Energy
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Commission

ETC 2025 workplan: emerging key insights

ETC Commissioners Meeting
20th March 2025

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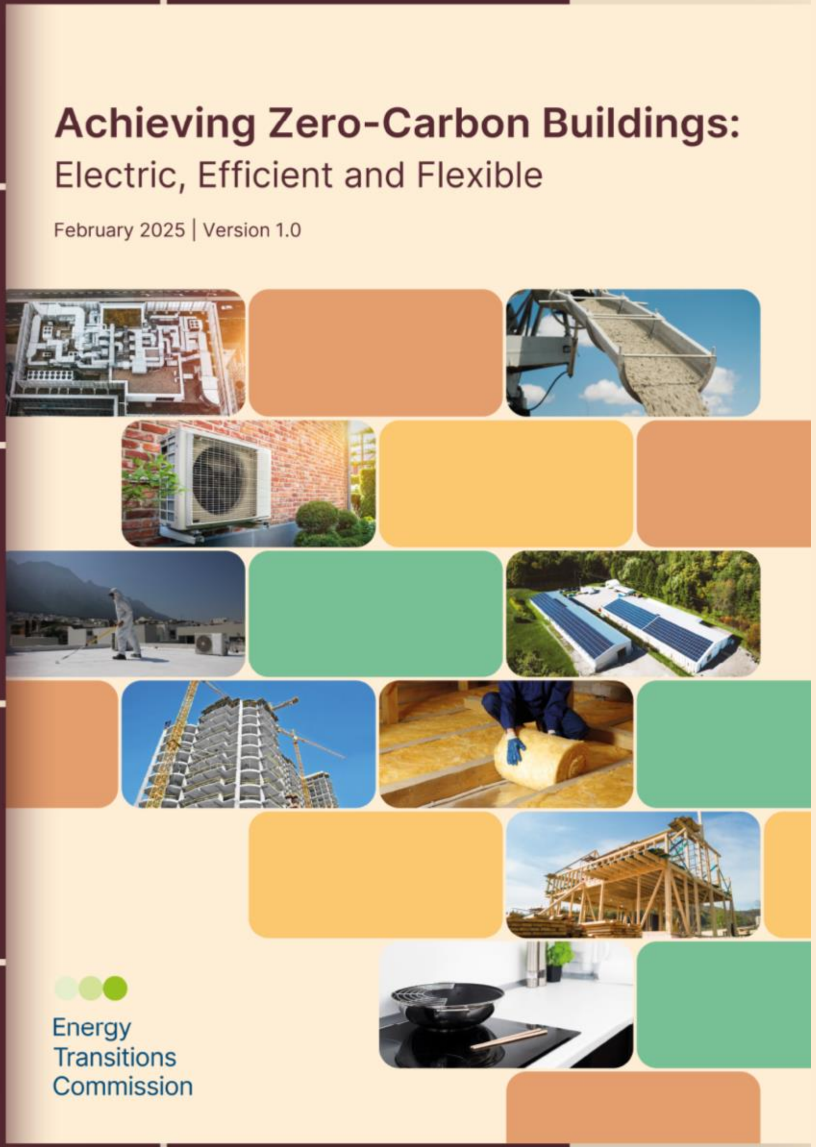
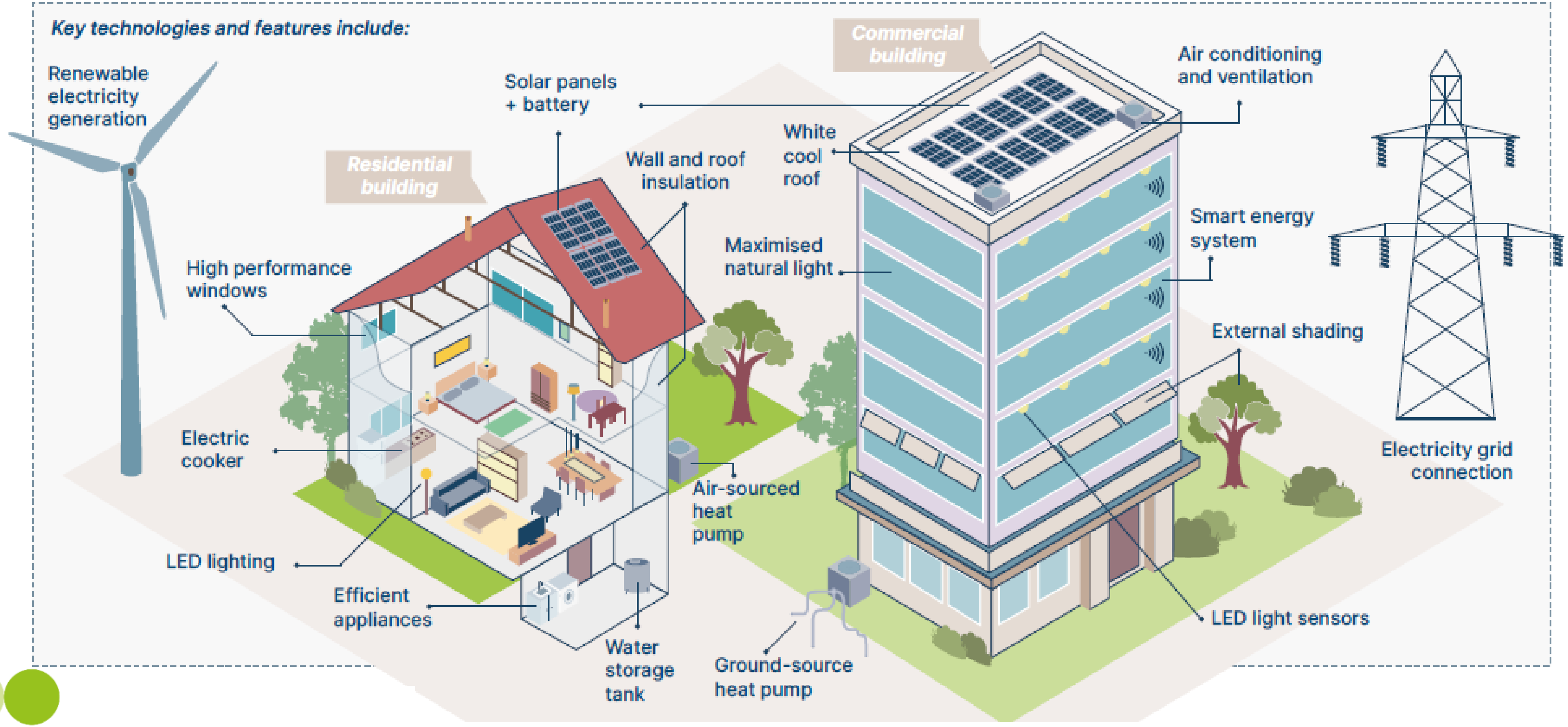
Key insights from the latest ETC report on Buildings decarbonisation



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

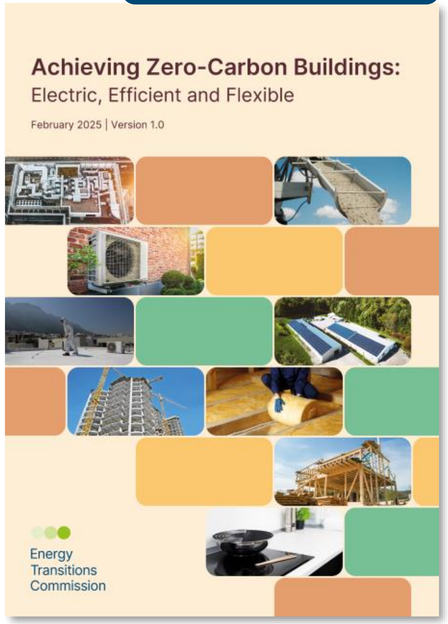
Three sets of technologies required for zero-carbon buildings

Electric		*Efficient*		*Flexible*
Clean heating technologies	+	Technologies to reduce total energy consumption	+	Technologies to shift energy consumption outside of peak times

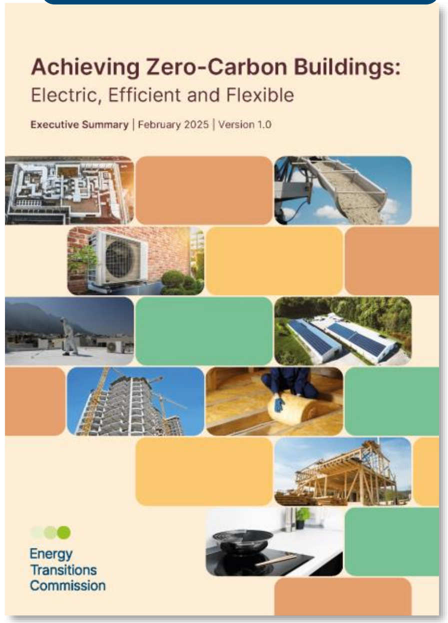


Support the buildings decarbonisation campaign by sharing our work

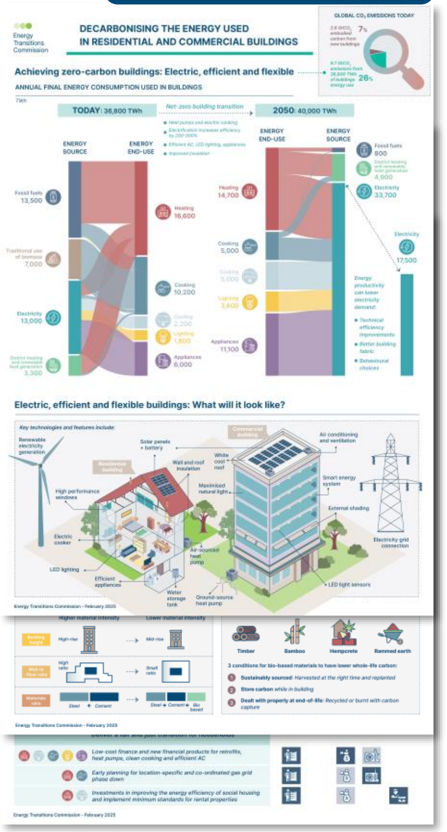
1 x Main report



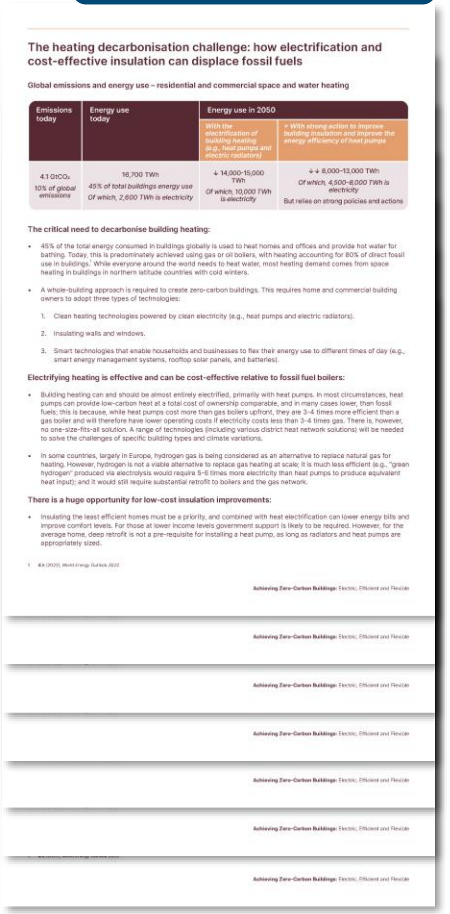
1 x Exec Summary



3 x Infographics



7 x Key messages



5 x Solution Toolkits

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

CN Construction News
THE TIMES
edie driving sustainable business.
SmartCitiesWorld Sharing Ideas to Solve Urban Challenges
FT FINANCIAL TIMES
BusinessGreen
euronews.
CANARY MEDIA
TRT
ET THE ECONOMIC TIMES

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 •
+ Follow

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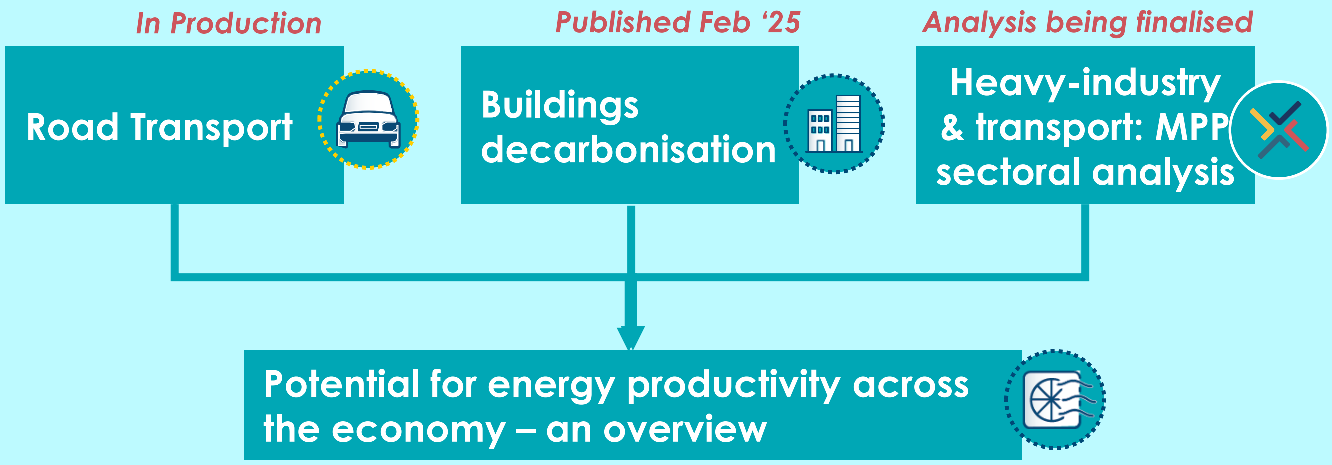
Potential for energy productivity improvement: integrated view of transport and industry

Overview of energy productivity will bring together three pieces of analysis

2025 ENERGY PRODUCTIVITY SERIES



The overview of energy productivity potential will draw on three inputs:

- **Road transport**, covering both passenger and freight aspects.
- **Buildings**, encompassing both in-use structures and those under construction.
- **Industry and long-distance transport**, consolidating insights from the Mission Possible Partnership (MPP) analysis.

