Energy
Transitions
Commission

Key ETC insights ahead of COP30

ETC Commissioners meeting

30 October 2025

Agenda

- **What is ETC doing at COP30?**
- COP28 energy efficiency target: opportunity to meet in next two decades
- Tripling Renewables: focus on Sunbelt opportunity and optimizing grids
- The role of Carbon Molecules in the Energy Transition

November 10–21

COP30
BRASIL
AMAZÔNIA
BELÉM 2025

COP30's six thematic action agenda axes:

1) **Energy, Industry & Transport**
2) Forests, Oceans & Biodiversity
3) **Agriculture & Food Systems**
4) Cities, Infrastructure & Water
5) Human & Social Dev.
6) Cross-cutting issues

Official ETC participation in axes **1 and **3***

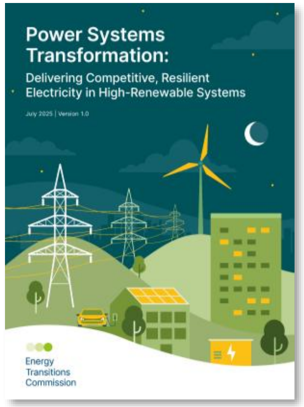
Priority theme days:

10-11: Adaptation, Cities, Infrastructure, Water, Waste, Local Governments, Bioeconomy, Circular Economy, and Tourism.

14-15: Energy, Industry, Transport, Trade, Finance, Carbon markets, and Non-CO_2 gases

ETC Attendance:

- Chairman **Adair Turner** [Belem]
- Head of Low-Carbon Fuels **Andrea Bath** [Belem]
- Co-Chair **Jules Kortenhorst** [Belem]
- ETC Vice Chair **Faustine Delasalle** [São Paulo]



Power Systems Transformation:
Delivering Competitive, Resilient Electricity in High-Renewable Systems
July 2025 | Version 1.0
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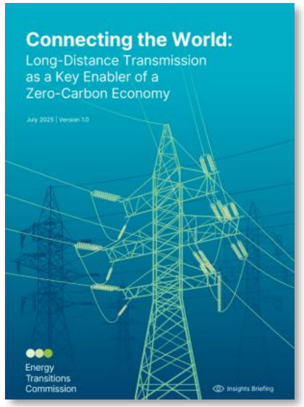

Connecting the World:
Long-Distance Transmission as a Key Enabler of a Zero-Carbon Economy
July 2025 | Version 1.0
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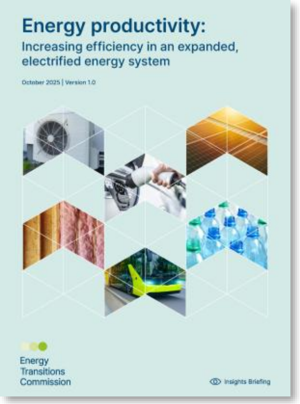

Energy productivity:
Increasing efficiency in an expanded, electrified energy system
October 2025 | Version 1.0
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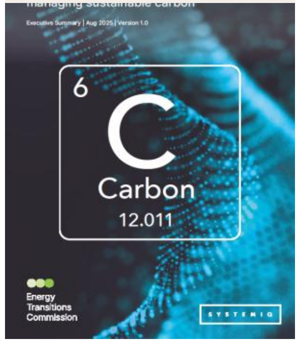
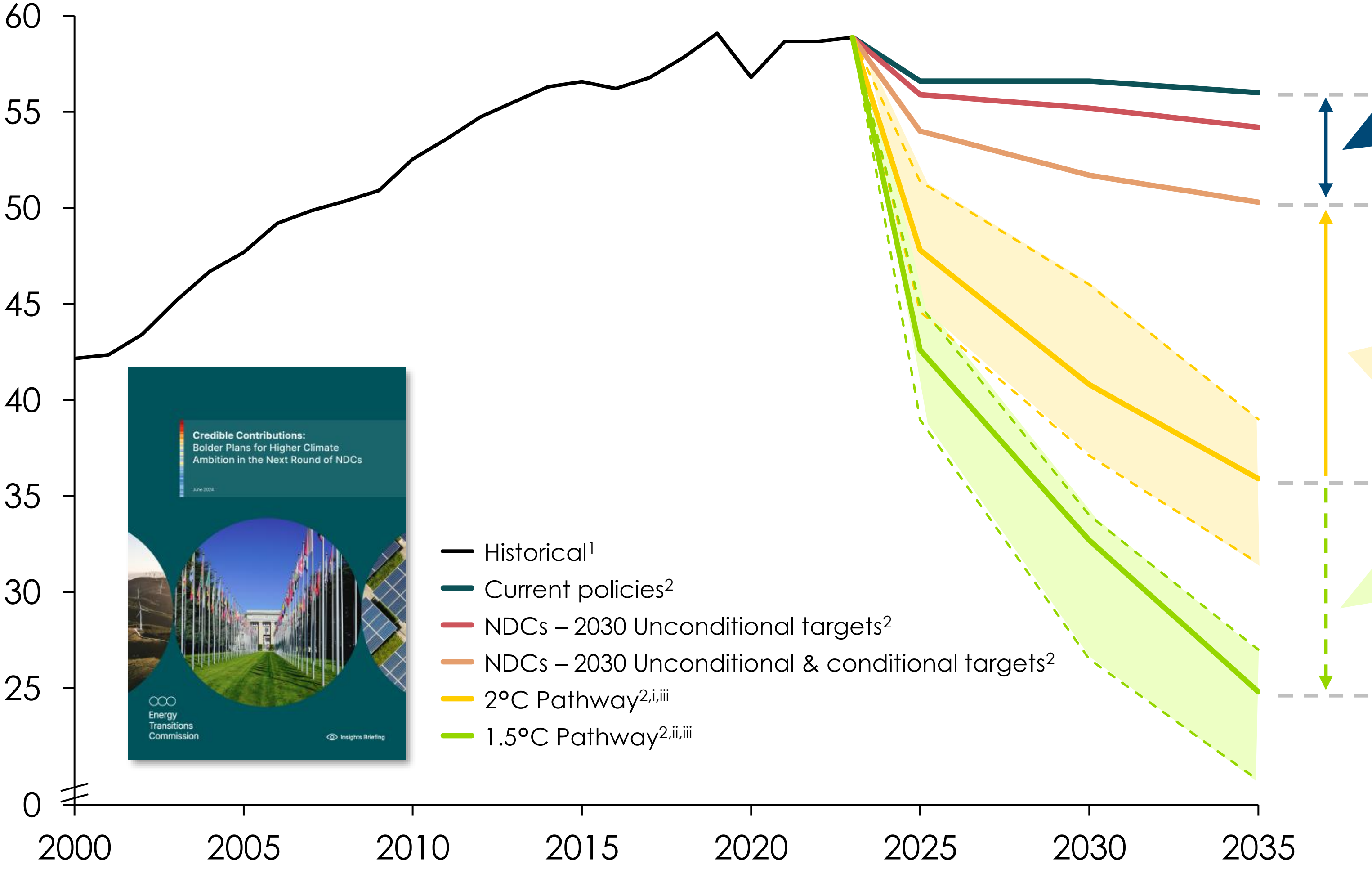
Cover not final



managing sustainable carbon
Executive Summary | Aug 2025 | Version 1.0
6
C
Carbon
12.011
Energy Transitions Commission
SYSTEMIQ

Just 62 (of 197) new Nationally Determined Contributions submitted so far; wide expectations are that NDCs 3.0 unlikely to fill ambition gap

Global GHG emissions



~6 $GtCO_2e$
Implementation gap

11–19 $GtCO_2e$
Ambition gap to 2°C

23–30 $GtCO_2e$
*Ambition gap to 1.5°C**

**Note: not all countries have adopted 1.5°C as their official target*

Main submissions

Key missing submissions

Notes: [i] Based on IPCC Working Group III Sixth Assessment Report scenario class c1 (limit warming to 1.5°C (>50%) with no or limited overshoot). [ii] Based on IPCC Working Group III Sixth Assessment Report scenario class c3 (limit warming to 2°C (>67%)). [iii] Range corresponds to range between tenth and ninetieth percentile, central line corresponds to median.

Sources: ETC (2024), Credible Contributions: Bolder Plans for Higher Climate Ambition in the Next Round of NDCs. Systemiq analysis for the ETC based on [1] IPCC (2022), Metadata Browser: Data for Figure SPM.5 - Summary for Policymakers of the WGIII Contribution to the IPCC AR6, [2] UNEP (2023), Emissions Gap Report: Broken Record; NDC 3.0 submissions registry accessed on June, 2025; Climate Watch NDC Tracker [accessed October 2025]

What we have been hearing about COP, and emerging events plan

What we are hearing…

- **Biofuels will be a large focus for Brazil**. Hesitancy to fully embrace renewables and electrification, particularly concerning electric vehicles.
- **New round of NDCs due,** though less than 1/3 of global emissions currently covered and most NDCs have been underwhelming.
- **Big focus on adaptation finance**, with vulnerable countries signalling urgency and demanding greater clarity that finance will flow.
- **Phasing down fossil fuels is still on the agenda,** though the transition faces resistance in the form of softening commitments and pressure from the US.

