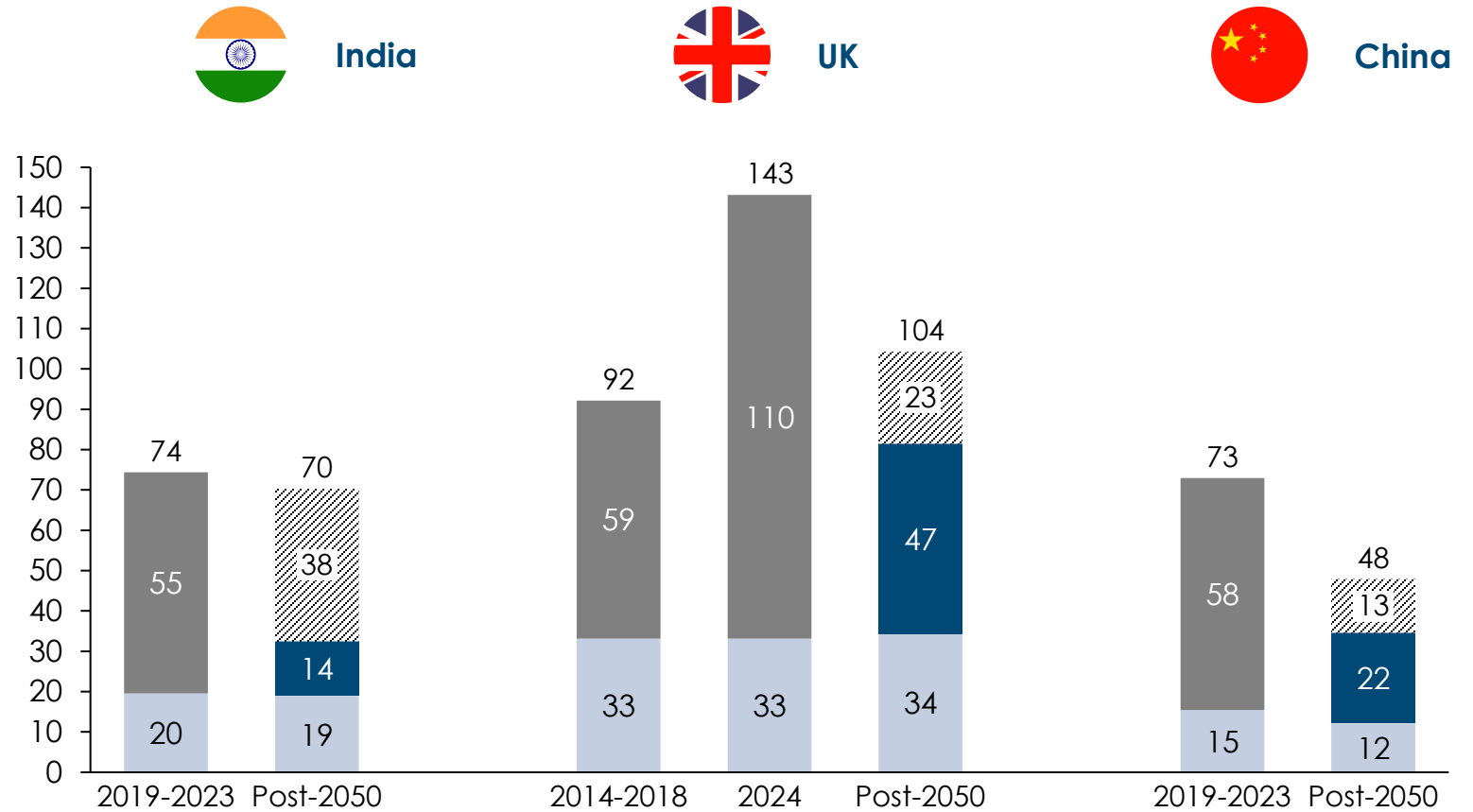


4 Total system generation and grid costs could be lower than current wholesale prices

Total system costs (generation and grids), recent vs post-2050

\$/MWh (real 2024\$)