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

$$\frac{\Delta\, Energy\ intensity}{Energy\ intensity_{t-1}}\ (\%)$$

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

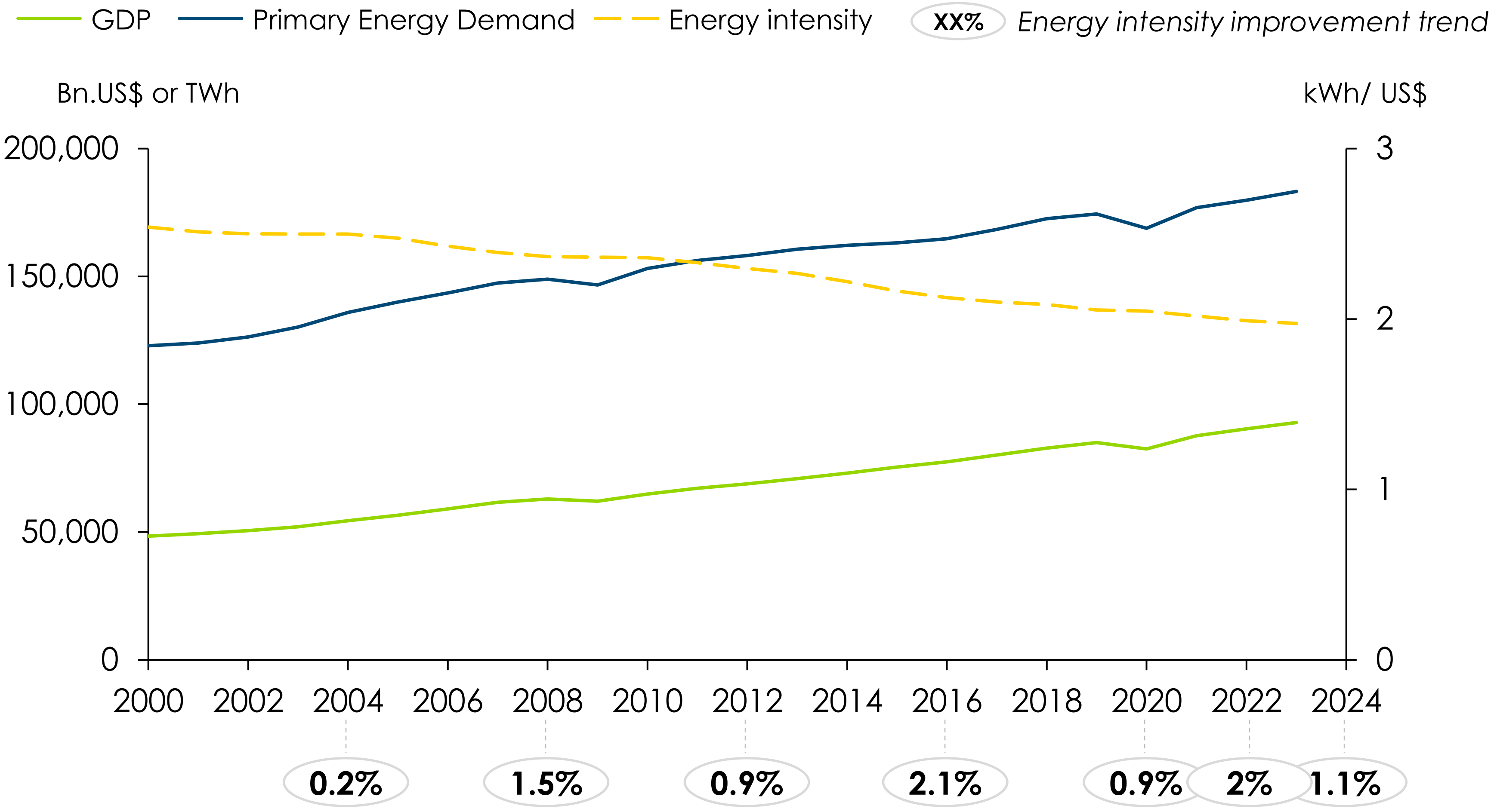
Useful Energy

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

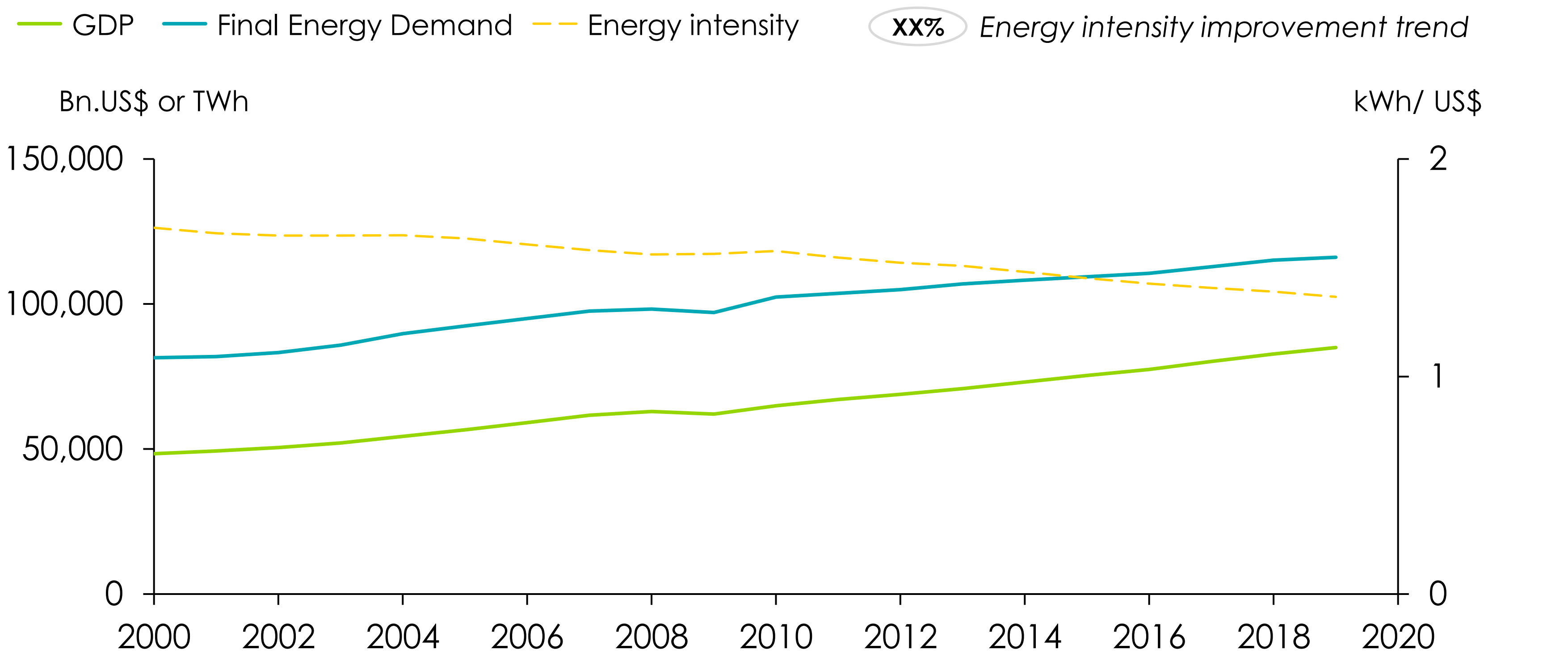
Source: Systemiq analysis for the ETC; World Bank Group; Our World in Data; IEA (2023), *Energy Efficiency 2023;*

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

Final

Total GDP vs. Final Energy Demand, 2000- 2019

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



Final Energy	**0.2%**	**1.5%**	**0.9%**	**1.8%**	**2.2%**
Primary Energy	**0.2%**	**1.5%**	**0.9%**	**2.1%**	**0.9%**

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

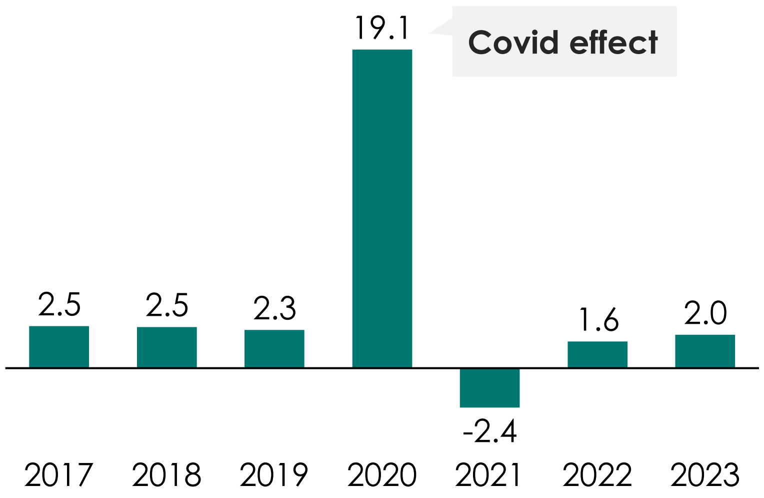
Source: Systemiq analysis for the ETC; World Bank Group; Our World in Data; IEA (2023), *Energy Efficiency 2023; IEA (2021) Key World Energy Statistics 2021*

Final energy demand intensity has improved in recent years, but at different rates

Final

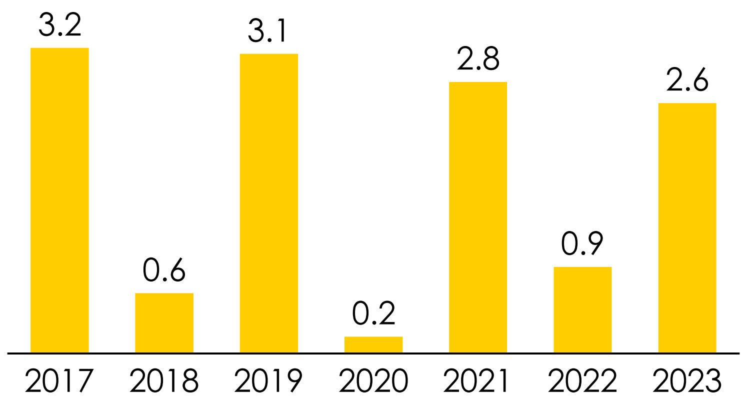
Global final energy demand intensity progress
% Annual improvement in final energy intensity

Road transport



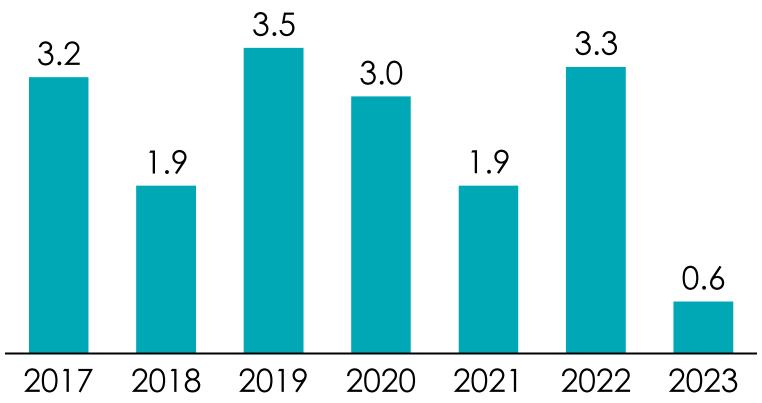
- **Improvement driven by some improved efficiency in ICE engines as well as electrification**, mainly in China – even if partially offset by larger, heavier SUV models

Buildings



- **Appliance improvements** despite rise in use - 25% improvement in saturated markets (EU, US) and 300% in emerging markets (Africa, ME) between 2022 and 2023.
- **Weather fluctuations** have large impact

Industry



- **Limited recent investment in productivity enhancing technology** in hard-to-abate industries.

Source: IEA (2022, 2023 and 2024) Energy Efficiency, IEA (2023) Energy End-uses and Efficiency Indicators Highlights

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

=

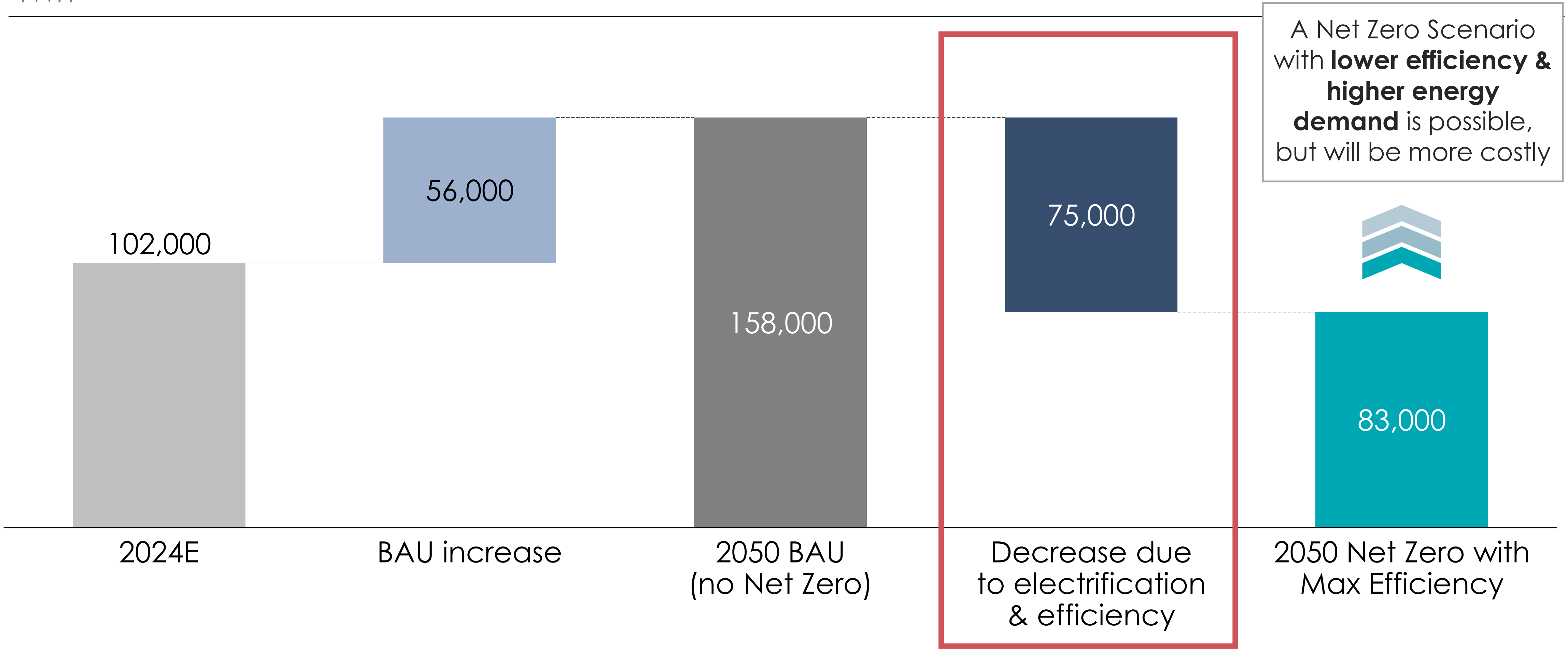
Reducing energy losses in the **power system** and **fuel production**

Reaching net-zero whilst maximising energy productivity gains can lead to lower energy demand without compromising on living standards

Preliminary

Global Final Energy demand

TWh



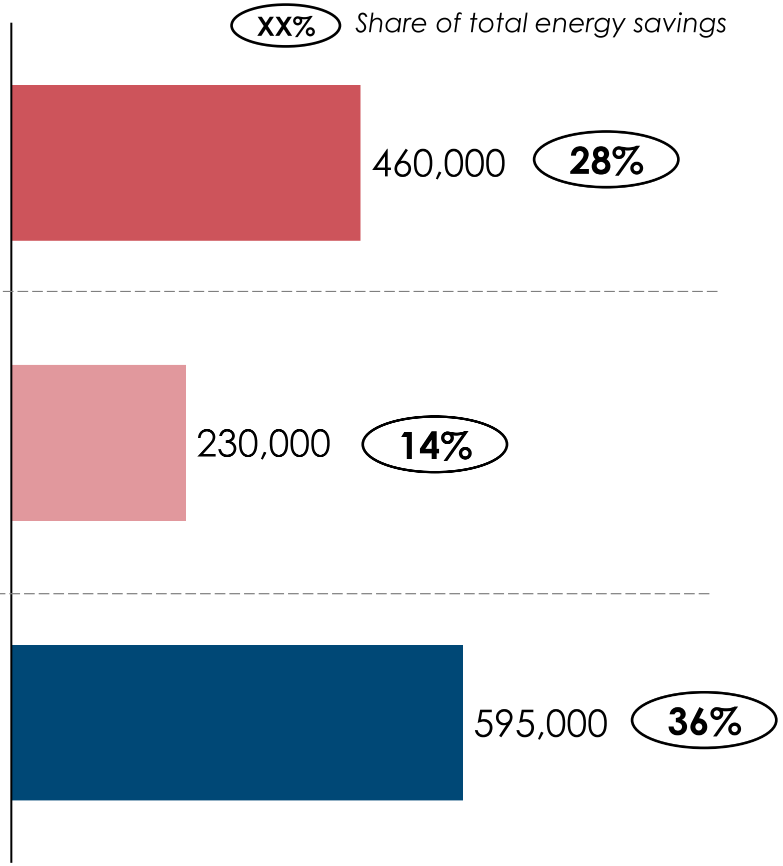
Source: Systemiq analysis for ETC; MPP (2023) Hard-to-Abate Sector Transition Strategies; ETC (2025) Buildings, BNEF (2023) Vehicle Outlook

Three key productivity levers: electrification, efficiency of appliances and vehicles and grid decarbonisation

Preliminary

	Main productivity levers	Key drivers
Final Energy	1 **Electrification**	• Electrification of heating and cooking in buildings • Switch to EVs
Final Energy	2 **Improvements in the efficiency of electrical appliances and vehicles**	• Efficiency standards on main household appliances (e.g. refrigerators, AC, lightning) • Improvements in heat pumps • Improvements in EVs
Primary Energy	3 **Grid decarbonisation**	• Higer share of renewable generation in the grid • Grid expansion