Key events currently on the radar

6th

11:50–12:00 – Sao Paulo Sustainable Innovation Forum, Fireside chat on energy efficiency with Faustine and Jon Creyts (RMI CEO)

12th

17:30–19:30 – Center for International Knowledge on Development (CIKD) event to accelerate international cooperation on climate change

13th

12:00–14:30 – Mission Possible Partnership hosted Clean Industry Day at Climate Action House, Adair to speak

19:00-21:30 – Arup event and ETC presentation

14th

16:00–17:30 – Schneider Electric and Mission Efficiency at French Pavilion, Adair to give energy efficiency keynote

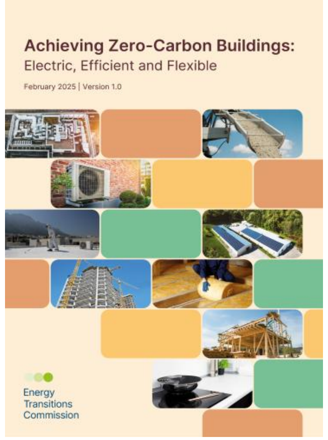
20th

11:30–12:30 – International Solar Alliance session on OSOWOG and long-distance interconnection

2025 ETC Reports – key messages to take to COP30

COP30
BRASIL
AMAZÔNIA
BELÉM 2025

February



Achieving Zero-Carbon Buildings:
Electric, Efficient and Flexible
February 2025 | Version 1.0
Energy Transitions Commission

A complete picture of the buildings sector's emissions and energy use. ETC describes how a combination of electric, efficient, and flexible solutions can decarbonise buildings.

May

The role of carbon credits in accelerated corporate action
May 2025
Version 1.0
Energy Transitions Commission

High-integrity carbon credits are required to scale up carbon dioxide removals and achieve corporate net-zero targets

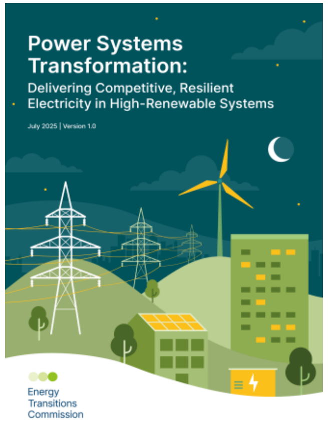
Responding to SBTi's updated Net-Zero Corporate Standards consultation

June

Global trade in the energy transition: Principles for clean energy supply chains & carbon pricing
June 2025 | Version 1.0
Energy Transitions Commission
Briefing Note

Global trade can accelerate the energy transition through two key areas: following principles for nearshoring supply chains and implementing carbon pricing.

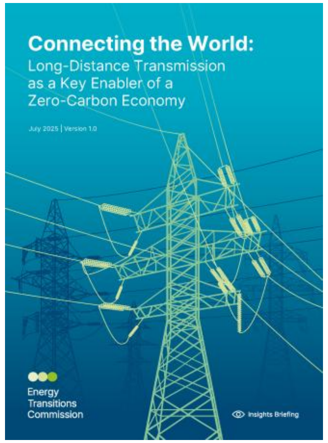
July



Power Systems Transformation:
Delivering Competitive, Resilient Electricity in High-Renewable Systems
July 2025 | Version 1.0
Energy Transitions Commission

Operating and balancing power systems with high shares of wind and solar (e.g. 70-80%+) is possible through technologies existing today, delivering system stability and round-the-clock electricity.

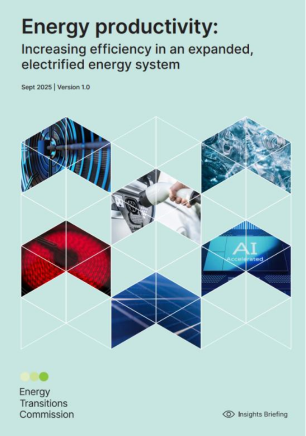
July



Connecting the World:
Long-Distance Transmission as a Key Enabler of a Zero-Carbon Economy
July 2025 | Version 1.0
Energy Transitions Commission
Insights Briefing

Long-distance interconnectors play an important role in connecting low-cost clean energy to where it's needed most.

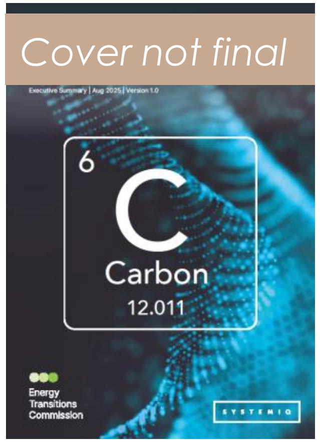
October



Energy productivity:
Increasing efficiency in an expanded, electrified energy system
Sept 2025 | Version 1.0
Energy Transitions Commission
Insights Briefing

The world can more than double GDP by 2050 while cutting energy use by harnessing electrification, efficient technologies, and smarter material use.

November



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Electrification and circularity can dramatically cut demand for carbon molecules while ensuring sustainable sourcing and safe end-of-life management resulting in zero net emissions.

ETC plans for COP30

COP30 BRASIL AMAZÔNIA BELÉM 2025

Inform

ETC COP30 Focus

- Power
- Long-distance transmission
- Energy Productivity
- Carbon Molecules

Regional

ETC regional teams focused on country specific content.

Pre-COP30 Briefing (5th Nov)

Member briefing highlighting key messages.

Amplify

Event Programme

ETC will not be hosting any panel events.

Participation in high profile events and to support members events with speakers & content.

Working with non-members including Global Optimism (Groundswell), Mission Efficiency, GABC, GRA and event organisers Climate Action, World Climate Foundation.

Contributing to Action Group 8 ‘Land restoration and sustainable agriculture’ with insights from Bioresources analysis.

Social Media

Amplifying the core messages, insights and activities through social media

Engage

Member Networking

Currently no plans to host an ETC member drinks/dinner. However, ETC member events will be hosted on the member portal and provide a good opportunities for networking.

Media Briefing

Pre-briefings with Tier 1 media outlets.

Broadcast media push – international channels

Member Meetings

Bilateral meetings with senior execs

Agenda

- What is ETC doing at COP30?
- **COP28 energy efficiency target: opportunity to meet in next two decades**
- Tripling Renewables: focus on Sunbelt opportunity and optimizing grids
- The role of Carbon Molecules in the Energy Transition

COP28 focused on three headline areas: tripling renewables, doubling energy efficiency, and a "transition away" from fossil fuel consumption

3x Renewable Power

Target 11,000 GW+ by 2030, growing:
- Solar ×5
- Wind onshore ×4
- Wind offshore ×8
- Geothermal ×7

Renewables to reach 62% of installed capacity by 2030

2x Energy Efficiency

Doubling the global rate of energy efficiency improvement to 4% per year

Key to limiting energy demand growth and keeping 1.5°C within reach

Fossil fuels. "Transition away from fossil fuels in energy systems, in a just, orderly and equitable manner … "

Notes: targets compared to capacity and efficiency rates as of 2022.