- Average wholesale power prices
- Cost of meeting balancing needs
- Wind/solar
- Transmission & distribution costs



Sources: Systemiq analysis for the ETC (2025); BNEF (2023), 2H 2023 LCOE: Data Viewer v.1.0; Ofgem (2025), Wholesale market indicators – Electricity Prices: Forward Delivery Contracts – Weekly Average (GB); IEA (2023), Electricity Market Report – Update 2023; Statista (2024), Average electricity prices for enterprises in China from September 2019 to September 2024

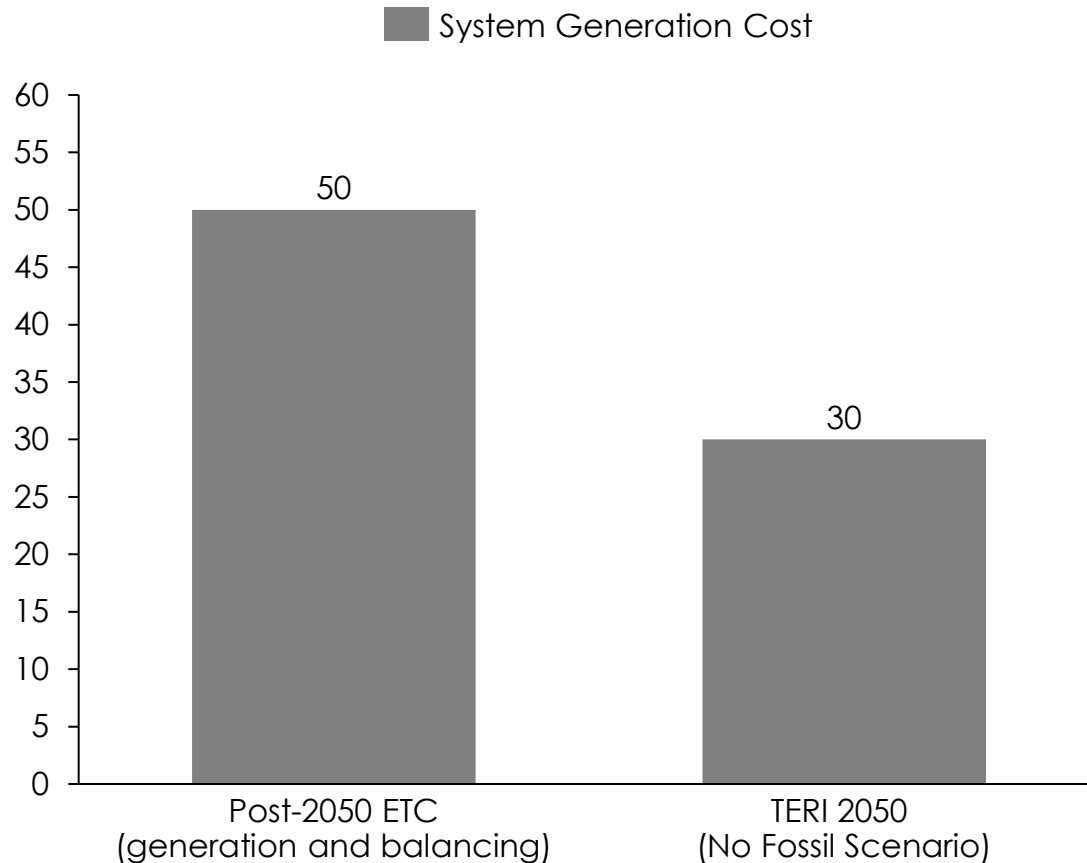


4 Next steps: we will compare our modelling with other detailed dispatch models



Comparison of our system generation cost outputs with TERI's 2050 forecasts¹

\$/MWh (real 2024\$)



Assumption differences

- We assume different future technology cost declines
- TERI include dispatchable sources including nuclear and hydro
- Excluding these in our analysis results in significant wind/solar overbuild
- More wind/solar capacity results in more battery capacity in our modelling