Cumulative energy saving *(2025-2050 TWh)*

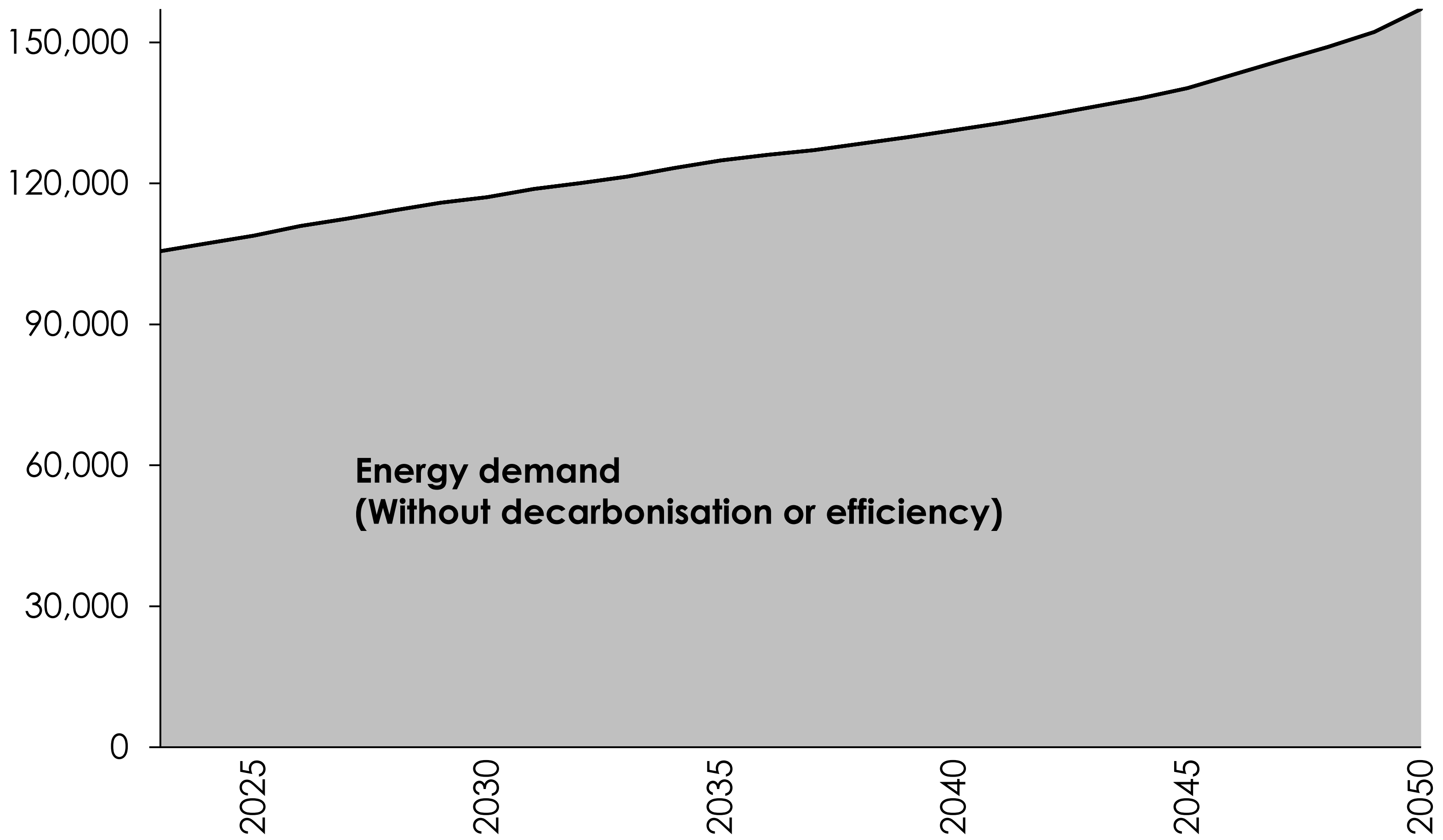


Baseline. Without any decarbonisation or productivity levers, rising energy demand

Preliminary

Final Energy demand vs. Productivity levers
TWh

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



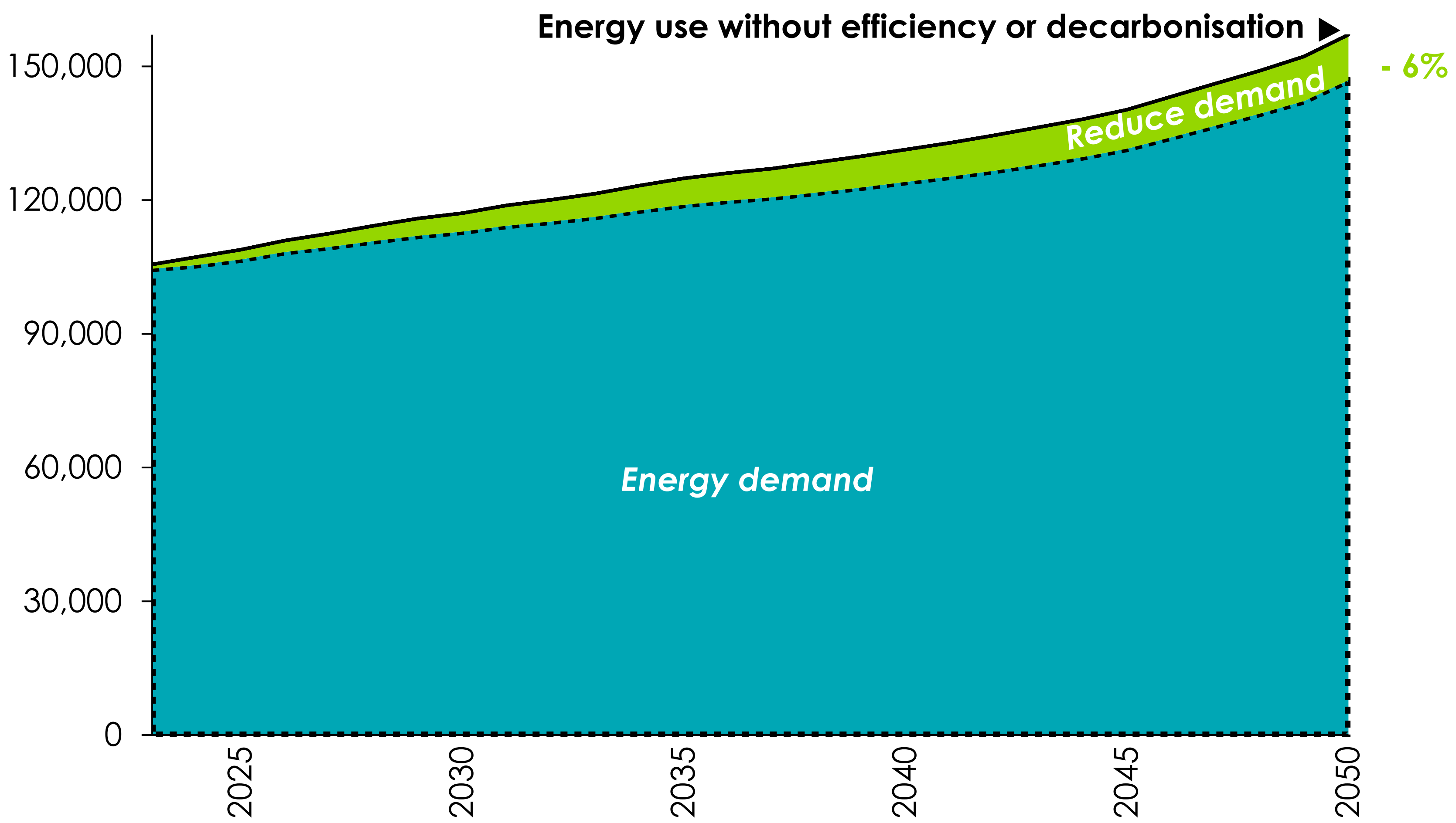
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

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)

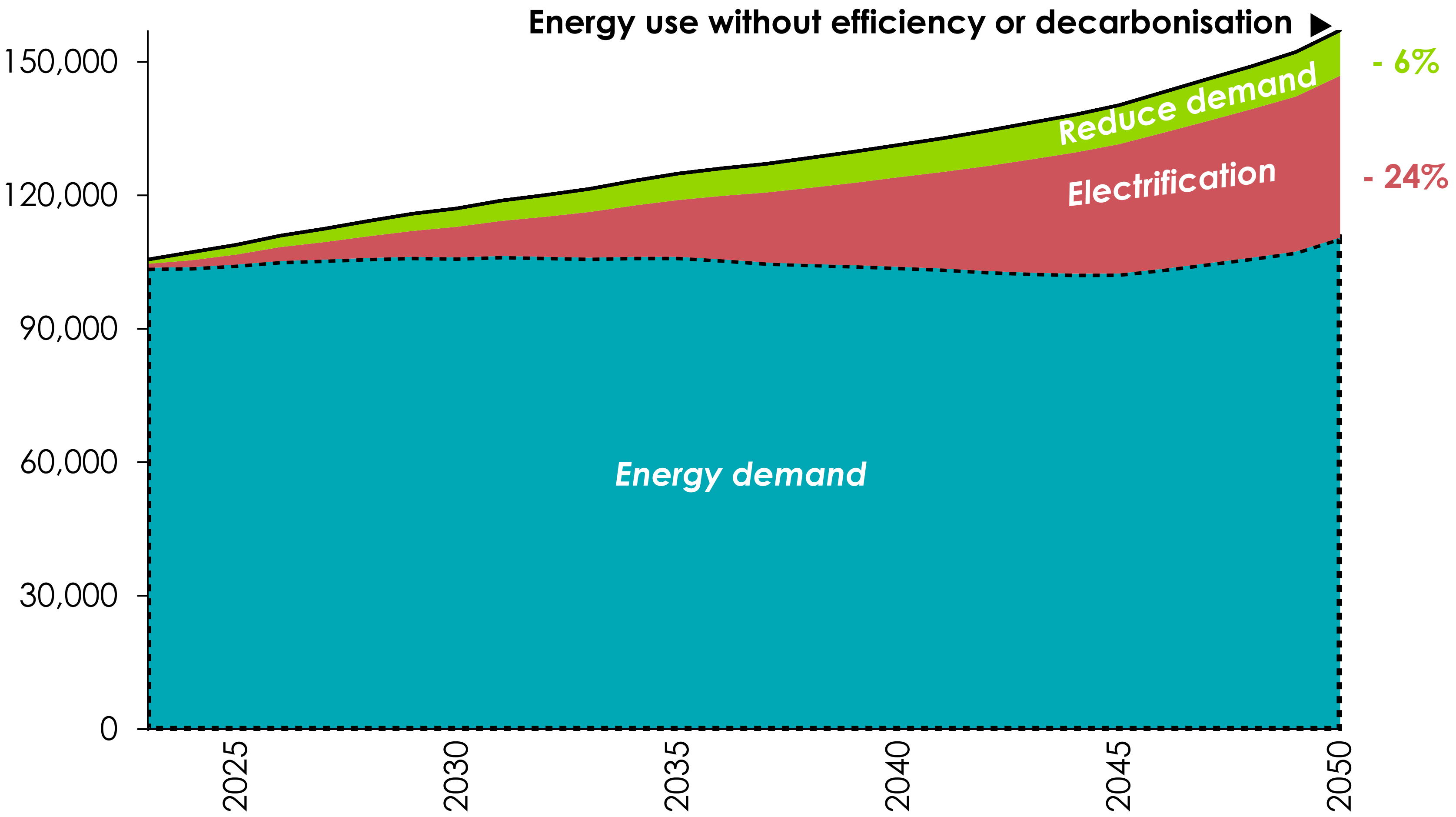
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

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



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

-30%

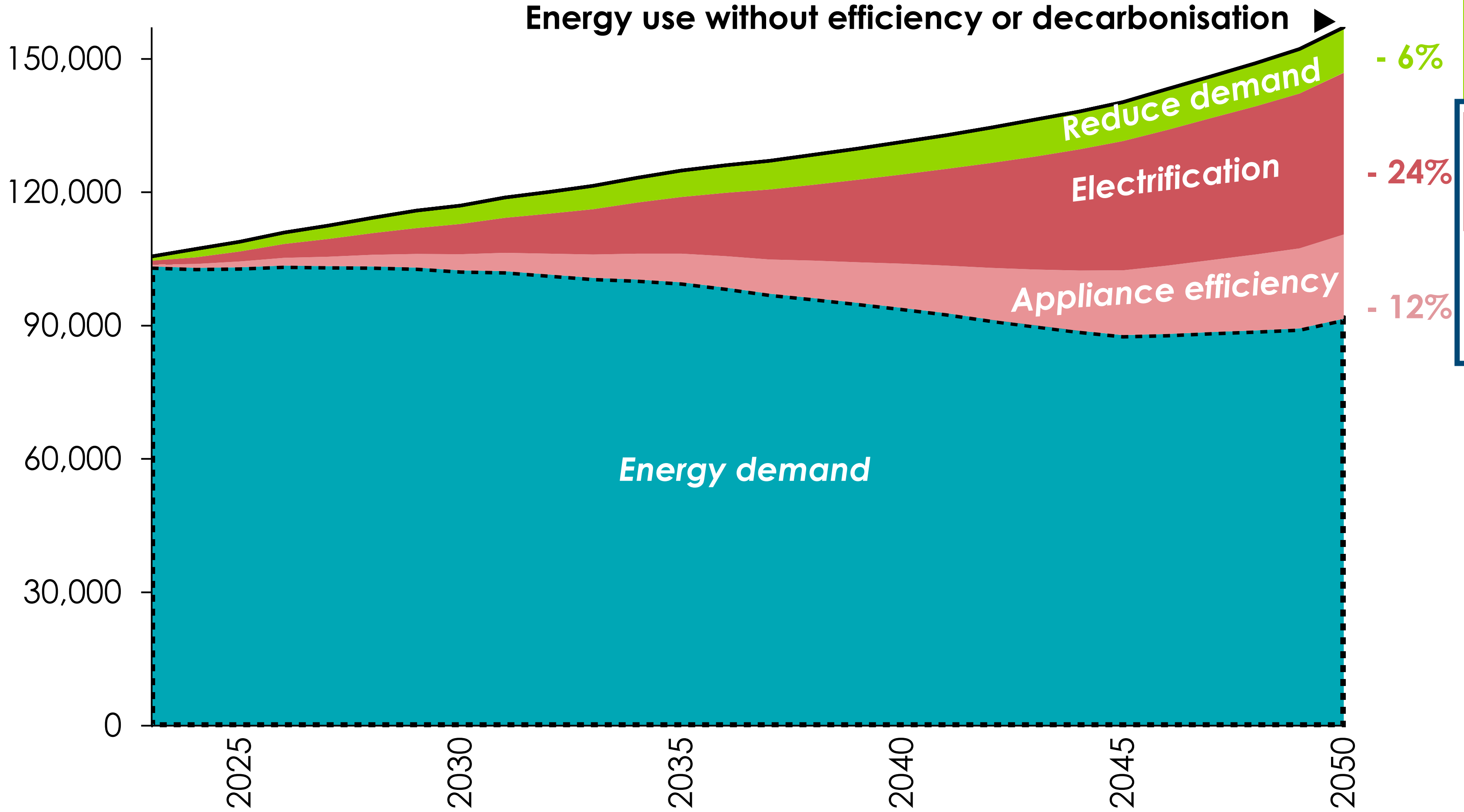
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

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

Key actions Preliminary

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



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

-42%

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

Detail next slide

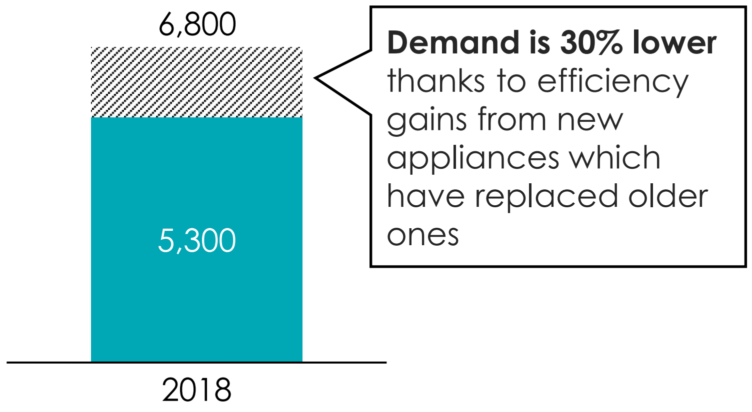
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

The stock turn-over effect: example on road transport and appliances standards

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

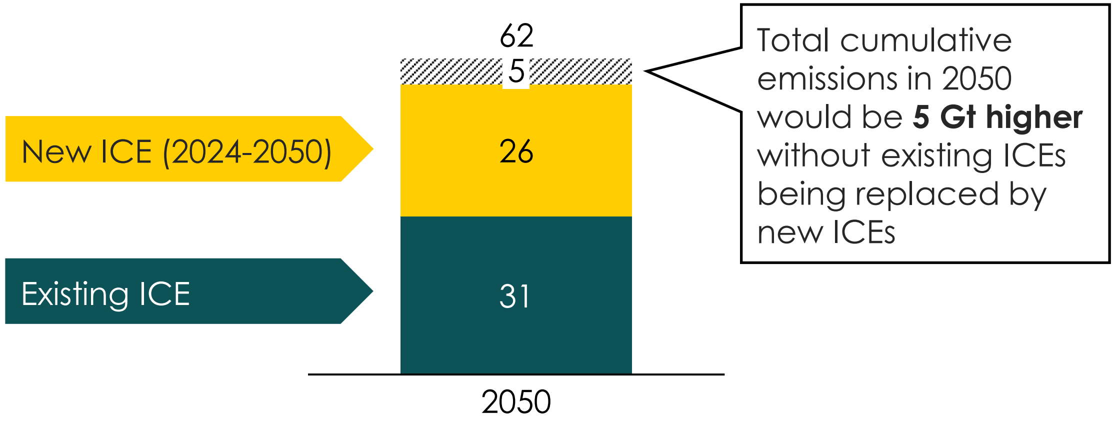
Historical	Outlook
Appliances	**Road transport**

Impact of stock turn-over on appliances final energy demand
TWh



Continuous efforts in **Energy Efficiency Standards and Labelling Programmes (EES&L)** resulted in a **30% annual decrease in appliances energy demand** relative to BAU

Impact of stock turn-over on projected cumulative CO2 emissions from ICEs
2023-2050 Gt CO2



Today, cars on the road typically last around **18 years**
A 2006 vehicle retiring in 2024 would be **consuming approximately 37% more fuel** than a **new 2024 ICE** vehicle.