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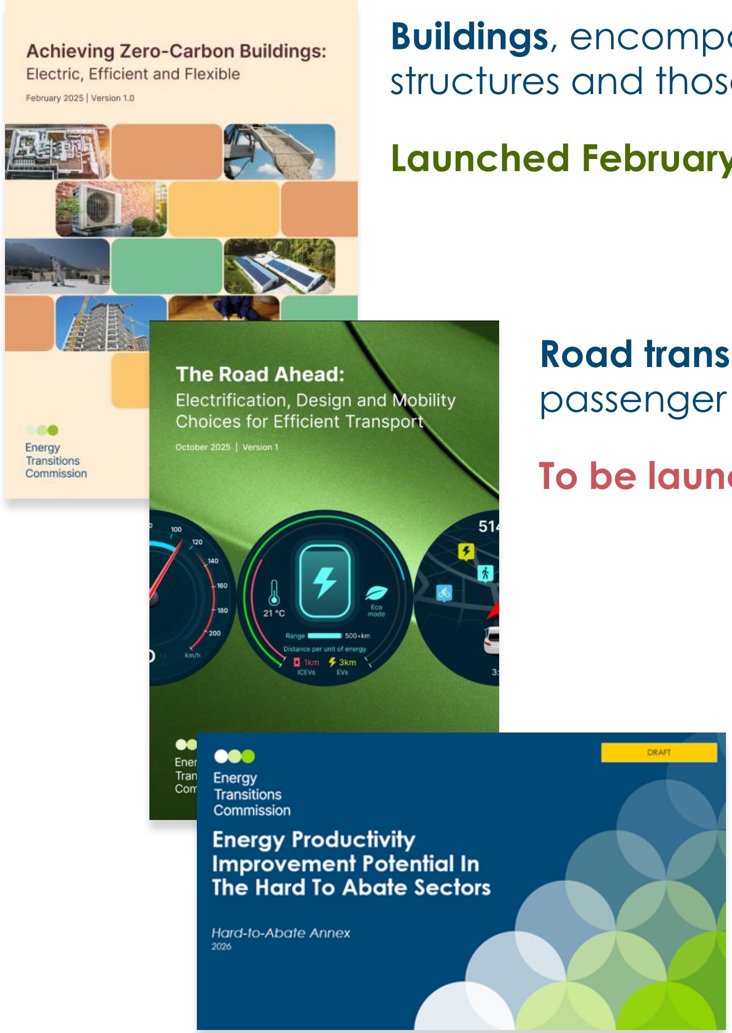
ETC work focus on **Energy Productivity =** economic output per unit of energy

ETC analysis of the opportunity for energy productivity brings together 3 detailed sectoral views



Achieving Zero-Carbon Buildings:
Electric, Efficient and Flexible
February 2025 | Version 1.0
Energy Transitions Commission

The Road Ahead:
Electrification, Design and Mobility Choices for Efficient Transport
October 2025 | Version 1

DRAFT
Energy Transitions Commission
Energy Productivity Improvement Potential In The Hard To Abate Sectors
Hard-to-Abate Annex
2026

Buildings, encompassing both in-use structures and those under construction.

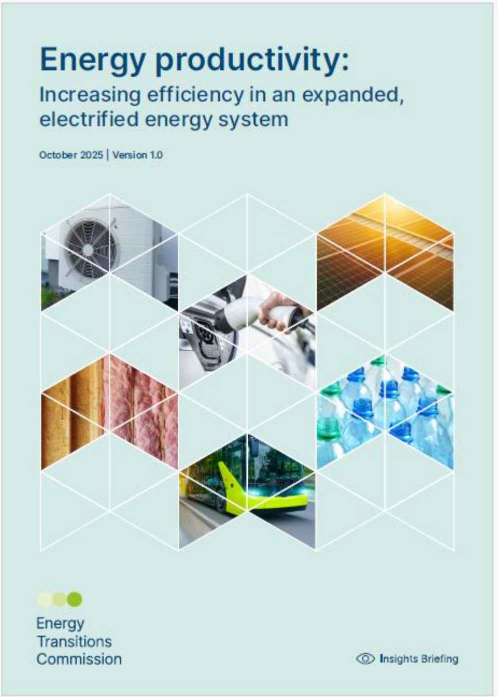
Launched February 2025

Road transport, covering both passenger and freight aspects.

To be launched Q4 2025

Heavy industry and long-distance transport, consolidating insights from the Mission Possible Partnership (MPP) analysis.

To be launched Q1 2026



Energy productivity:
Increasing efficiency in an expanded, electrified energy system
October 2025 | Version 1.0
Energy Transitions Commission
Insights Briefing

An economy-wide overview of the potential for energy productivity, laying out key priority actions, future final, primary and useful energy demand; impact on living standards, costs and resources; implications for COP28 target, and of rebound effects and AI

ETC's Energy Productivity work is distinct in several ways

1. **Energy services can grow while energy input declines**
   The report brings clarity that it is possible to support continued economic and social development — with more energy services— while using less energy overall.

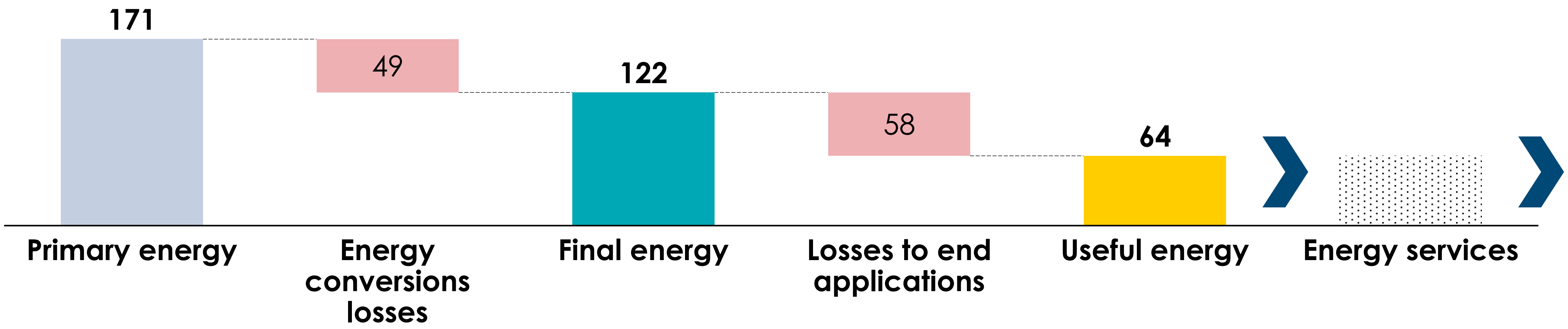
2. **Productivity beyond just efficiency**
   Productivity includes improvements in how we use materials (e.g. recycling and re-use) and how services are delivered (e.g. shared mobility, smart controls). Electrification and high-efficiency equipment remain however the main levers.

3. **A sharper definition of maximum annual improvement potential, to meet COP28 target**
   This analysis breaks down target by sector and technology, clarifies whether primary or final energy is being measured, and highlights where rapid progress can be made in next decade.

Global energy flows can be measured in primary, final, and useful energy

Global energy flows

000 TWh, 2023



Human welfare and satisfaction, and social wellbeing

E.g.

- Crude Oil
- Coal

- Refining losses
- Heat losses in generation

- Electricity
- Diesel

- T&D losses
- Energy to wheel losses

- kWh of heat to spaces
- kWh of kinetic energy to car wheels

- Warm or cooled spaces
- Kilometers travelled

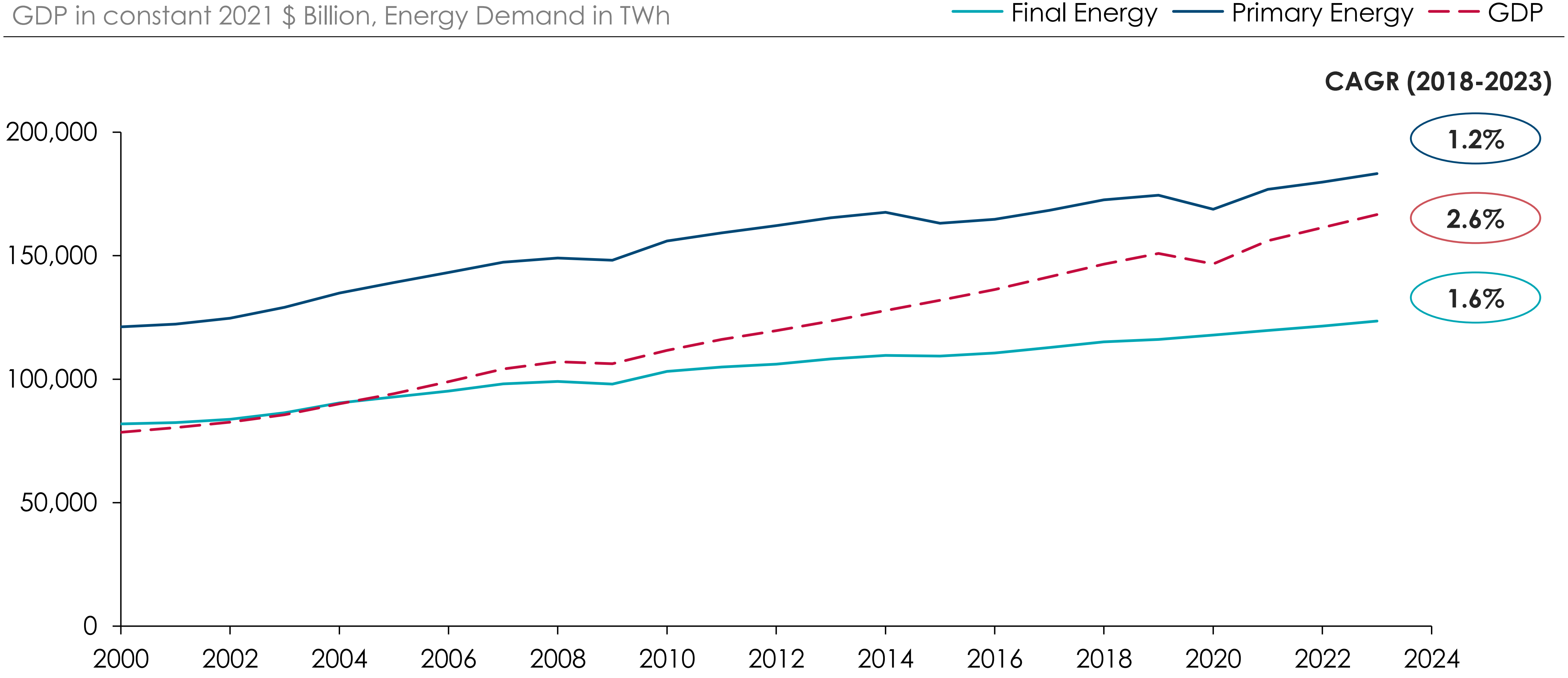
What people need

Source: Systemiq analysis for the ETC, IEA (2025) World Energy Review, IEA (2024) World Energy Outlook, International Institute for Applied Systems Analysis, *IIASA PFU Dataset*. Available at https://tntcat.iiasa.ac.at/PFUDB/dsd?Action=htmlpage&page=about. [Accessed May 2025].