Considerations for our analysis

- Our assumed system with maximised wind/solar is oversimplified leading to an overreliance on batteries to shift supply
- Accounting for dispatchable low carbon sources could decrease overall system costs, in line with TERI's analysis
- Evaluating impacts on consumer bills will require these sources to be incorporated in more realistic scenarios

¹Comparison of generation and balancing costs, excluding transmission costs. Sources: TERI (2024), *Electricity Transition Pathways to 2050*

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Five key enablers to deliver future power systems at low cost

Strategic vision & planning

- **Smart targets for deployment** – including renewables, grids, energy storage, and flexibility
- **Accurate models and forecasting** – to help set targets and enable integration of new technologies
- **Political will for the transition** – To enable both phasing down of fossil, and plans for flexibility deployment (including across borders)



Market design

- Market access
- De-risked revenue streams
- Pricing signals (incl. locational pricing, carbon pricing)



Grid regulations

- Reform of grid fees
- Evolution of connection rules
- Modernisation and harmonisation



Data, AI and smart grids

- Data and AI modernisation
- Advanced metering and digitalisation



Supply chain, workforce and financing regimes

- Supply chain concerns
- Workforce education
- Anticipatory financing



Consumers

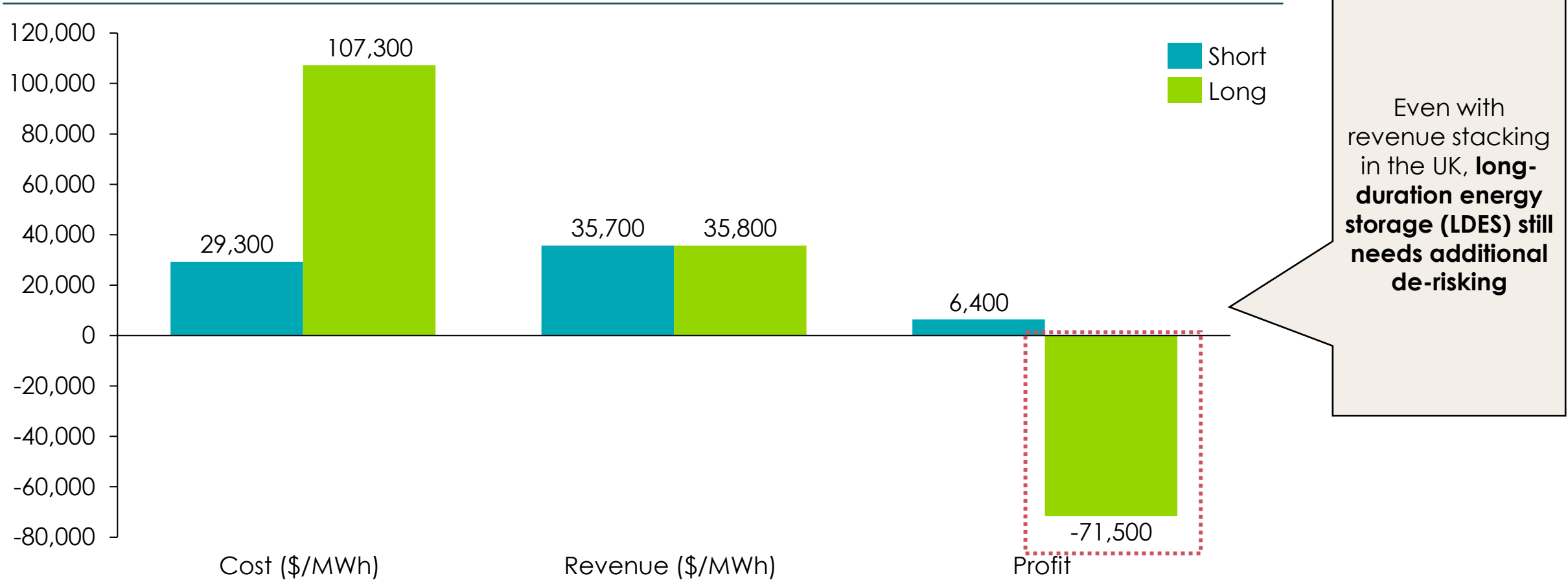
- Consumer engagement and trust-building