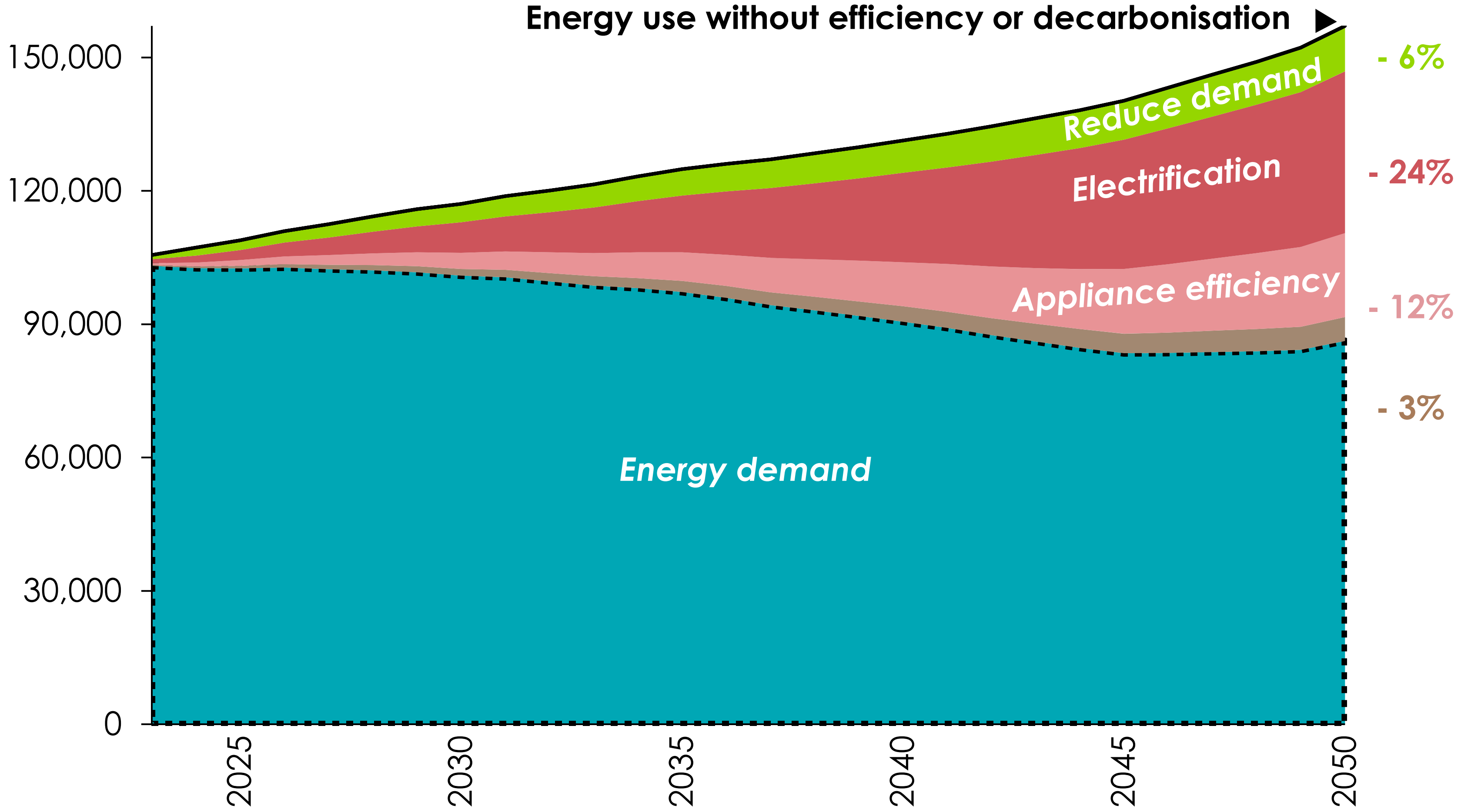
Note: ICE means Internal Combustion Engine Vehicles, EV means Electric Vehicles. We consider that the combustion of a barrel of oil equivalent results ~405 kg CO_2.
Source: Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels; IEA (2018) Achievements of Energy Efficiency Appliance and Equipment Standards and Labelling Programmes; ETC (2025) Buildings report, IEA (2022) Energy Efficiency*

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



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

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

Better insulation in buildings: better buildings codes and fabric improvements

-45%

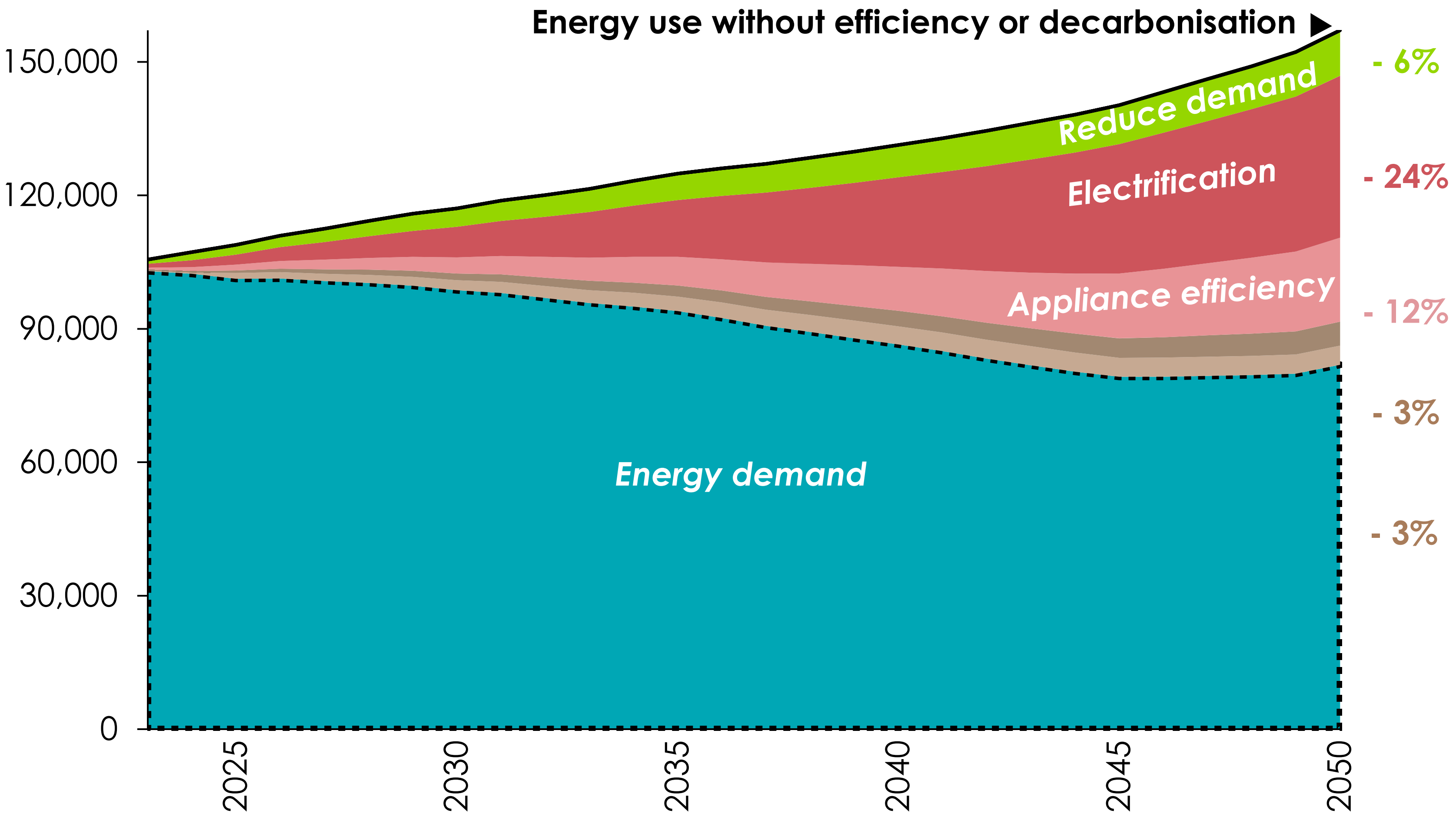
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP)

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



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

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

Better insulation in buildings: better buildings codes and fabric improvements

Everything else – sector-specific interventions

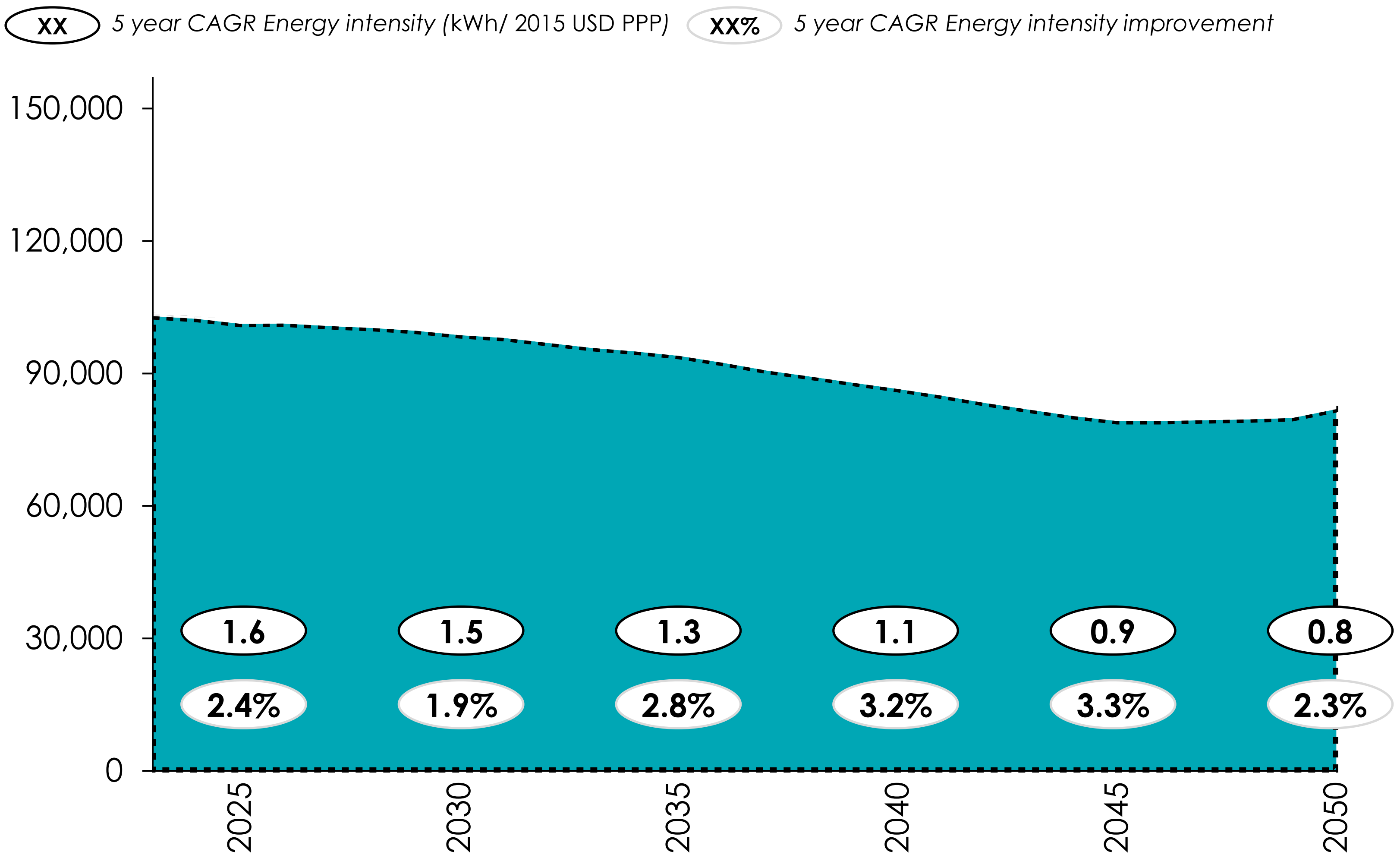
-48%

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

Final energy demand intensity falls by half with all efficiency levers combined

Preliminary

Final Energy demand with electrification and efficiency
TWh



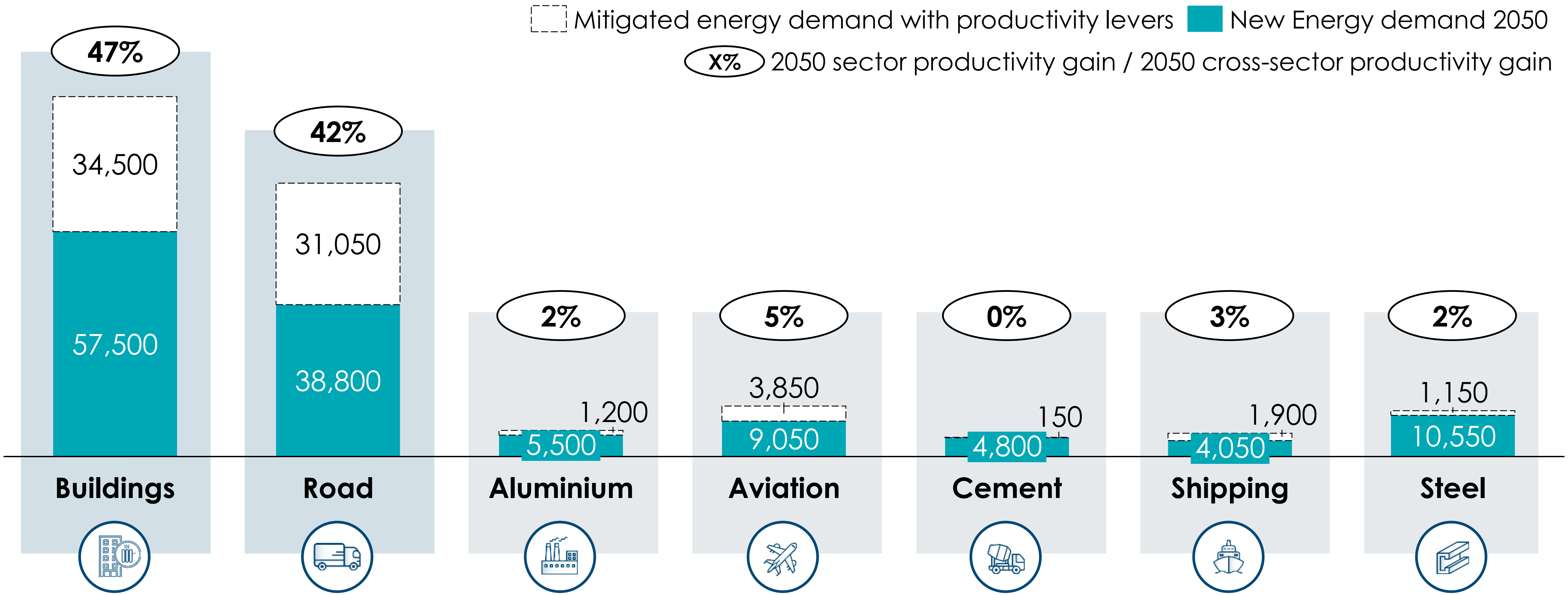
Note: Does not include Chemical levers, Road to be adjusted
Source: Building Report (ETC), Road Report (ETC), STS (MPP), OECD Real GDP Long Term forecast accessed in March, 2025