Energy productivity improvements have varied over time, but, in spite improvements, primary and final energy demand still grows with GDP

Total GDP vs. Energy Demand, 2000–2023

GDP in constant 2021 $ Billion, Energy Demand in TWh

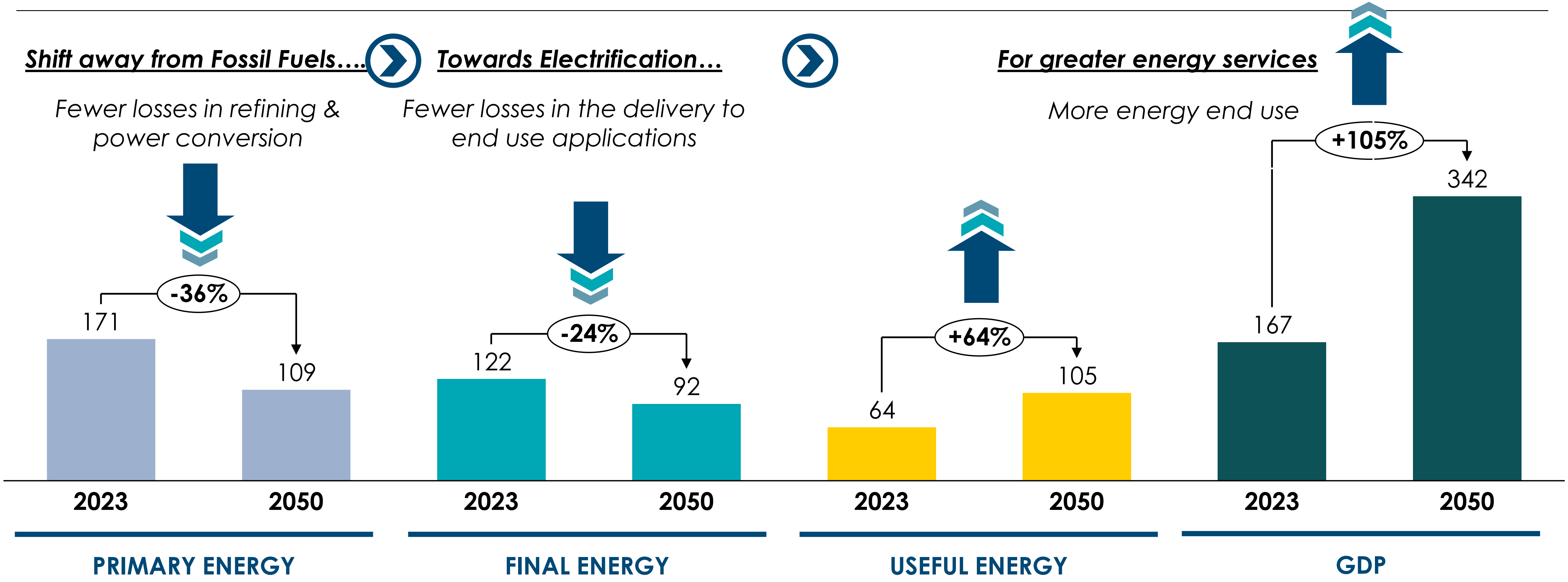


Source: Systemiq analysis for the ETC; World Bank Group, GDP, PPP (constant 2021 international $). Available at:: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD. [Accessed August 2025]. Our World in Data, Global GDP over the long run. Available at: https://ourworldindata.org/grapher/global-gdp-over-the-long-run. [Accessed on August, 2025]; IEA (2024), *World Energy Outlook 2024;* International Institute for Applied Systems Analysis, *IIASA PFU Dataset*. Available at https://tntcat.iiasa.ac.at/PFUDB/dsd?Action=htmlpage&page=about. [Accessed May 2025].

Through productivity actions, the world can deliver a doubling of global GDP and expanded energy services, while requiring less primary and final energy

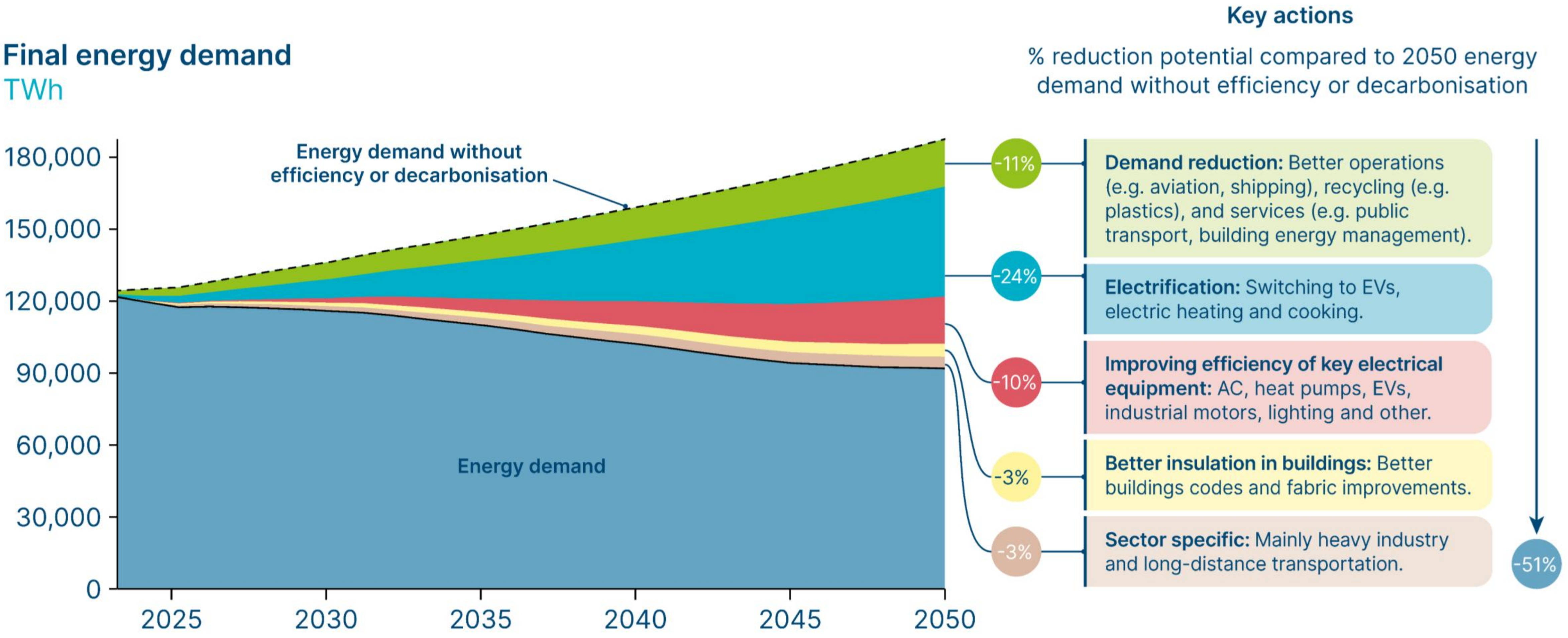
NZ Energy demand with Productivity levers

Energy in 000 TWh; GDP in constant 2021 Tn.US$



Source: Systemiq analysis for the ETC; IEA (2025), *World Energy Outlook*; MPP (2023), *Hard-to-Abate Sector Transition Strategies*; ETC (2025), *Achieving Zero-Carbon Buildings*; ETC (2023), *Fossil Fuels in Transition*; BNEF (2023), *Electric Vehicle Outlook*; Systemiq (2022), *Planet Positive Chemicals*