5 Support mechanisms required to ensure that technologies are bankable, particularly large assets that are high cost such as LDES

UK Short and long-duration energy storage revenue model, 2023

All markets stacked, £/MW



Even with revenue stacking in the UK, **long-duration energy storage (LDES) still needs additional de-risking**

Source: Systemiq analysis for the ETC (2024) using data from - Modu Energy, National Grid ESO. Note: We assume a BESS of 80MW as this is the average size BESS project in the UK in 2023. Other assumptions include; 500 cycles per year, OPEX of \$£/kWh, 8% annualization factor, 93% lifecycle efficiency and electricity at \$0.06/kWh. For revenue modelling, we also assume that the revenue stack would be 55% frequency response, 5% balancing mechanism, 20% wholesale and 20% capacity market, as per figures from Modu Energy for 2023. We also assume for revenue stacking that the battery would play across all markets; in reality, this would require extensive data and workforce management that make it unlikely. We also assume that the battery would play in both T4 and T1 capacity auctions.



5 Conclusion and next steps

- **Clean power systems can deliver 24/7 electricity at competitive costs**, with Sunbelt regions reaching this point first due to cheap solar and storage, while wind-heavy systems require broader balancing solutions
- **Balancing needs vary by region**, with short-duration solutions (e.g., batteries) already cost-effective, while medium- and ultra-long-duration storage (e.g., hydrogen, CCS) still require innovation and policy support
- **Grid expansion and investment must accelerate**, but optimization can reduce costs and delays, with demand-side flexibility, advanced grid technologies, and interconnectors playing key roles
- Clean power systems based on wind and solar **can be cost competitive with today's systems**
- **Next steps**: drafting the power report ready for publication in June