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



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

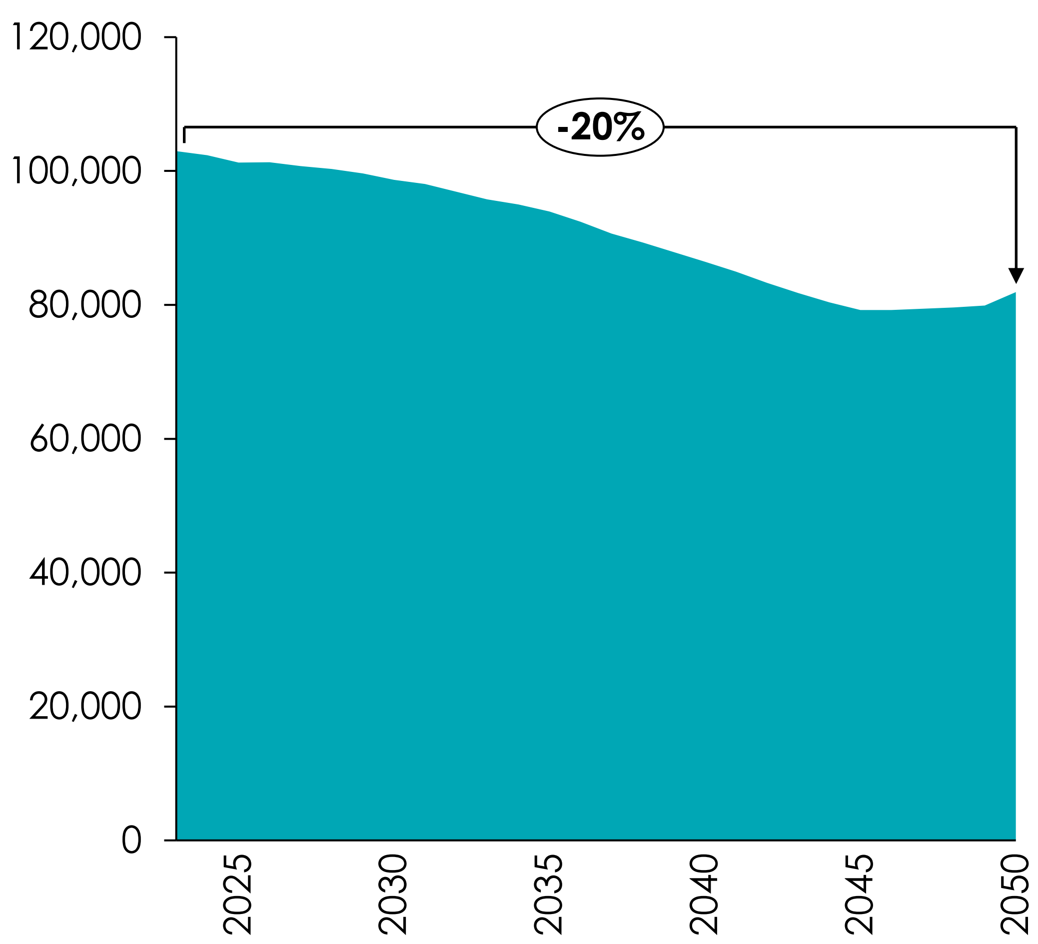
=

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

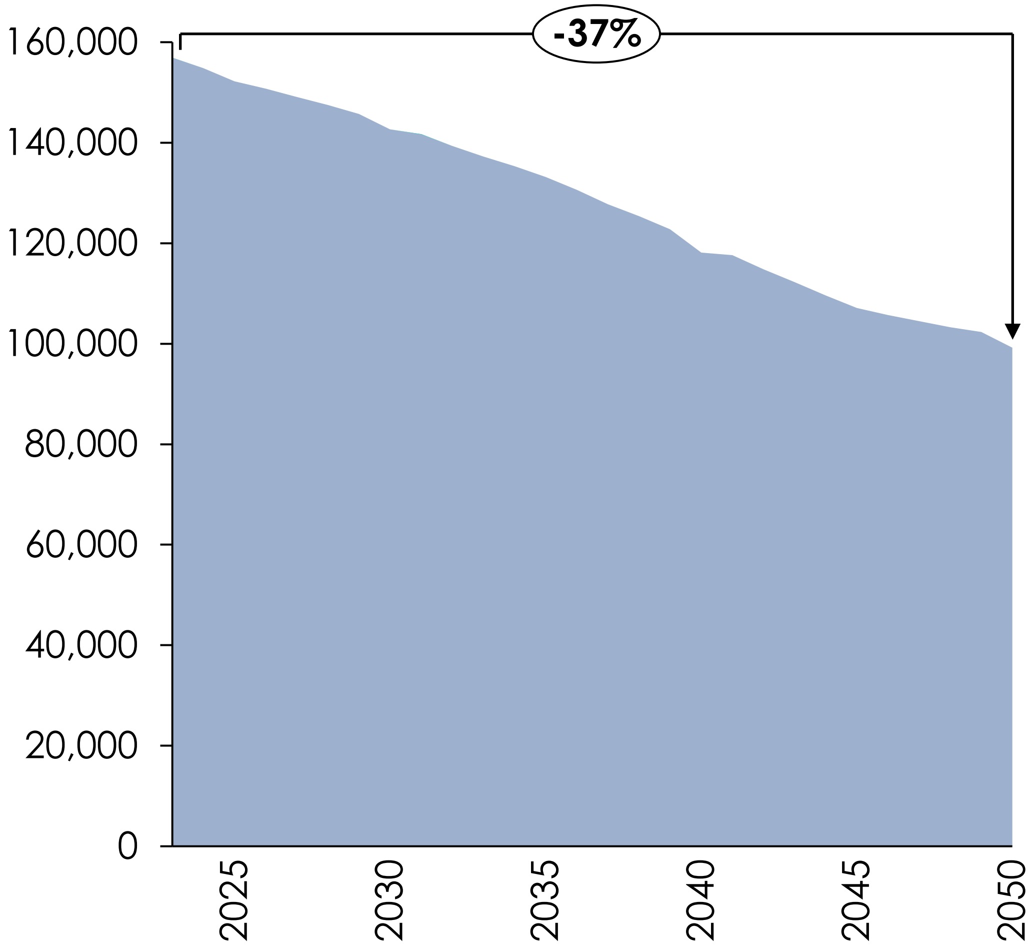
Primary energy demand decreases even more drastically than final energy demand due to clean electrification

Preliminary

Net Zero Final Energy with Productivity levers
TWh



Net Zero Primary Energy demand with Productivity levers
TWh

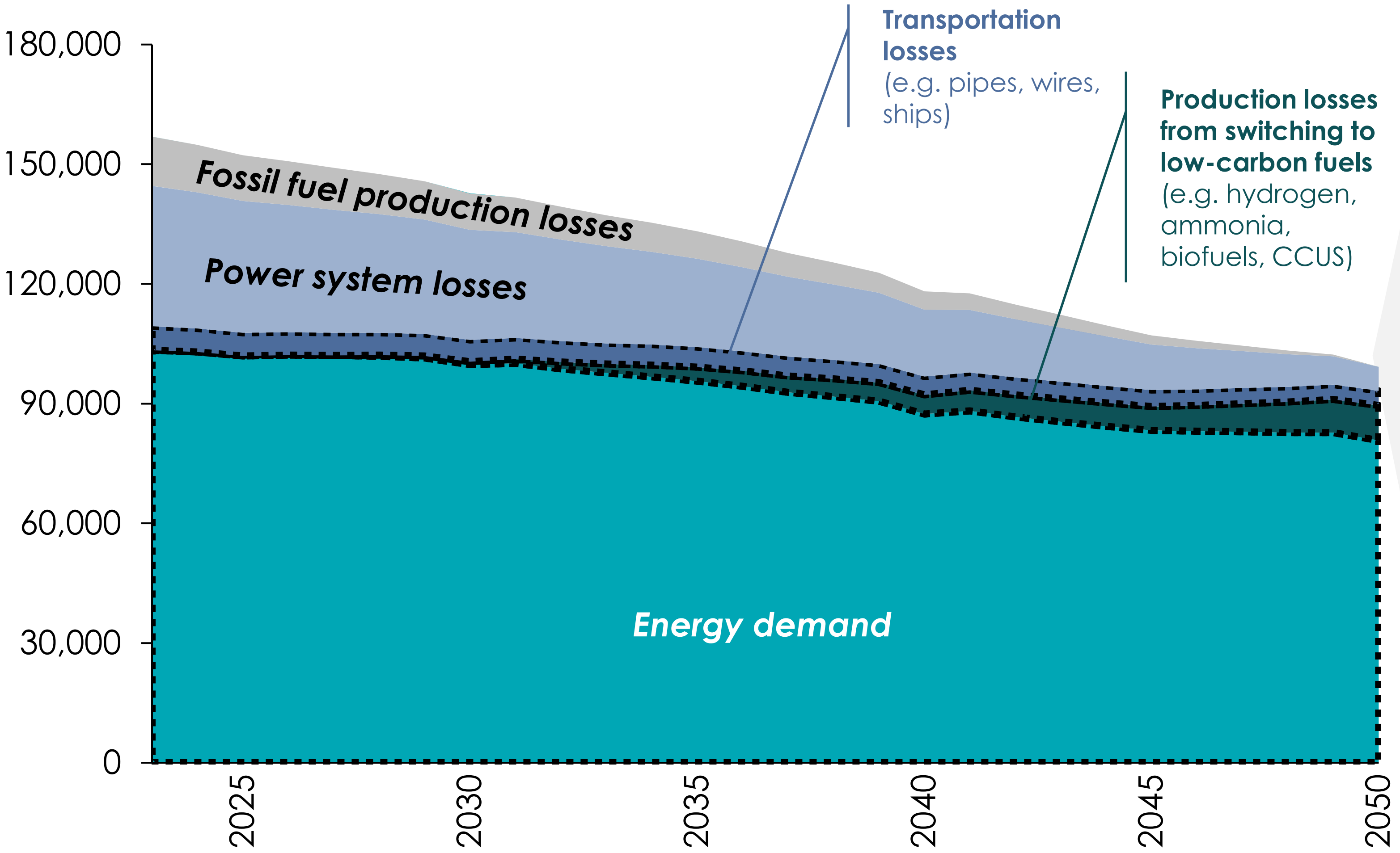


Note: Does not include Chemical levers, Road to be adjusted
Source: Systemiq analysis for ETC;

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

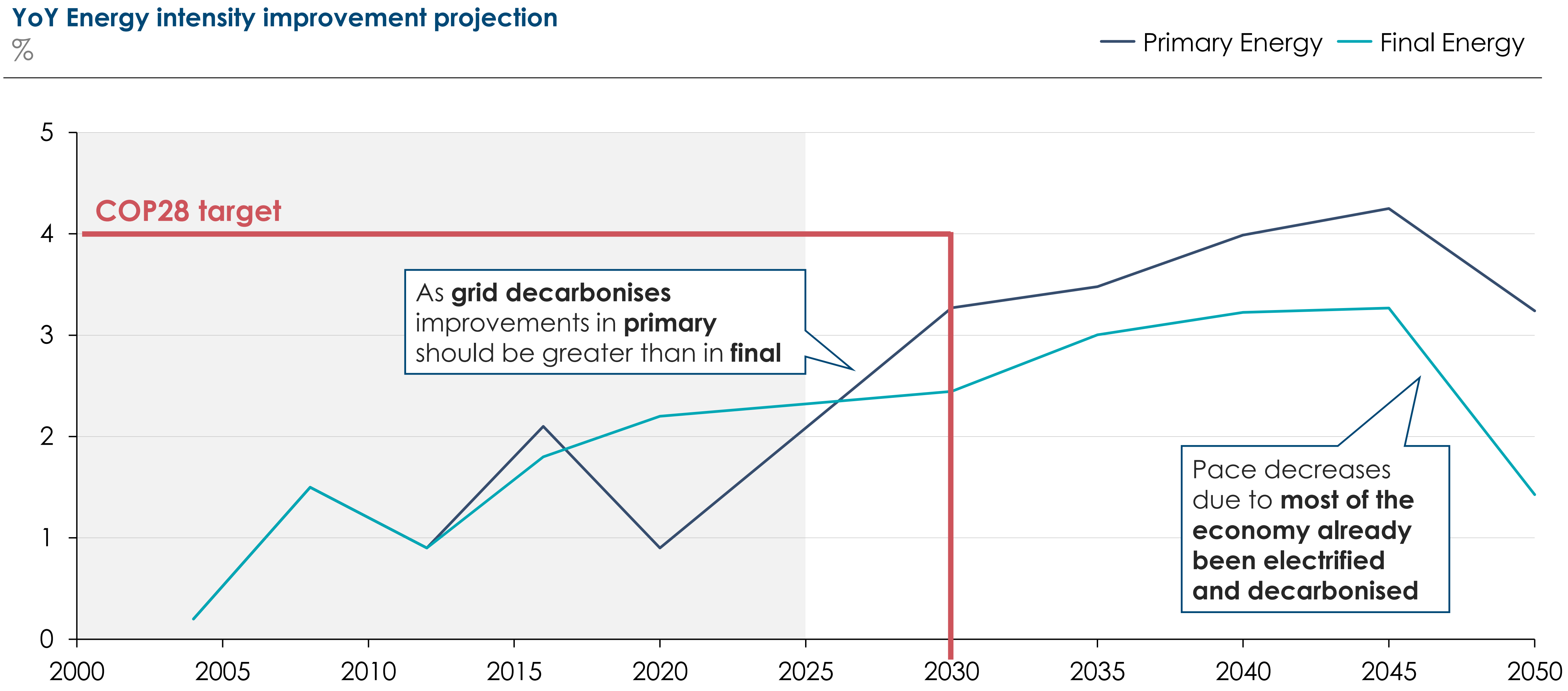


- **Growth of the power system** as direct fossil use is displaced via electrification decreases primary losses, due to electricity being 20 to 60% more efficient than fossil fuel combustion
- Further reductions on primary losses are possible as **power system decarbonises and grid emissions declines**

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

ETC analysis shows a feasible 3.5% energy intensity improvement by 2030, below the 4% from COP28 targets

Preliminary



Source: Systemiq analysis for ETC, OECD Real GDP Long Term forecast accessed in March, 2025

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	• **Set and uphold full ICE sales bans by 2035** • Develop **charging infrastructure** by investing in **fast chargers** and expanding the charging network at all levels
Final Energy	2 Improvements in the efficiency of electrical appliances and vehicles	• **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	• 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	• **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

Recap: Power systems transformation work timeline

	Date	Deliverable
Workshop 1: Grid build challenge	March 26th 2024	Briefing note published in September 2024
Workshop 2: Key technologies to balance the system : *dispatchable generation, storage assets*	June 18th	
Workshop 3: Key technologies to balance the system: *demand side flexibility*	Oct 9th	Briefing Note published in February 2025
Workshop 4: Sizing the system balancing challenge	Oct 24th	
Workshop 5: Potential of long distance cross-border transmission	Dec 9th	Insights Briefing to be published in 2025
Workshop 6: Key enablers	Feb 3rd 2025	
Power systems transformation report	Q2 2025	Report publication

Where we are today

Power report structured in 5 chapters

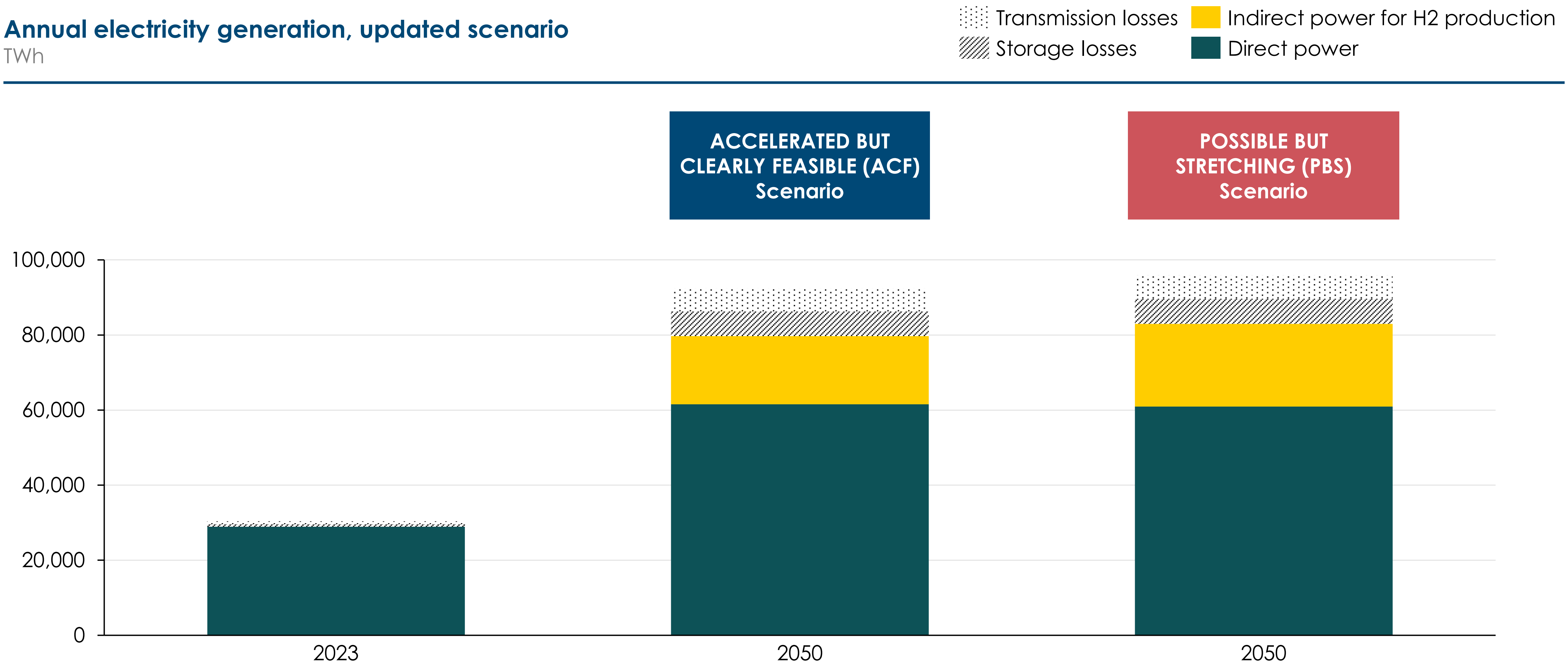
1	**Introduction**	Clean electrification is critical to net-zero, power demand will grow by 3x by 2050; decarbonisation in many locations will be primarily via wind and solar
2	**System Balancing**	System balancing varies by region, set of technologies exist to deliver balancing at low cost
3	**Grid 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