Productivity actions can reduce final energy demand 25% from today; 50% compared to business-as-usual



Key actions

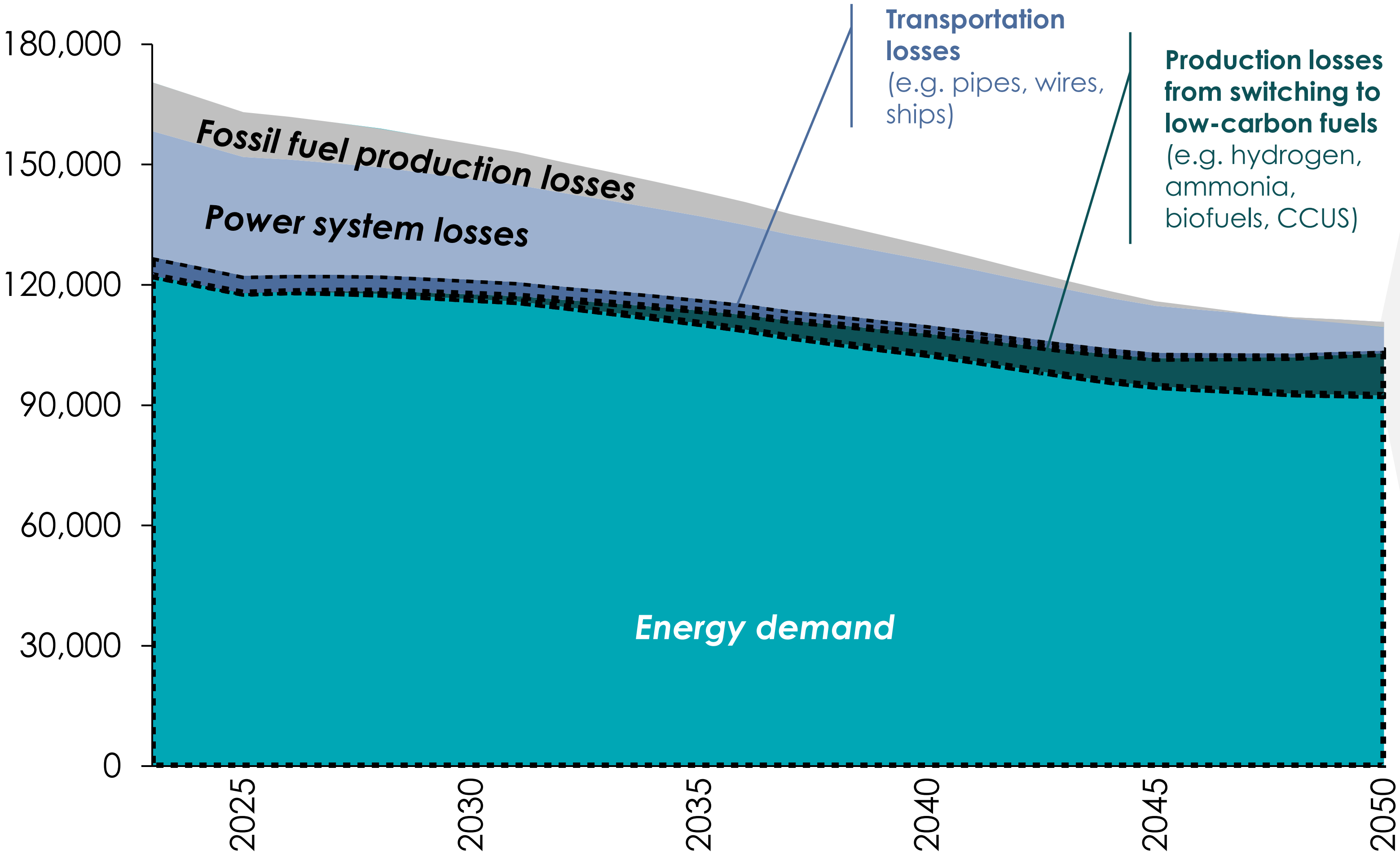
% reduction potential compared to 2050 energy demand without efficiency or decarbonisation

- **Demand reduction:** Better operations (e.g. aviation, shipping), recycling (e.g. plastics), and services (e.g. public transport, building energy management).
- **Electrification:** Switching to EVs, electric heating and cooking.
- **Improving efficiency of key electrical equipment:** AC, heat pumps, EVs, industrial motors, lighting and other.
- **Better insulation in buildings:** Better buildings codes and fabric improvements.
- **Sector specific:** Mainly heavy industry and long-distance transportation.

Source: Systemiq analysis for the ETC; IEA (2025), *World Energy Outlook*; MPP (2023), *Hard-to-Abate Sector Transition Strategies*; ETC (2025), *Achieving Zero-Carbon Buildings*; ETC (2023), *Fossil Fuels in Transition*; BNEF (2023), *Electric Vehicle Outlook*.

Primary to final productivity opportunity: a phase down of fossil fuel consumption, along with the switch from thermal generation to renewables

Primary energy demand
TWh



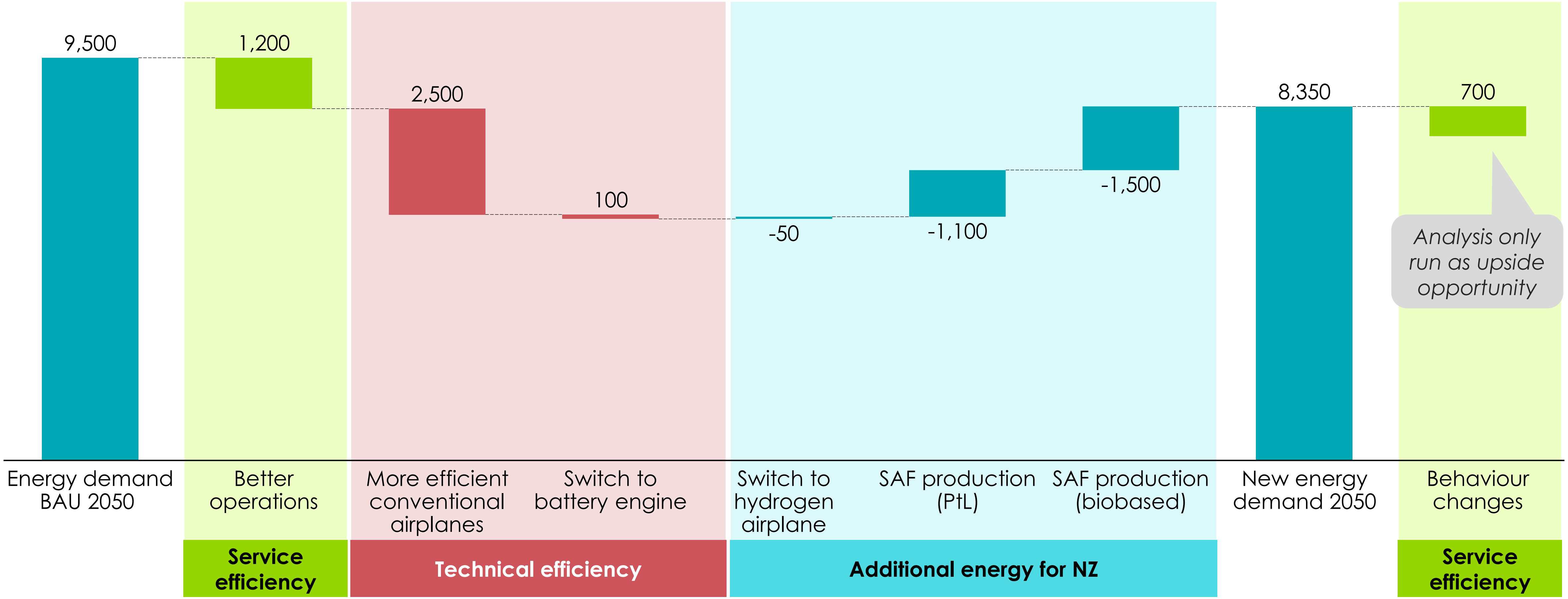
Reductions on primary losses driven by:

- **Growth of renewables in the power system**, which are more efficient than fossil generation
- **Lower fossil fuel conversion losses** (e.g. in refining) decline as fossils phase down

Source: Systemiq analysis for the ETC; IEA (2025), *World Energy Outlook*; MPP (2023), *Hard-to-Abate Sector Transition Strategies*; ETC (2025), *Achieving Zero-Carbon Buildings*; ETC (2023), *Fossil Fuels in Transition*; BNEF (2023), *Electric Vehicle Outlook*.