Agenda

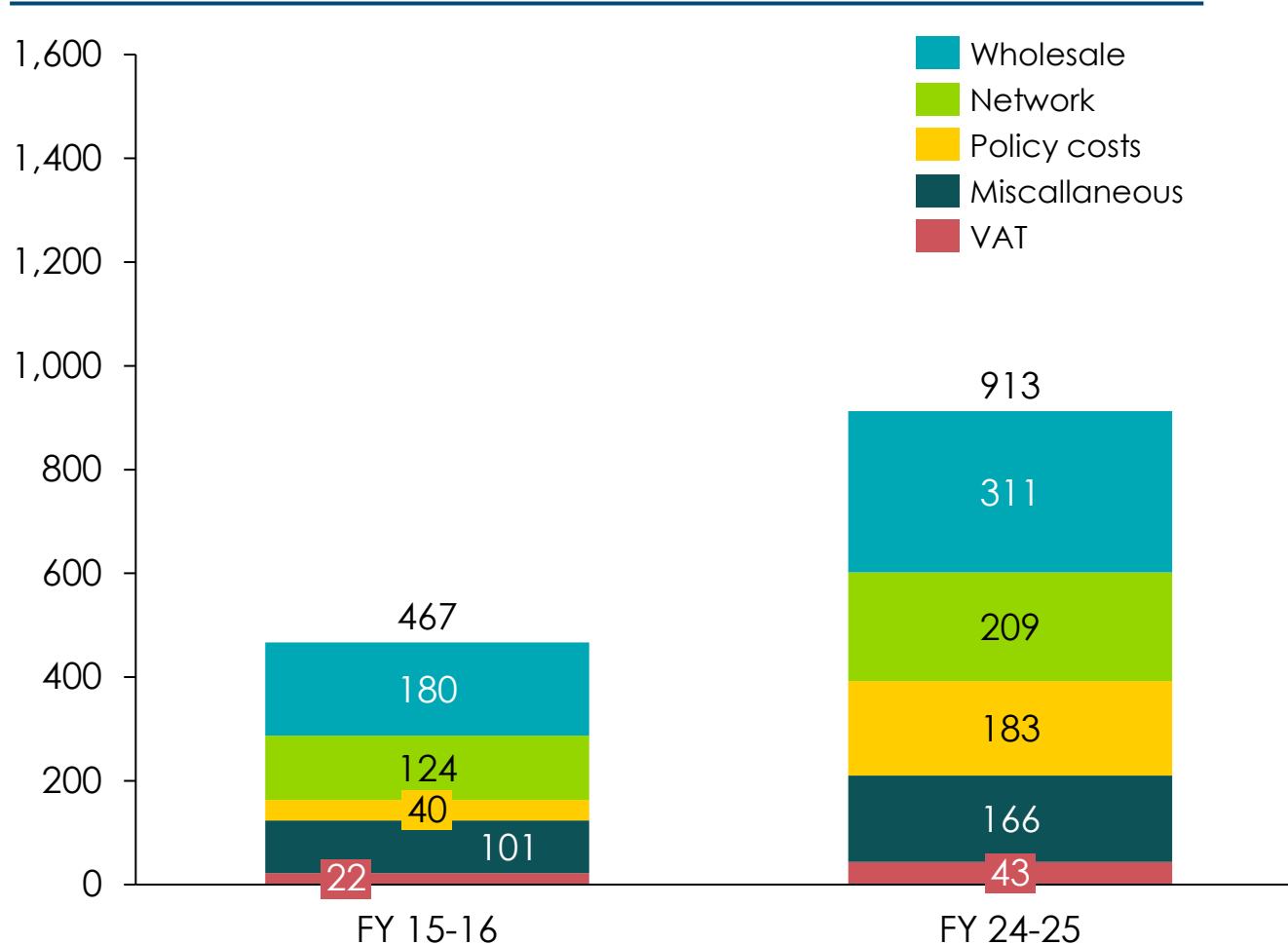
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6 UK electricity bills have grown over time

Typical UK electricity bill 2025 and 2015

GBP per kWh



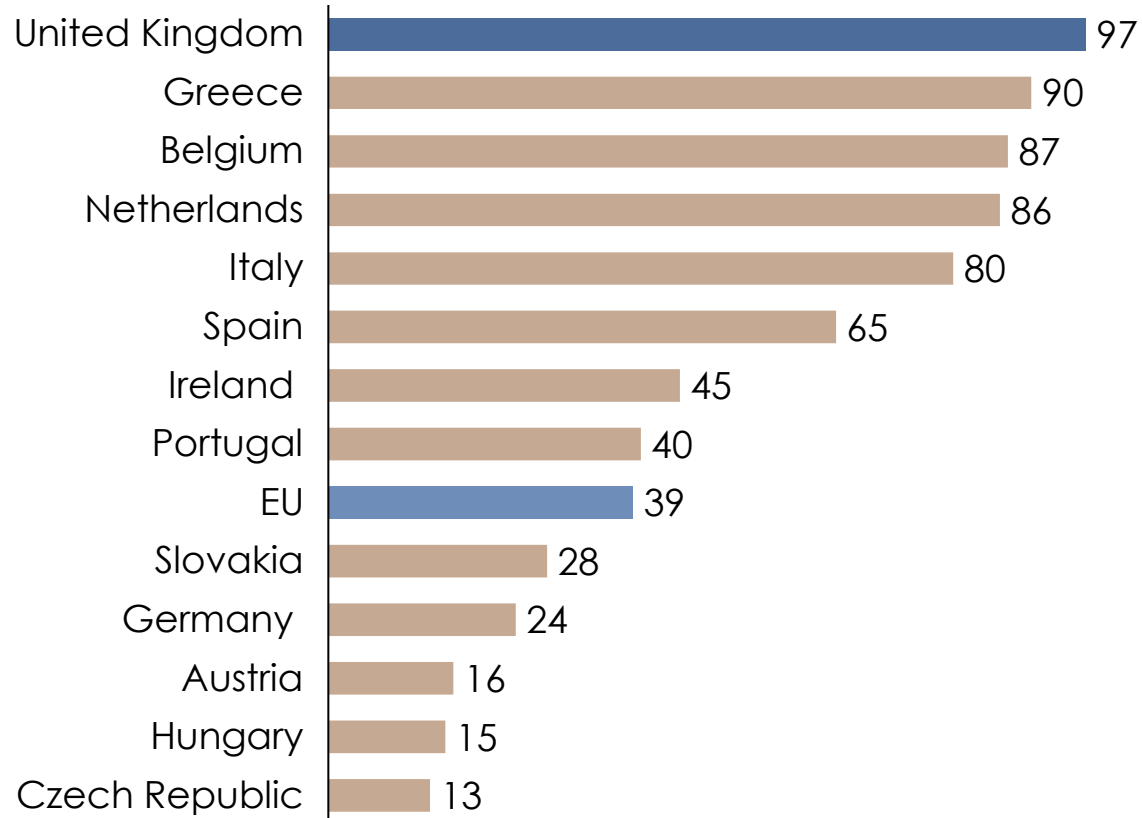
Increasing costs have been led by several trends, including:

- 1 **High wholesale prices** driven by gas, as marginal price setter
- 2 **Expanding the network** to connect new capacity and upgrade old infrastructure
- 3 **Policy costs e.g. for CFDs and previous subsidies**, e.g. Renewables Obligations Contracts (ROCs)
- 4 **Smart meter** rollout

6 Gas sets the marginal price for a very high share of hours

Share of natural gas in setting the wholesale, day-ahead electricity prices in 2021

%



1 High wholesale prices

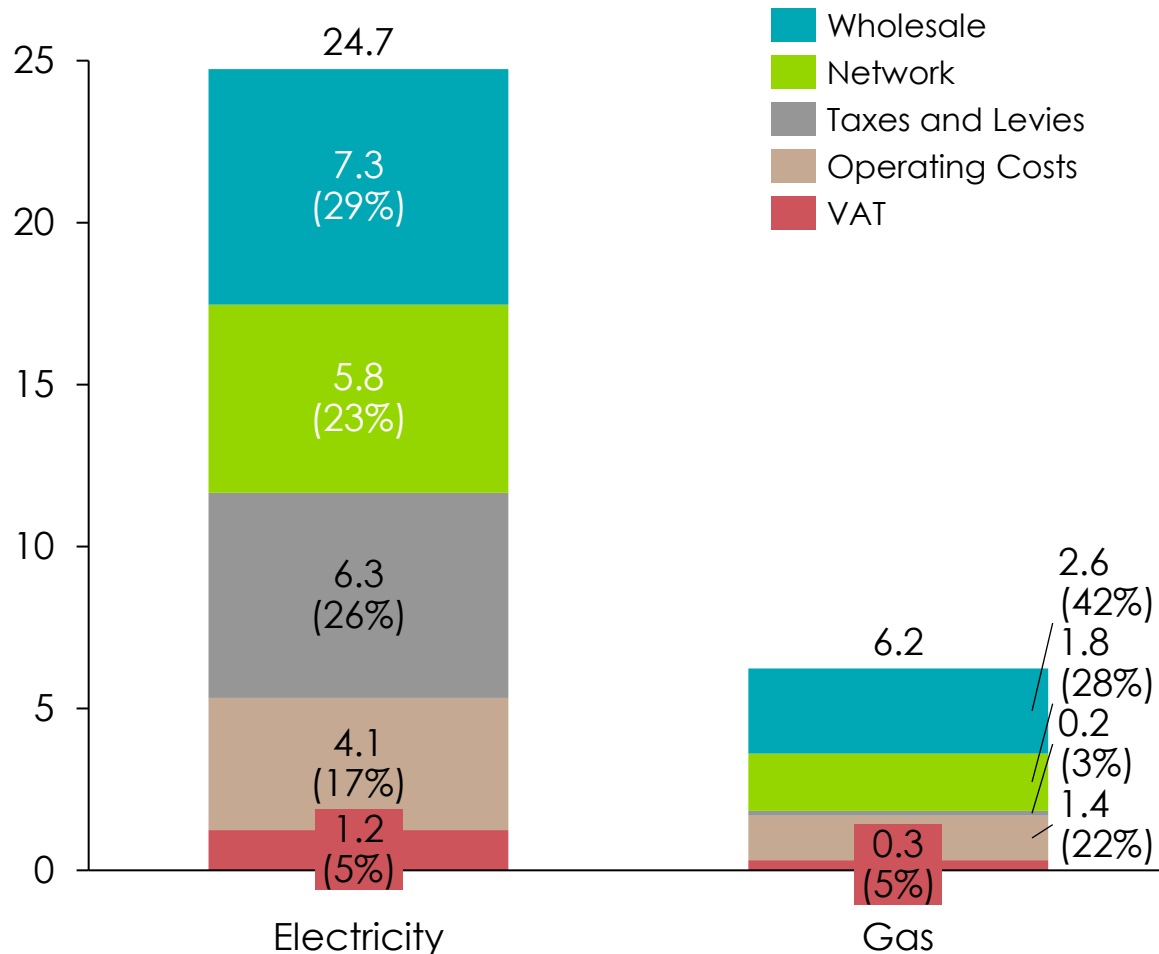
In the UK, particularly high exposure to gas setting the marginal price, due to:

- 1) **Lower storage** vs other European markets
- 2) **Grid constraints limiting transmission** and forcing expensive redispatch

6 A rebalancing of UK energy bills required to address imbalances

Typical UK electricity (LHS) and gas (RHS) unit price, 2025

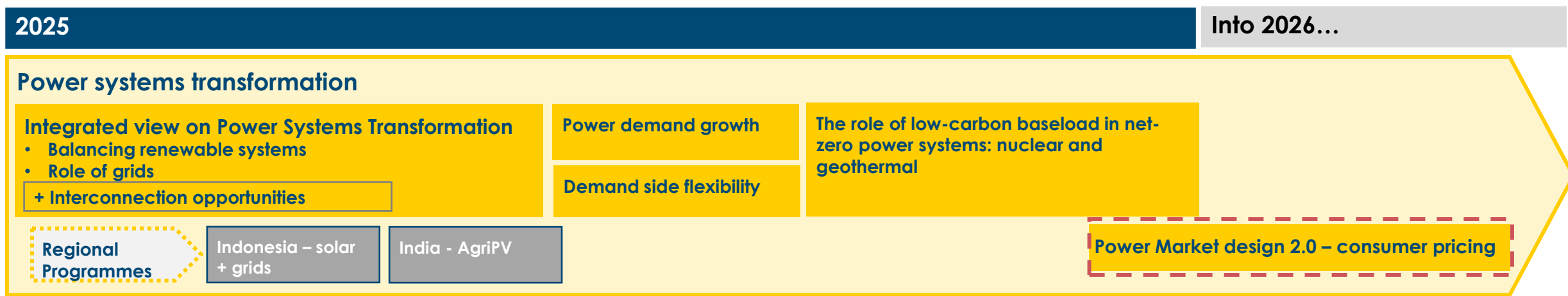
GBP per kWh



- Electricity bills in the UK are **significantly higher than gas due to taxes, levies, and network costs**, despite similar wholesale prices
- The current cost structure places a **disproportionate burden on electricity**, increasing consumer bills
- **Reforming this imbalance** is essential to lower household energy costs and support an affordable transition to clean power
- **Lessons also relevant for other geographies, particularly in EU**

Note: excluding standing charges.
Source: Ofgem, The ECO Experts

6 Issues around consumer bills, including questions on locational marginal pricing, will be addressed in future work



↑

These issue areas will be tackled in this block of work, and will include analysis of

- 1) Consumer bills
- 2) Locational marginal pricing