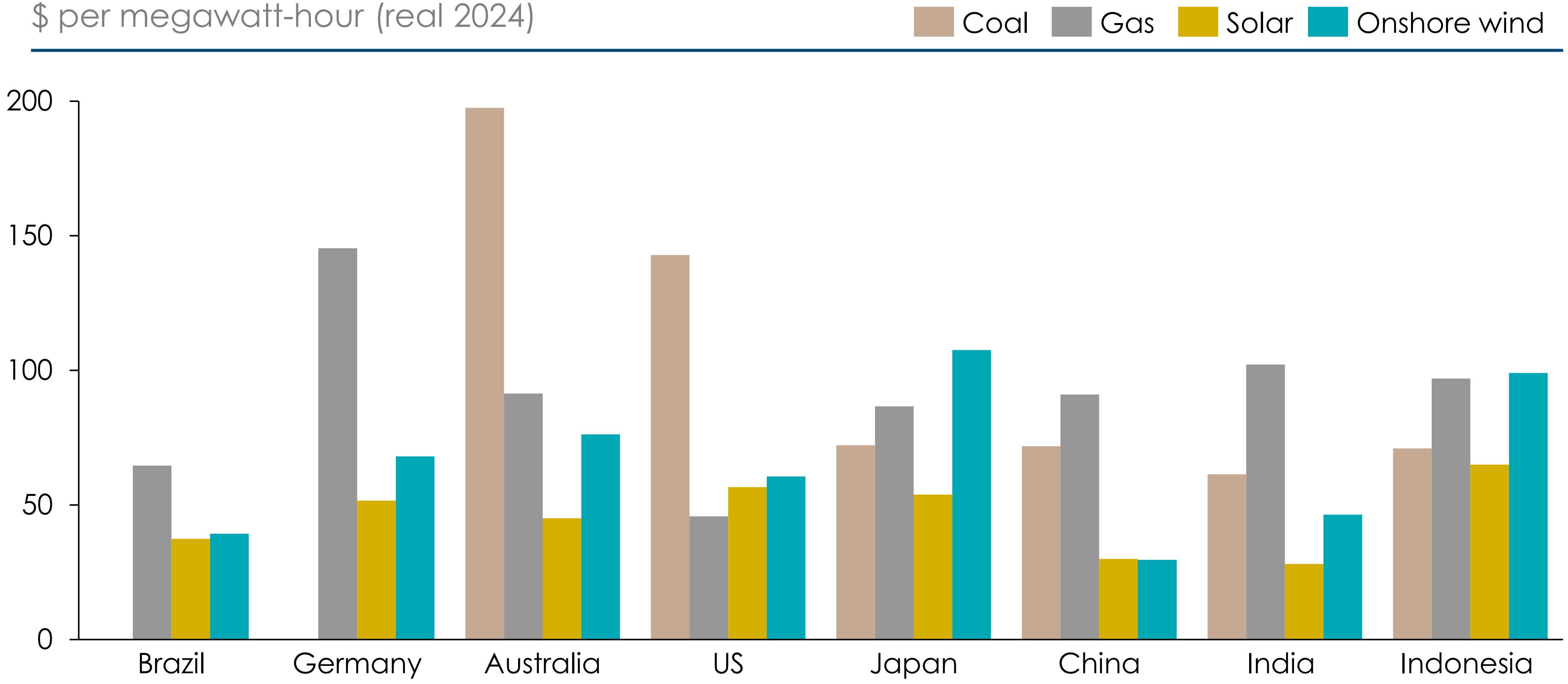


Source: Ember, Systemiq analysis for the ETC (2024)

1 Solar and wind are cost-competitive in many regions

New bulk generation LCOE costs in selected markets (BNEF)

$ per megawatt-hour (real 2024)

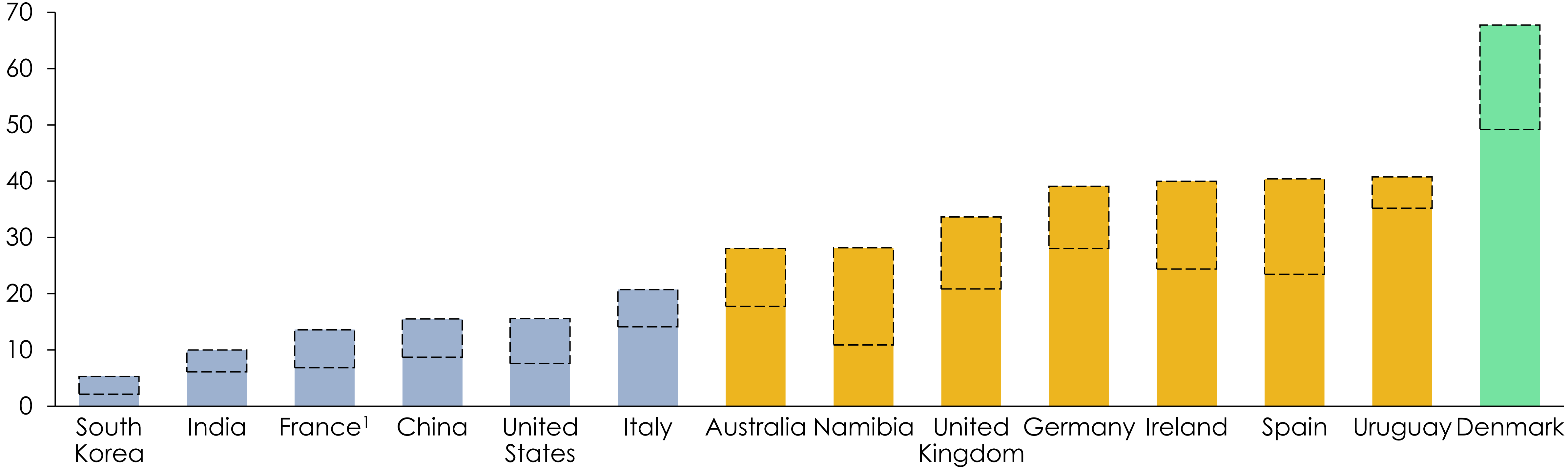


Note: All LCOE calculations are unsubsidized. Project size is at utility scale. Capacity factors for wind are P50. PV capex is in $/MW(DC). In countries where carbon schemes exist, the LCOEs and marginal cost of generation estimates of fossil fuel power plants include a carbon price. The LCOE range represents 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.

1 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, 2024



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
% Growth from 2024 to 2030

[1] France'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 However, two key questions remain open in the debate around the feasibility of power systems with high shares of wind and solar

1) Technical operation challenge

In many regions, **ongoing concerns that operating an electricity system with a high share of variable renewable energy could lead to technical challenges in maintaining grid stability;** these include issues with frequency regulation, voltage control, and system inertia, as traditional fossil fuel plants, which historically provided these services, are phased out

2) Cost concerns

Broader concern that shifting to a system dominated by variable renewables will lead to **prohibitively high costs to balance variable generation**. Without sufficient dispatchable backup, there are concerns that systems could struggle to meet demand during extended periods of low wind and solar generation, increasing reliance on costly peaking plants or imports

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

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2 Systems can meet balancing challenge

- **Technical system operation in clean power systems can be managed**, provided via new technologies, already real-world examples where wind and solar provide most of the electricity generation at certain times of the year

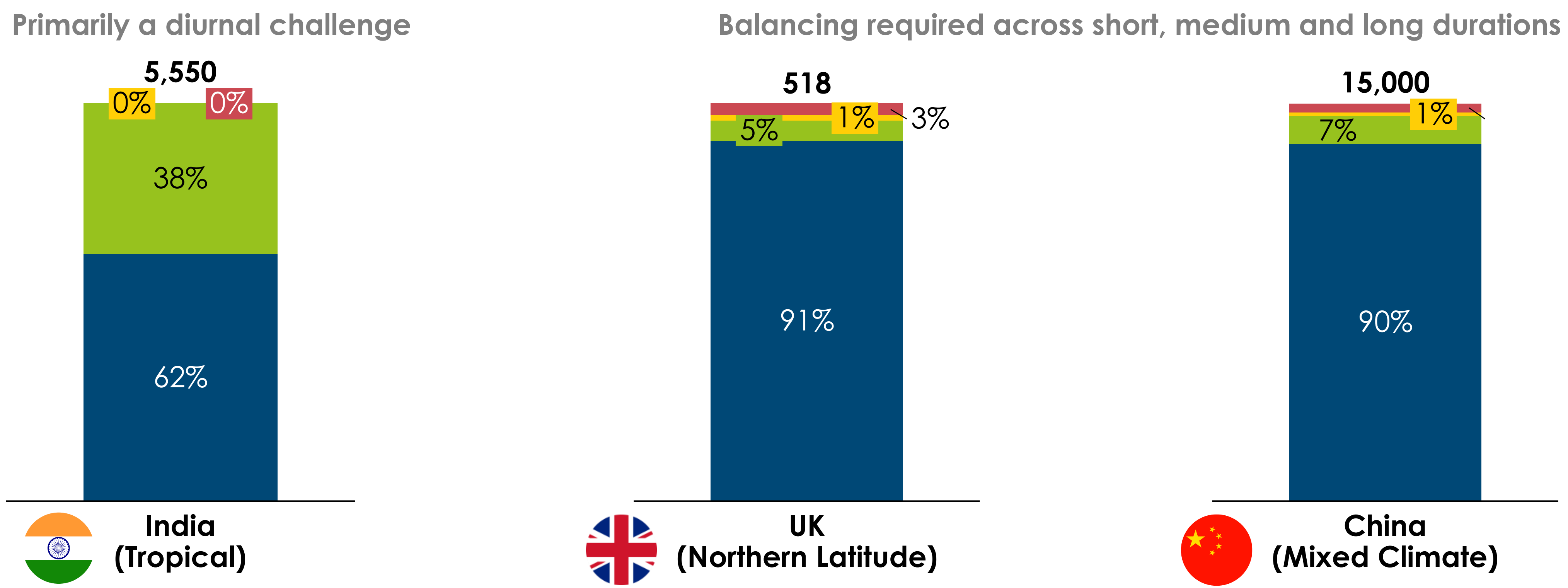
- **Balancing challenge occurs across several durations, and can be met by a mix of available technologies:**
  - **Short-duration balancing** is increasingly cost-effective (e.g. lithium-ion, demand side flexibility)
  - **Medium- and long-duration balancing** remains more costly, requiring a mix of storage technologies, interconnection, and flexible dispatchable generation
  - **Ultra-long duration balancing** to fully decarbonize the 'last mile' remains the highest-cost challenge, requiring hydrogen, CCS, or limited unabated gas at very low utilization in extreme conditions.

- **The cost of balancing varies by region, influenced by the availability of wind, solar and balancing requirement**;
  - In many Tropical/Equatorial geographies with fast-growing electricity demand, round the clock electricity can increasingly be provided by solar & batteries at low cost, outcompeting fossil options
  - In some geographies ("Northern latitude", ~15% of electricity demand today), challenge will require longer duration balancing routes, which are more expensive but can still be competitive with today's system costs

2 The balancing challenge differs across regions

Balancing variability for India, UK, and China

% of TWh of annual demand provided by specified generation/storage



= $51/MWh (real 2024$)
Total system generation and balancing cost

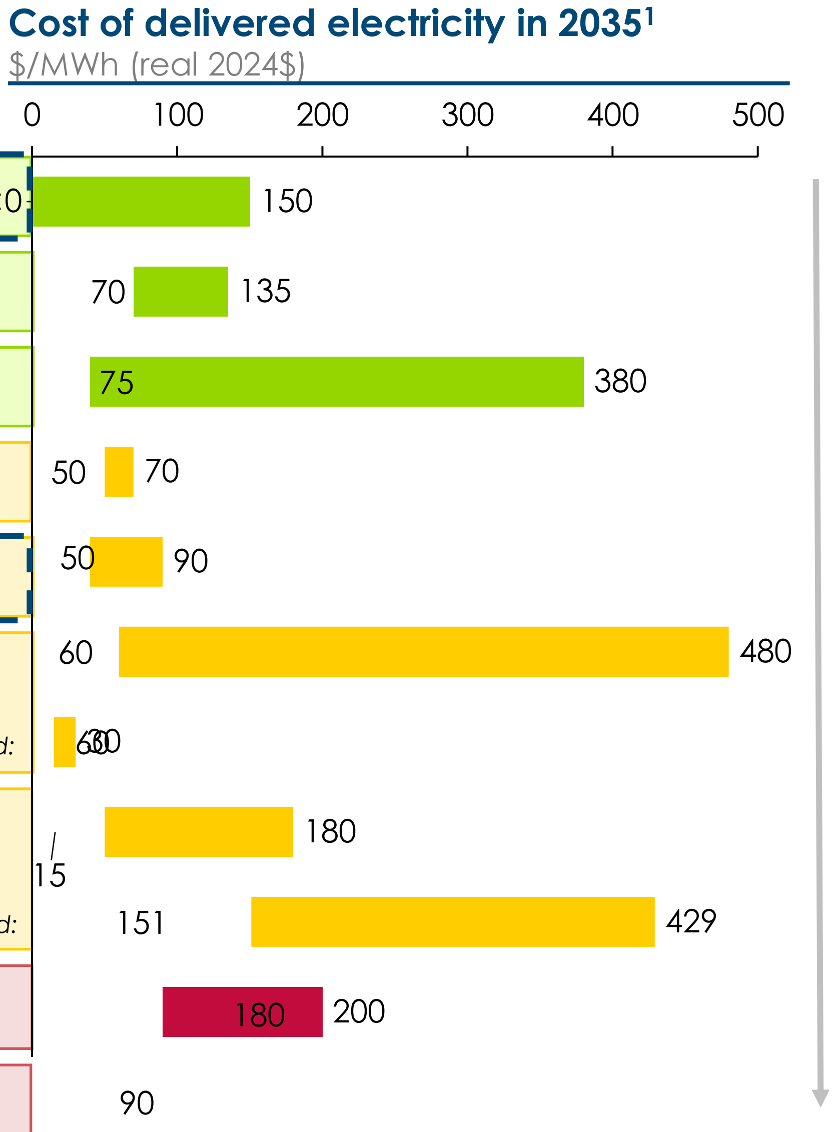
= $70 / MWh (real 2024$)
Total system generation and balancing cost

= $36 / MWh (real 2024$)
Total system generation and balancing cost

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)

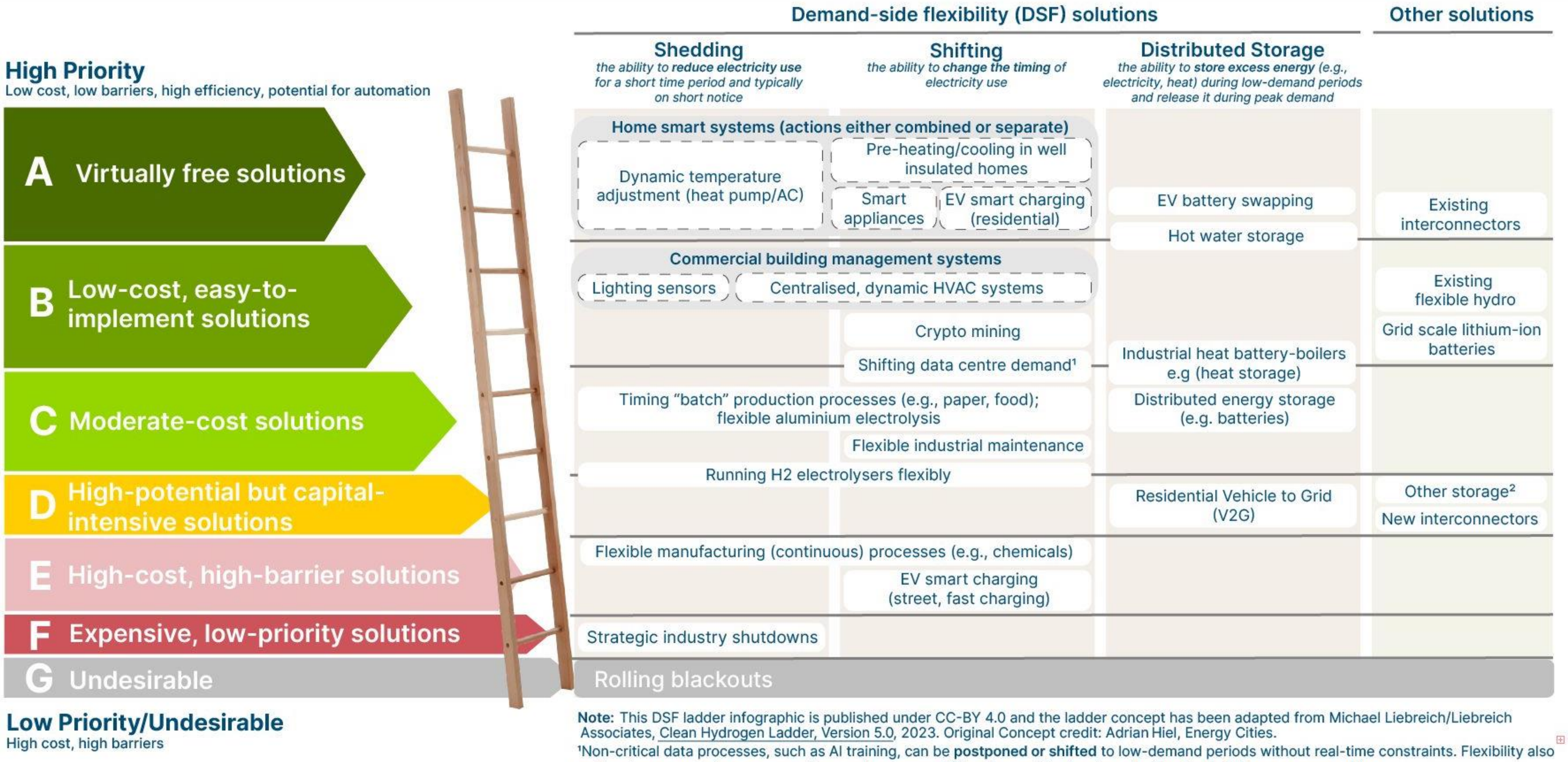
2 The costs associated with different balancing solutions vary significantly

Balancing needs	Key zero-carbon balancing technologies across durations	
Short / hourly duration (up to 8 hours)	• Demand-side flexibility	<0
	• Lithium-ion and sodium-ion batteries	
	• Heat storage	
Medium-Long duration (up to 50 hours)	• Energy storage (pumped hydro, compressed air, batteries)	
	• Long-distance transmission (for balancing)	
	• Running nuclear flexibly	*Existing:* / *New build:*
	• Running hydro flexibly	*Existing:* / *New build:*
Ultra-long (50 hours+)	• H2 in CCGT, CCS on CCGT (low utilisation)	
	• Unabated gas (low utilisation)	



[1] The DSF range 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.