In aviation, making conventional airplanes more efficient is single most important lever

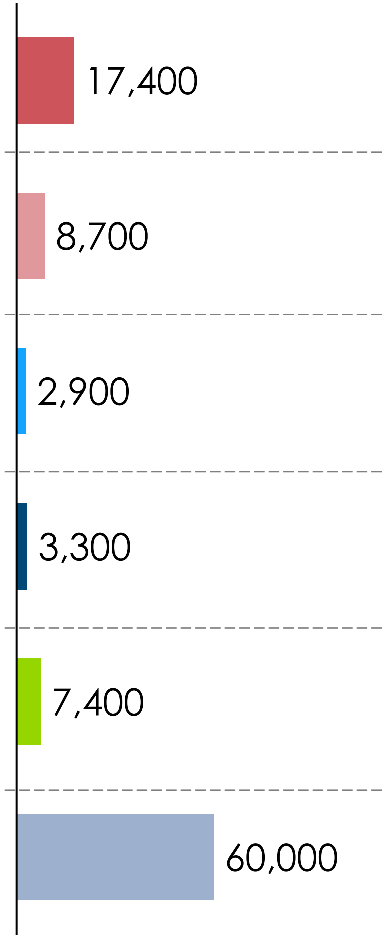
Primary energy demand in 2050 and impact of productivity levers
TWh



Analysis only run as upside opportunity

Source: Schäfer, A. (2019). "Technological, economic and environmental prospects of all-electric aircraft". *Nature Energy*. **4** (2): 160–166., MPP analysis

There are 6 key energy productivity actions that can help drive improvement



	Main productivity actions	Energy saving *(TWh/year)*	Priority areas for actions
Final Energy	**1 Electrification**	17,400	① Electrification of road transport ② Electrification of heating (high latitude countries) ③ Electrification of cooking (mainly south/southeast Asia and Africa)
	2 Equipment/vehicle efficiency improvement	8,700	④ Improving the efficiency of electric equipment (e.g. ACs, industrial motors, LEDs) and road vehicles through standards and stock turn-over
	3 Better insulation in buildings	2,900	⑤ Improved building insulation and smart energy management via buildings codes and renovations
	4 Heavy industry and long-distance transportation	3,300	⑥ Efficiency improvements in heavy industry, shipping and aviation led by global carbon prices and fuel mandates effects
	5 Reduced demand	7,400	⑦ Demand reduction via increased material recycling and reuse ⑧ Demand reduction via operational efficiencies and modal shift in transport
Primary Energy	**6 Power sector decarbonisation**	60,000	⑨ Decarbonisation of power generation with renewables and the supporting infra-structure (storage, flexibility and grids)

Source: Systemiq analysis for ETC.

Many productivity actions are already cost-effective, specially when regarding savings during their life-time from lower running costs[1]

🟢 Cheaper than current alternative 🟡 Comparable or slightly higher than the current alternative 🔴 Considerably higher than the current alternative

Main productivity actions

		Example of main technologies	Capital cost	Running cost	Total cost
Final Energy	Electrification	Passengers EVs	🟢	🟢	🟢
		Heat Pumps	🔴	🟢	🟢
		Electric cooking[2]	🟡	🟡	🟡
	Equipment/vehicle efficiency improvement	Efficient air conditioners	🟡	🟢	🟢
		Industrial motors	🟡	🟢	🟢
		LEDs	🟡	🟢	🟢
	Better insulation in buildings	New buildings: envelopes and fabrics	🟡	🟢	🟢
		Retrofit buildings: envelopes and fabrics	🔴	🟢	🟡[3]
	Heavy industry + long distance transportation	Lightweight aircrafts	🟡	🟢	🟢
		Aerodynamic vessels	🟡	🟢	🟢
		Heat recover in heavy industry	🔴	🟢	🟢
	Reduced demand	Plastics recycling (mechanical)	🟡	🟢	🟡
		New public transportation and/or cycling lanes	🟢	🟢	🟢
		Buildings smart energy system	🟡	🟢	🟢
Primary Energy	Power sector decarbonisation	Clean power generation & balancing	🟡	🟢	🟢
	Low-carbon fuels	Hydrogen and derivatives	🔴	🔴	🔴
		Biofuels	🟡	🔴	🔴

Note: 1. Scores represent typical cost impact for each category of action, but with significant variation by individual circumstance. Cost indications are before the impact carbon prices to offset any green cost premium / 2. Cooking counterfactual in the table is biomass, for gas costs should be comparable. / 3. Can be cost effective for specific well designed combinations of measure

Source: Systemiq analysis for ETC; IEA (2025), *Global EV Outlook 2025*; ETC (2025), *Achieving Net-Zero Buildings*; CLASP (2025), *World's Best MEPS*. Available at: https://www.clasp.ngo/tools/worlds-best-meps/ [Accessed July 2025]; ICCT (2013), *Long-term potential for increased shipping efficiency through the adoption of industry-leading practices*; MPP (2022), *Making Net-zero Aviation Possible*; Systemiq (2022), *Planet Positive Chemicals.*

Maximising energy productivity during the energy transition can deliver significant benefits

Investments

- Improved energy productivity could **reduce $600 billion of investment every year** for new electricity generation and storage

Resources

- Improved energy productivity could reduce the **land requirements by about 0.2 million km^2,** the equivalent to Ecuador’s or UK’s land size.

Imports

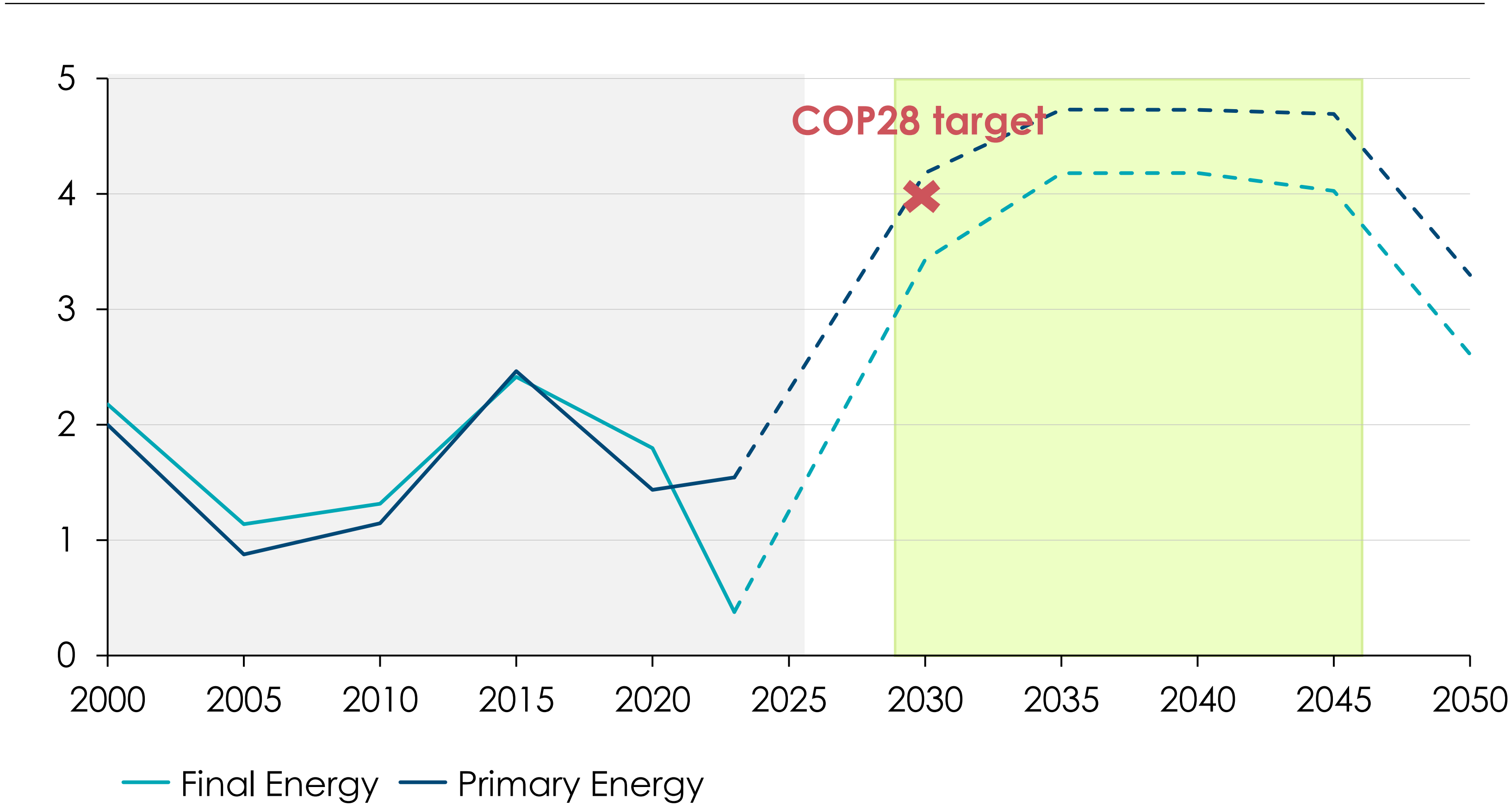
- Reducing energy demand will **improve energy security by cutting reliance on imports**. Through energy productivity levers, German energy imports could be reduced by 25% by 2035, cutting the import bill by €20 billion annually (in 2023 prices),