2 Short-duration flexibility “ladder” highlights key opportunities



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

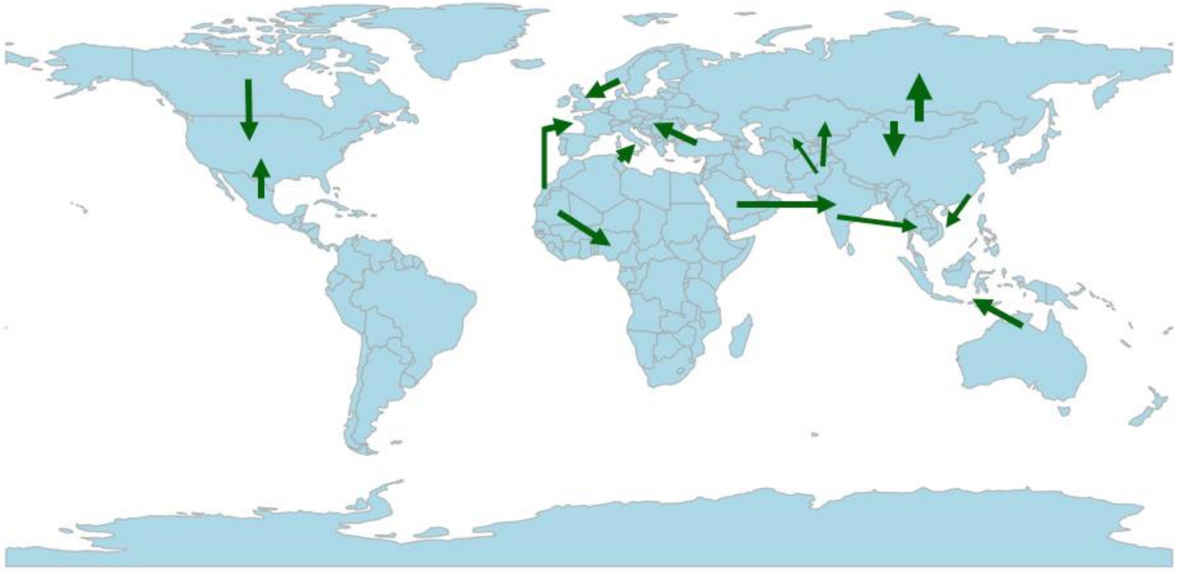
Long distance transmission can help to deliver:

- 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



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3 Grids will need to expand, optimisation is critical

- **Grids must expand significantly to support growing electrification**, with network capacity needing to increase by at least 50% by 2050 in a net-zero scenario; even with all optimization measures in place, substantial new grid infrastructure will still be required, but efficiency improvements can reduce scale and cost of expansion

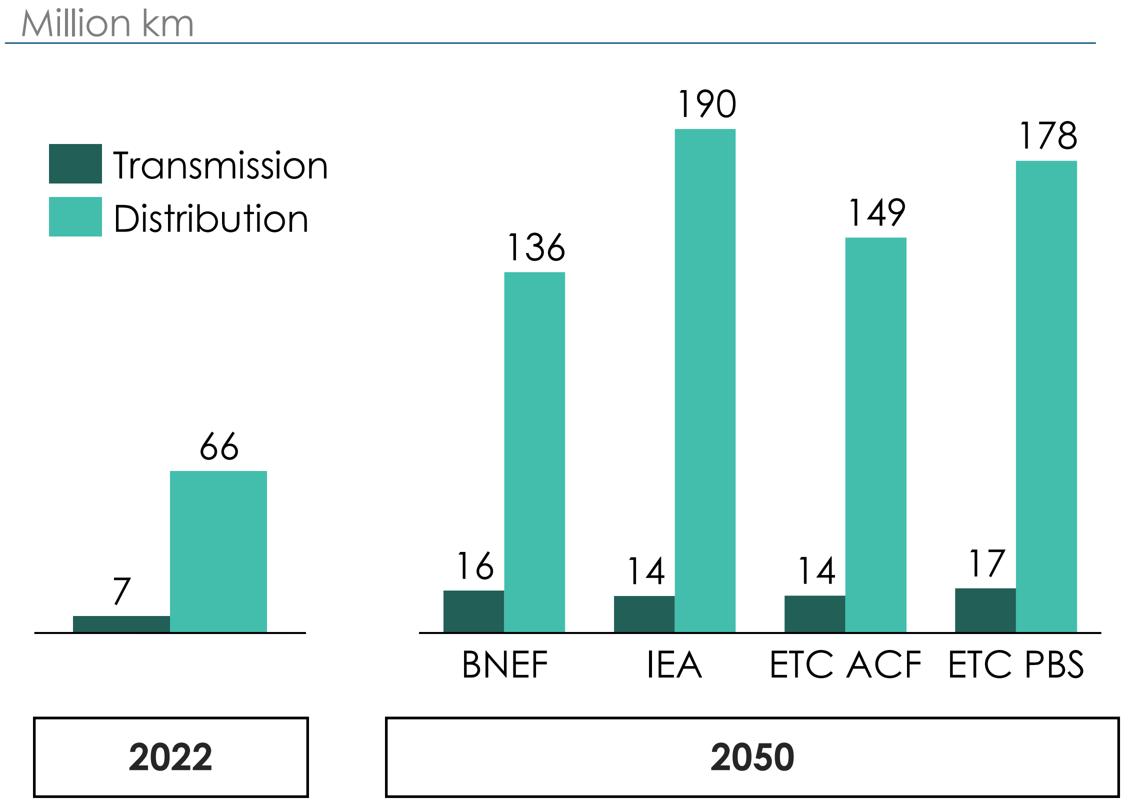
- **Significant investments in grid infrastructure are required** and must outpace demand growth to avoid bottlenecks; **while these investments will increase system grid costs in the short-term, over the longer term the costs spread over a larger system likely to lead to grid costs in line with today's**
  - While grid capital expenditure will rise in the near term, one-third of spending will be required regardless of net-zero goals, as ageing infrastructure in developed countries needs replacement

- **Deploying demand side flexibility (DSF) and innovative grid technologies (IGTs) can reduce the scale of the build & investment challenge,** as well as help mitigate societal concerns (e.g. NIMBYism)

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

3

Estimated wires required under assumptions



- 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

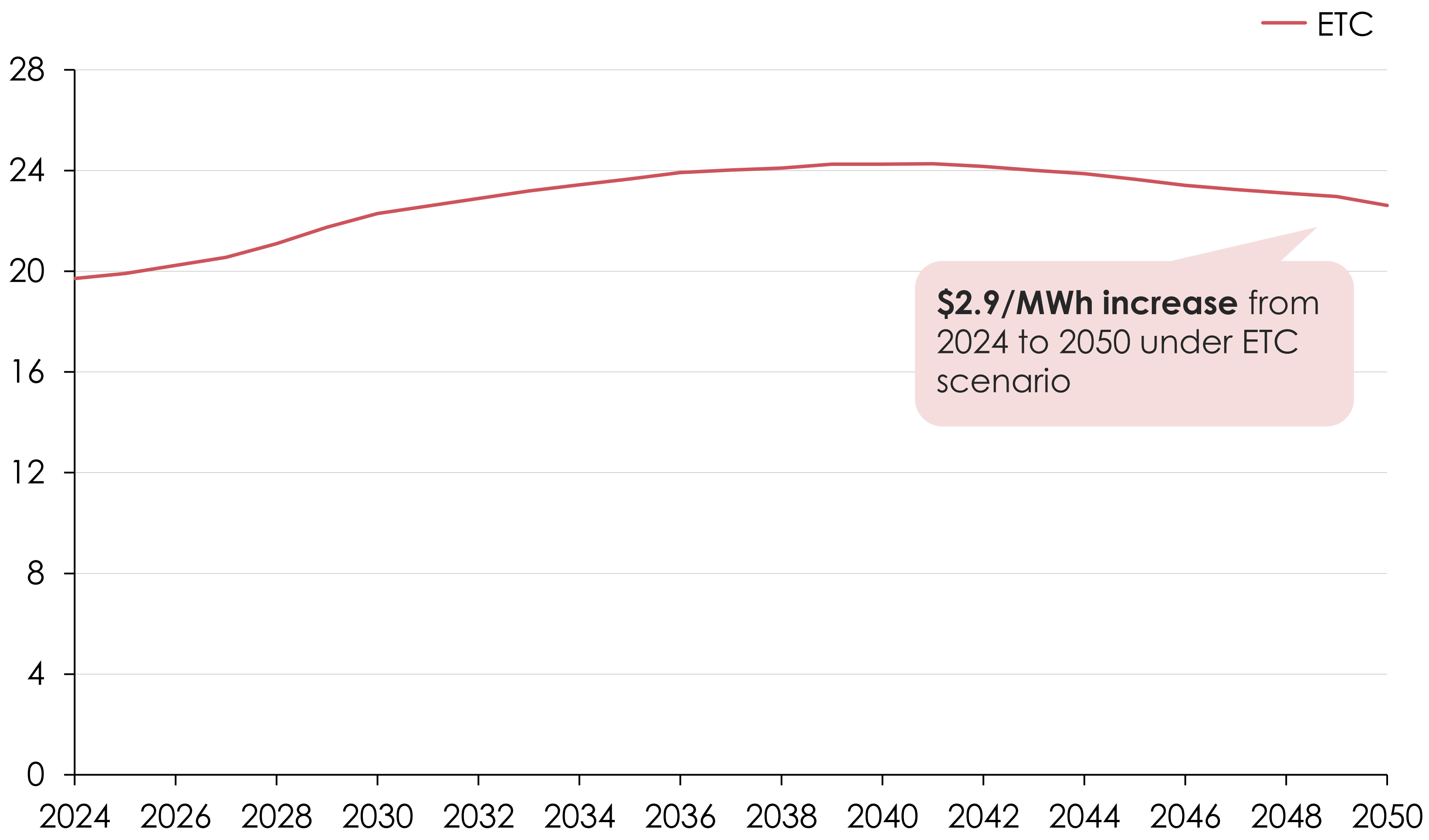
- However, even full deployment of all optimisation routes will not eliminate the need to build new grids

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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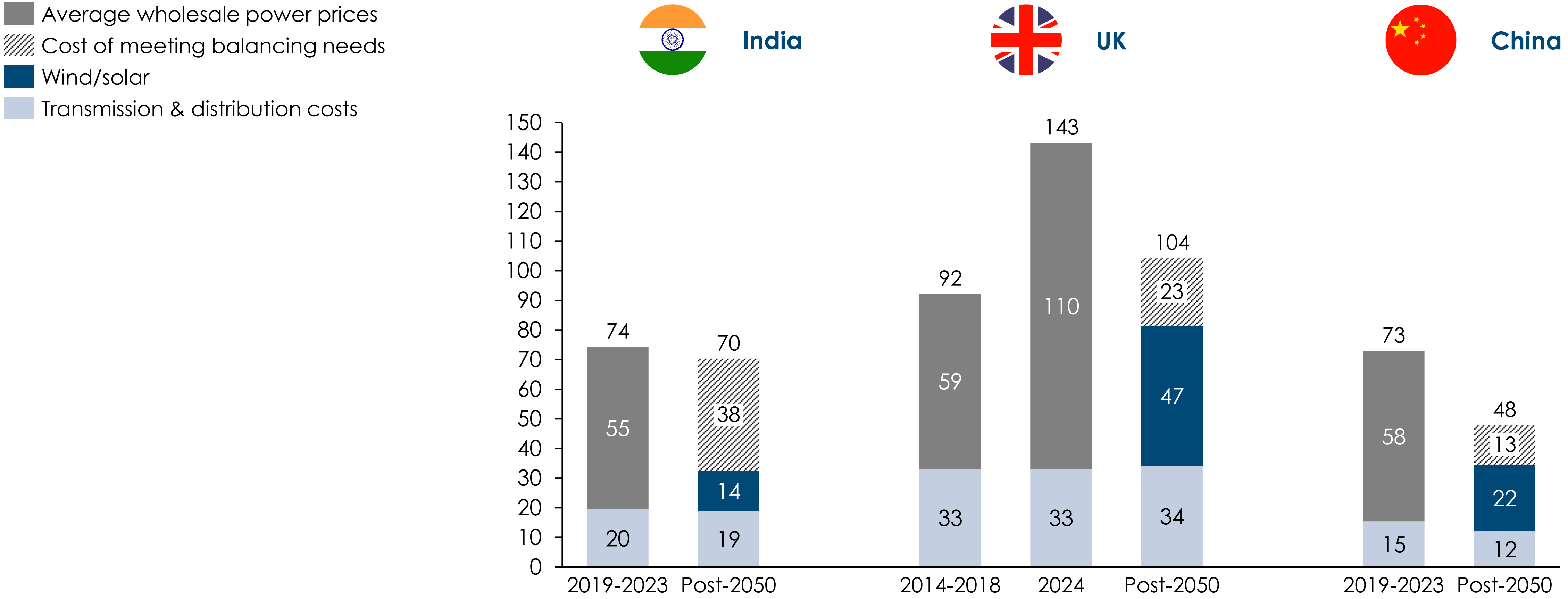
4

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

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

$/MWh (real 2024$)

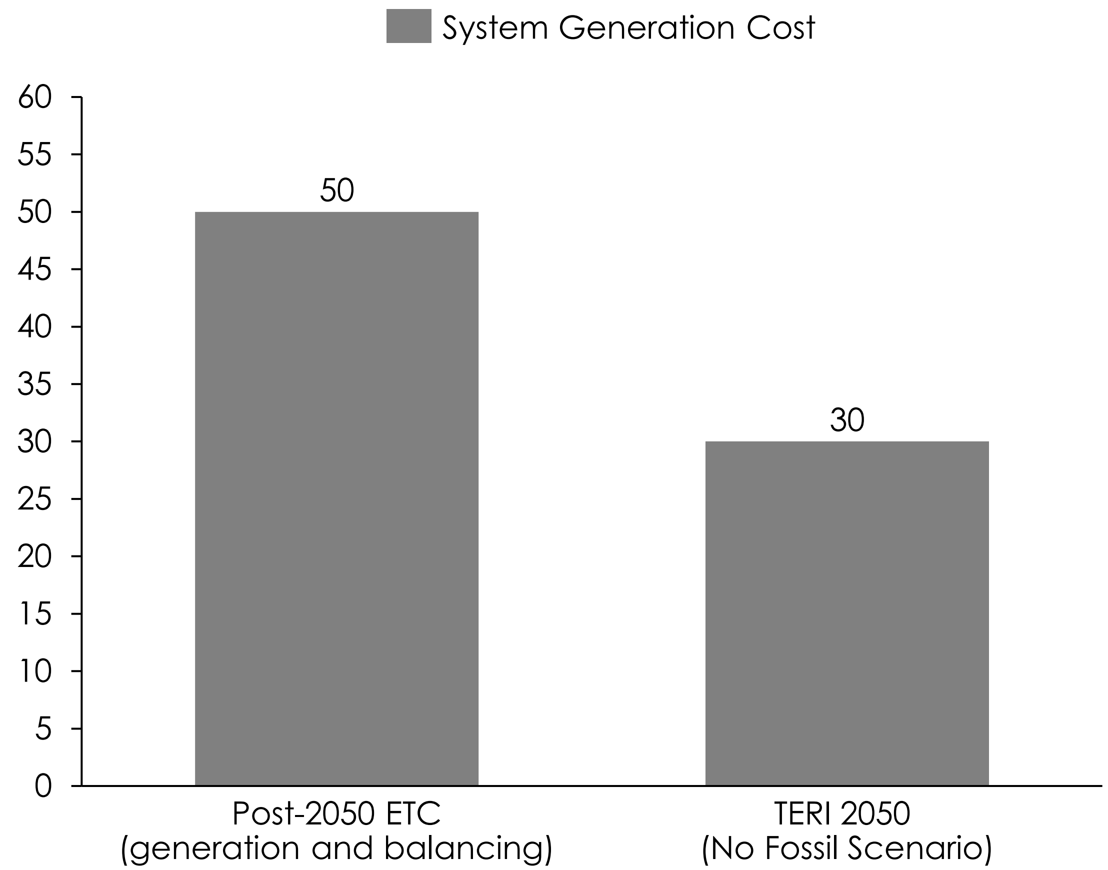


Sources: Systemiq analysis for the ETC (2025); BNEF (2023), 2H 2023 LCOE: Data Viewer v.1.0; Ofgem (2025), *Wholesale market indicators – Electricity Prices: Forward Delivery Contracts – Weekly Average (GB)*; IEA (2023), *Electricity Market Report – Update 2023*; Statista (2024), *Average electricity 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 forecasts[1]

$/MWh (real 2024$)



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

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

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5 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 Market design principles to support new technologies

- **Across the set of key technologies, revenue certainty is essential to scale new projects; in some cases, merchant markets alone are too volatile or insufficient**

- **A range of mechanisms exist to provide revenue certainty**; the choice will depend on the market, technology and investment risk profile. These options include;
  - **'Unbundled' mechanisms** - these rely on separate contracts for different revenue streams, meaning projects must secure multiple agreements to cover their costs. Examples:
    - Cap and Floor, Corporate Power Purchase Agreements (PPAs), Capacity Markets, Tolling Agreements
  - **'Bundled mechanisms'** - These consolidate multiple revenue streams into one contract, simplifying cash flows and reducing the need for additional agreements. Examples:
    - Contracts for Difference (CfDs), Round-the-Clock (ROTC) Auctions

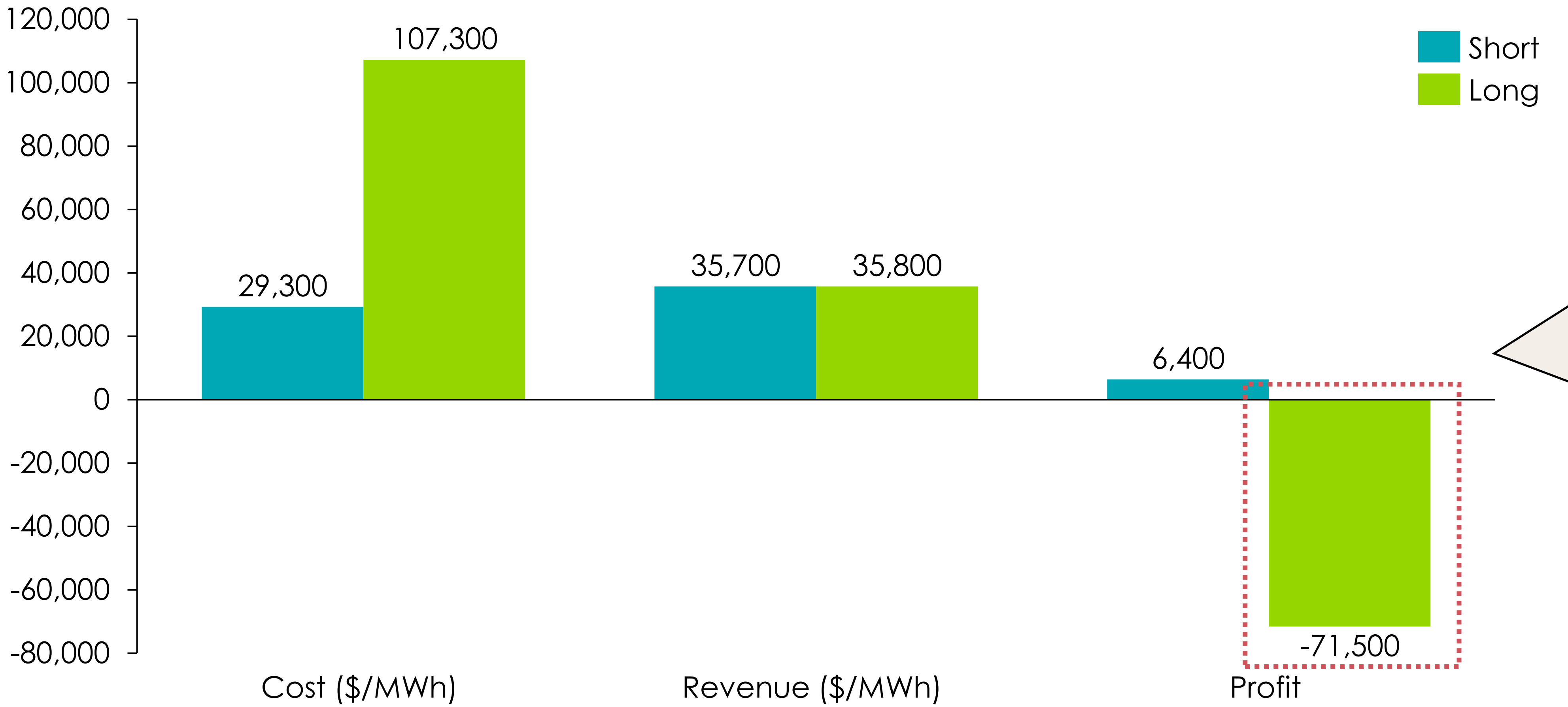
- While these include government and corporate-backed structures, **government-backed will be more common and critical in ensuring system-wide needs are met**

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) Modo 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 Modo 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

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6 Future clean, balanced systems can be cost competitive with today's systems

- Earlier, we showed how **future, clean systems complete with balancing and grid costs can be cost competitive with today's systems.** We can, therefore, be confident in the knowledge that these systems are technically achievable on a cost-basis

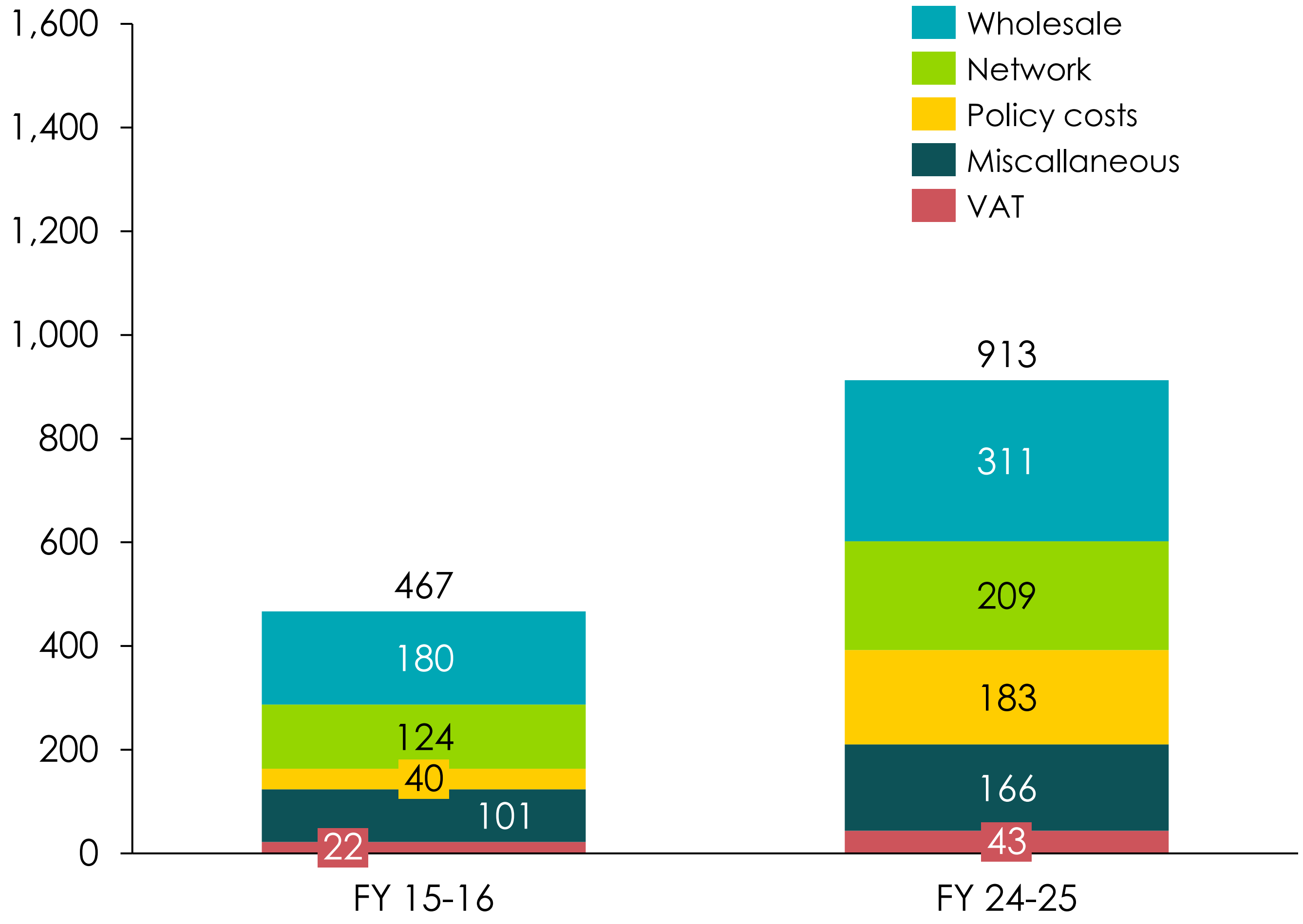
- **However, while our long-term outlook is positive, we must balance this with an understanding of how this transition will impact consumers and stakeholders in the nearer-term**

  - In particular; as we emphasise this positive outlook to consumers, we need to ensure that **immediate benefits of the transition** are also felt to build public support and ensure economic and social equity

  - This is a priority in markets where electricity prices are increasing e.g. Australia and European markets such as the UK, Germany, Norway,

6 UK electricity bills have grown over time

Typical UK electricity bill 2025 and 2015
GBP per kWh



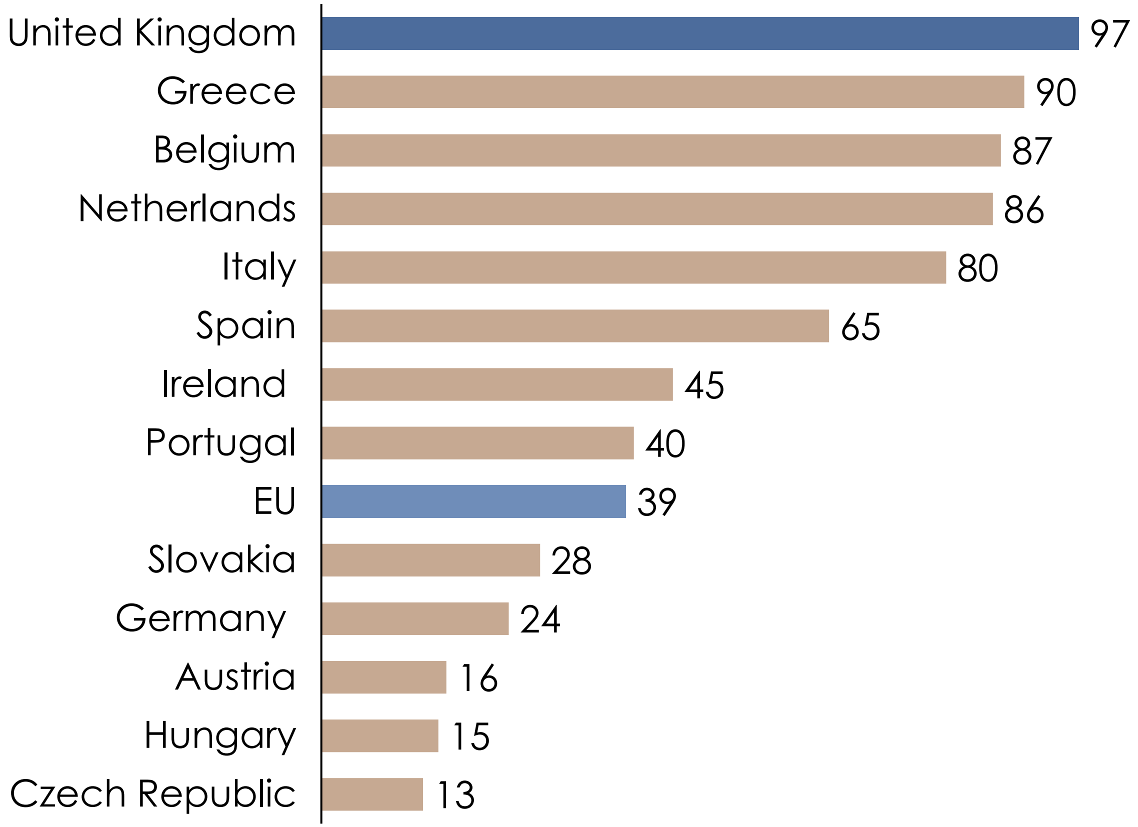
Source: OFGEM price cap, NESO forecasts, Ben James data and calculations (2025)

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
%



Source: BBC

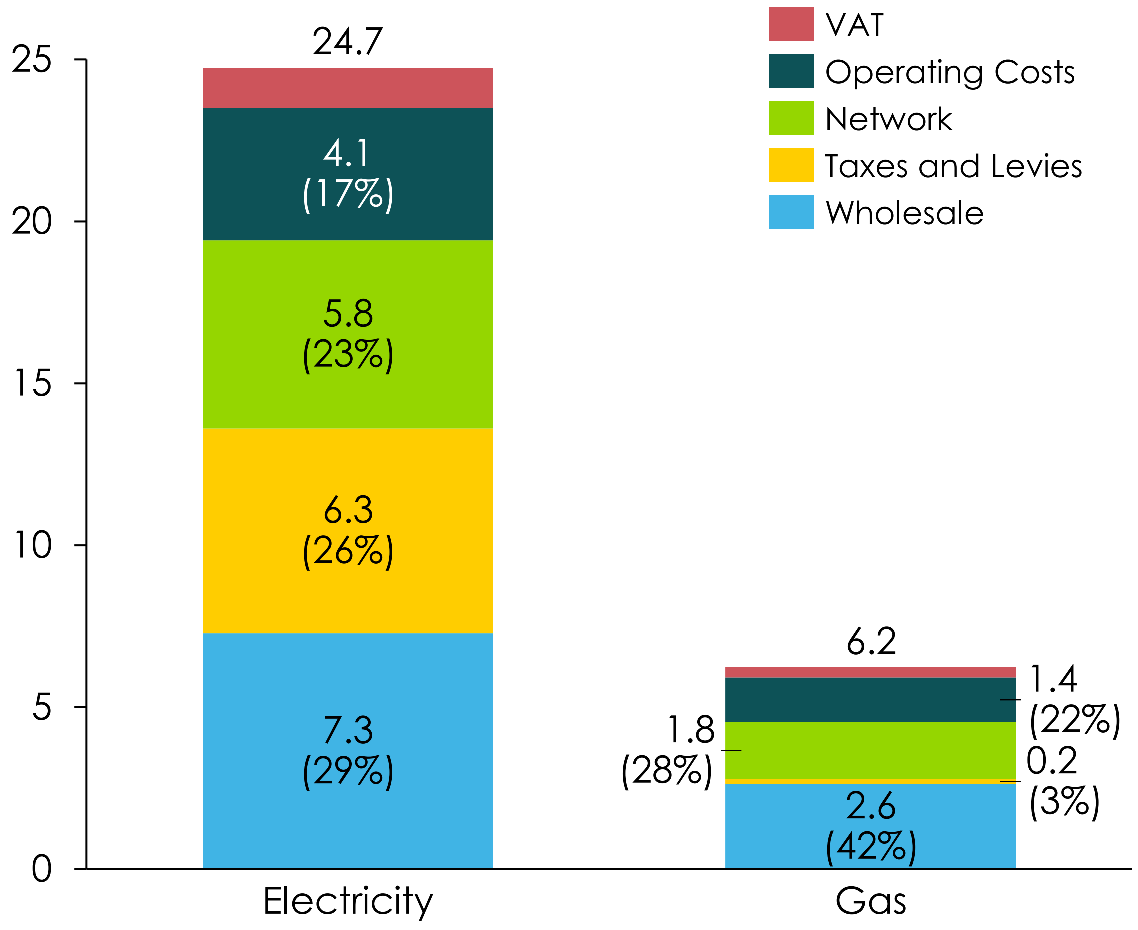
1 High wholesale prices

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**

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

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