Source: ETC (2023) Material and Resource Requirements for the Energy Transition; ETC (2025) Achieving Zero-Carbon Buildings; ETC (2025) The Road Ahead; ETC (2024) NDCs, NCQG, and Financing the Transition: Unlocking Flows for a Net-Zero Future; Eurostat; Clean Energy Wire (2025) Fossil fuel imports to Germany go down as costs increase

ETC analysis shows COP28 target can be met one-off in the next two decades

5-Year CAGR Energy productivity improvement projection

%



- **Energy productivity gains vary over time**; recent years have not seen significant improvements
- **However, there is a clear opportunity for a one-off increase** driven by electrification and renewables
- **After mid-2040s, improvement pace decreases** due to most of the economy already been electrified and decarbonised, and a slow down in GDP growth projection

Note: CAGR = Compound annual growth rate.
Source: Systemiq analysis for the ETC; World Bank Group, GDP, PPP (constant 2021 international $). Available at:: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD. [Accessed August 2025]. Our World in Data, Global GDP over the long run. Available at: https://ourworldindata.org/grapher/global-gdp-over-the-long-run. [Accessed on August, 2025]; IMF Real GDP Annual Growth. Available at: https://www.imf.org/external/datamapper/datasets/WEO. [Accessed on August 2025]; IEA (2024), *World Energy Outlook 2024*.

A 3-step approach for countries to seize the opportunity of faster energy productivity improvement

1. **Develop national policy frameworks** which identify opportunities by sector

2. Implement policies to improve final energy productivity, with strong **focus on electrification and equipment/vehicle efficiency**

3. Set clear plans to for **power sector decarbonisation**

Source: Systemiq analysis for the ETC.

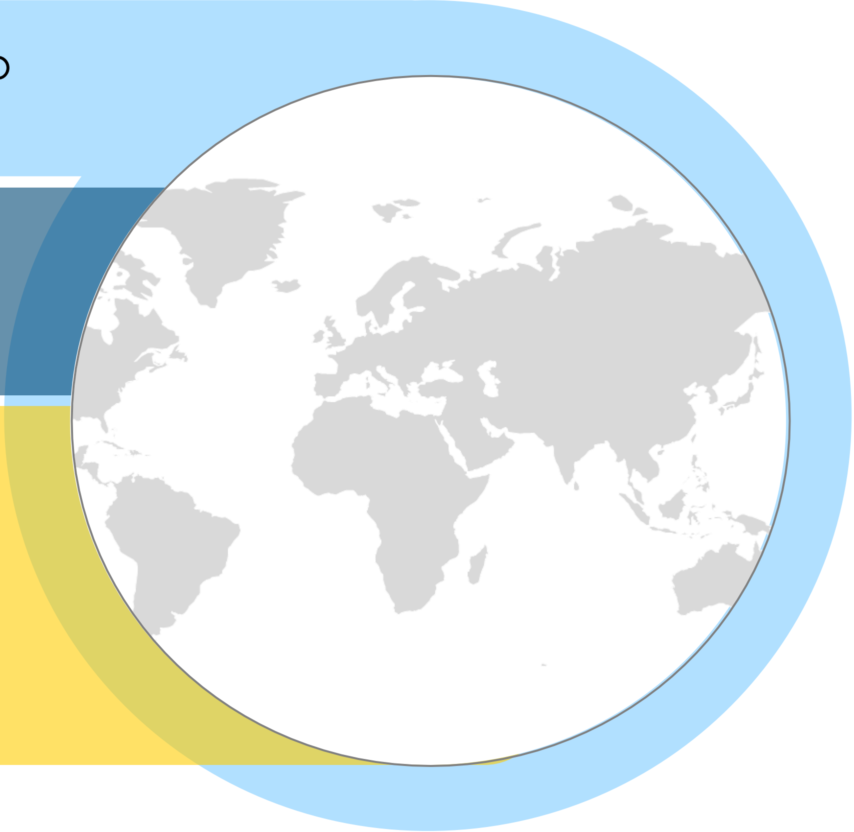
Different regions will have a mix of different priorities regarding productivity actions

- **In all countries, electrifying road transport** offers a major opportunity to cut oil use - in many countries it will also reduce energy imports.

- **High-latitude regions** must **replace gas boilers** with electric heat pumps, as well as continuing to **improve the strong product standards** that have driven efficiency advances to date.

- **Developing economies**, should combine efficient **AC and insulation** in buildings to **reduce peak electricity demand**, increase electrical appliance efficiency standards and stock turnover.

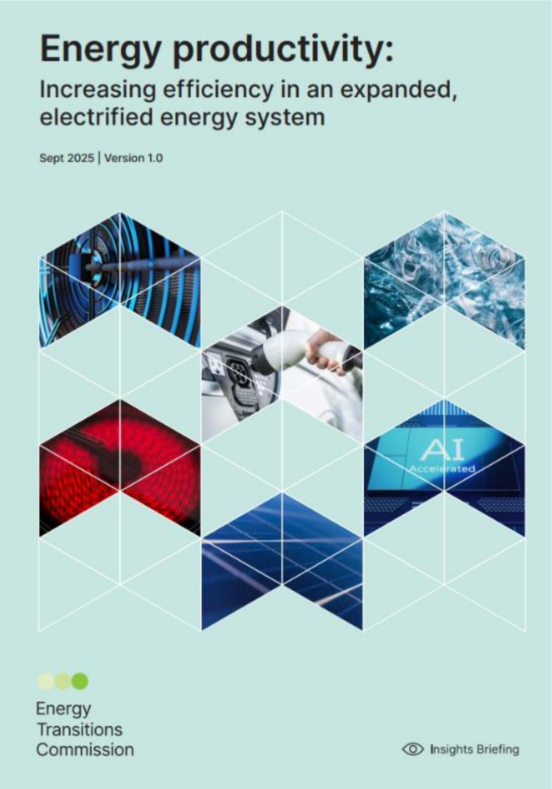
- **Some developing economies** should also focus on the **replacement of traditional biomass** with cleaner cooking fuels or electricity, which can also deliver major health gains



Source: Systemiq analysis for the ETC.

Insights Briefing Launch Campaign Plan – Staged roll out

Phase 1 - October
Energy Productivity Insights Briefing



Energy productivity:

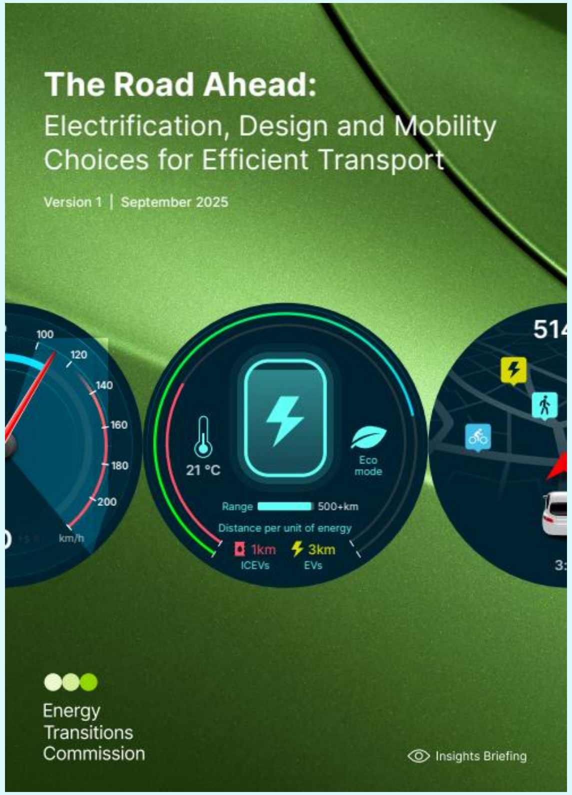
Increasing efficiency in an expanded, electrified energy system

Sept 2025 | Version 1.0

Energy
Transitions
Commission

Insights Briefing

Phase 2 – December
Electrification of Road Transport



The Road Ahead:

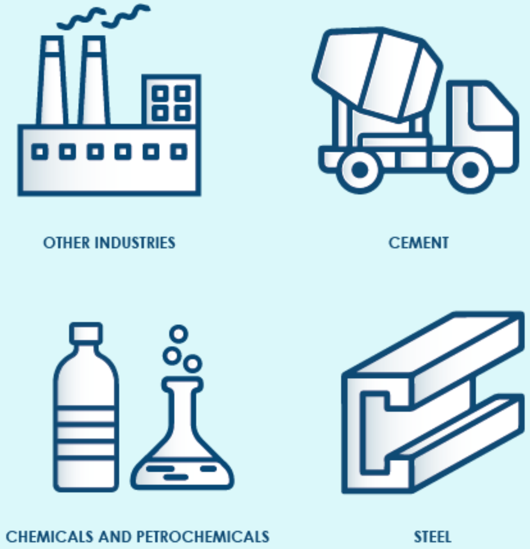
Electrification, Design and Mobility Choices for Efficient Transport

Version 1 | September 2025

Energy
Transitions
Commission

Insights Briefing

Phase 3 – early 2026
Harder to Abate – productivity potential review



Next steps of the ETC's *Energy Productivity* work

1

Media outreach and digital

- **Press release distribution** to media contacts, with regional focus on Brazil
- **Broadcast media campaign around COP30**
- **Targeted podcast campaign**
- **Social media campaign and amplification** in the run up to COP30

2

Focusing efficiency community

Mission Efficiency

Briefing group and submitting "*Plans to Accelerate Solutions*"

Setting COP30 narrative

Climate High-Level Champions

"Friends of ETC" briefing sessions and events (COP30 and beyond)

3

Working with new partners

Exploring using ETC analysis to help countries develop national policy frameworks

Developing comprehensive energy efficiency indicators

IRENA
International Renewable Energy Agency

2026 – the ETC team will be seeking opportunities to apply the analysis to other use cases (ongoing campaign about road and hard-to-abate)

Agenda

- What is ETC doing at COP30?
- COP28 energy efficiency target: opportunity to meet in next two decades
- **Tripling Renewables: focus on Sunbelt opportunity and optimizing grids**
- The role of Carbon Molecules in the Energy Transition

COP28 focused on three headline areas: tripling renewables, doubling energy efficiency, and a “transition away” from fossil fuel consumption

3x

Renewable Power

Target 11,000 GW+ by 2030, growing:
- Solar ×5
- Wind onshore ×4
- Wind offshore ×8
- Geothermal ×7

Renewables to reach 62% of installed capacity by 2030

2x

Energy Efficiency

Doubling the global rate of energy efficiency improvement to 4% per year

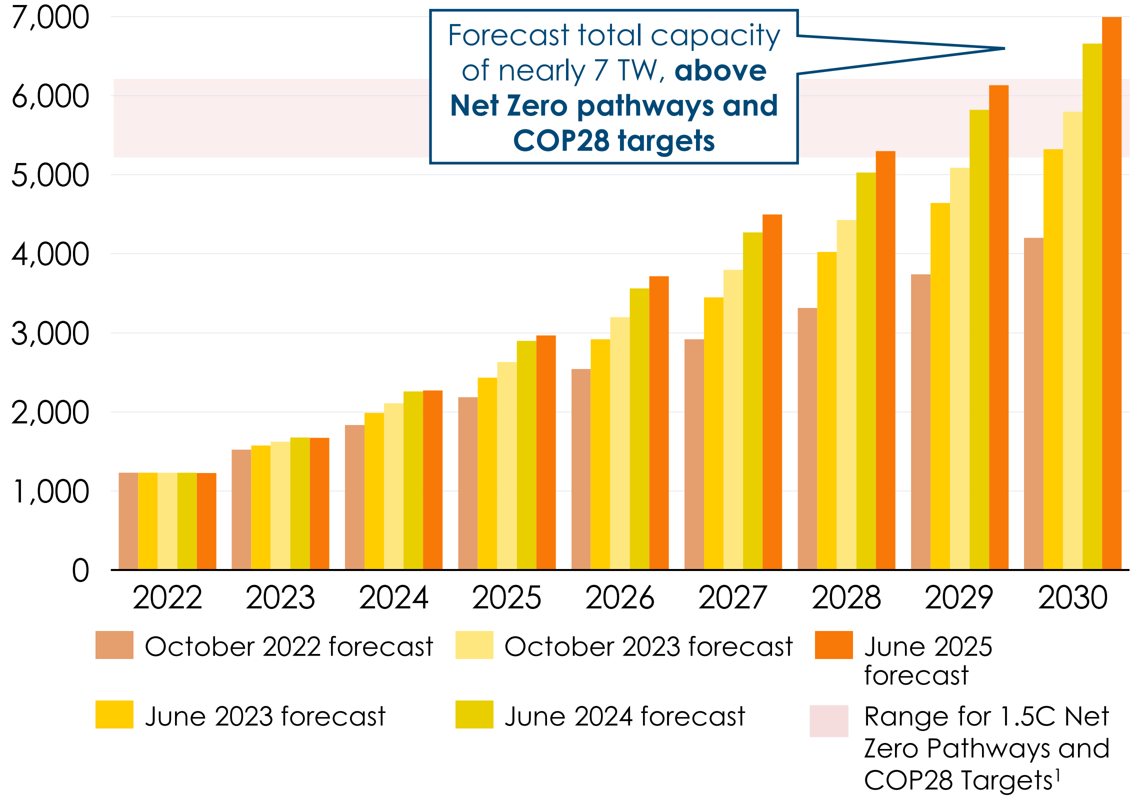
Key to limiting energy demand growth and keeping 1.5°C within reach

Fossil fuels. “Transition away from fossil fuels in energy systems, in a just, orderly and equitable manner … “

Massive capacity expansions means solar will hit target, while wind deployment is slower than required

BNEF: Recent solar forecasts now aligned to ETC 2030 milestones

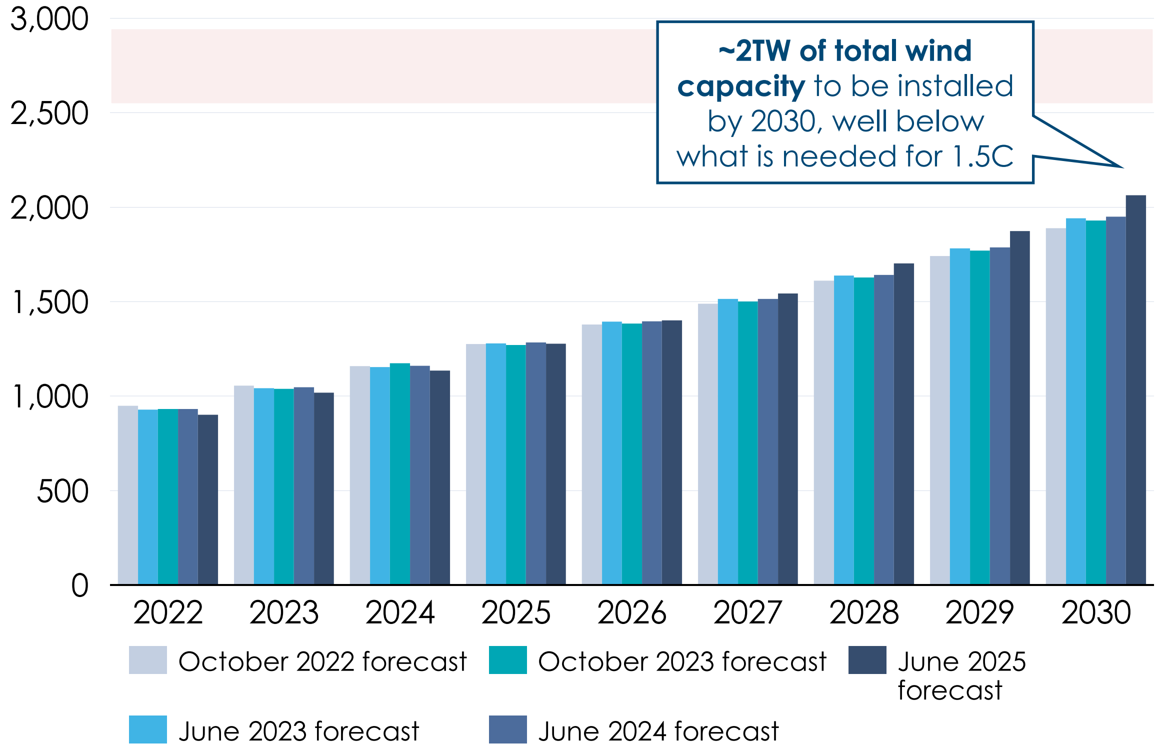
GW total capacity installed



Forecast total capacity of nearly 7 TW, **above Net Zero pathways and COP28 targets**

BNEF: Recent wind forecasts still fall behind ETC 2030 milestones

GW total capacity installed



~2TW of total wind capacity to be installed by 2030, well below what is needed for 1.5C

Solar forecasts accelerating due to manufacturing capacity buildup and the modularity of panels

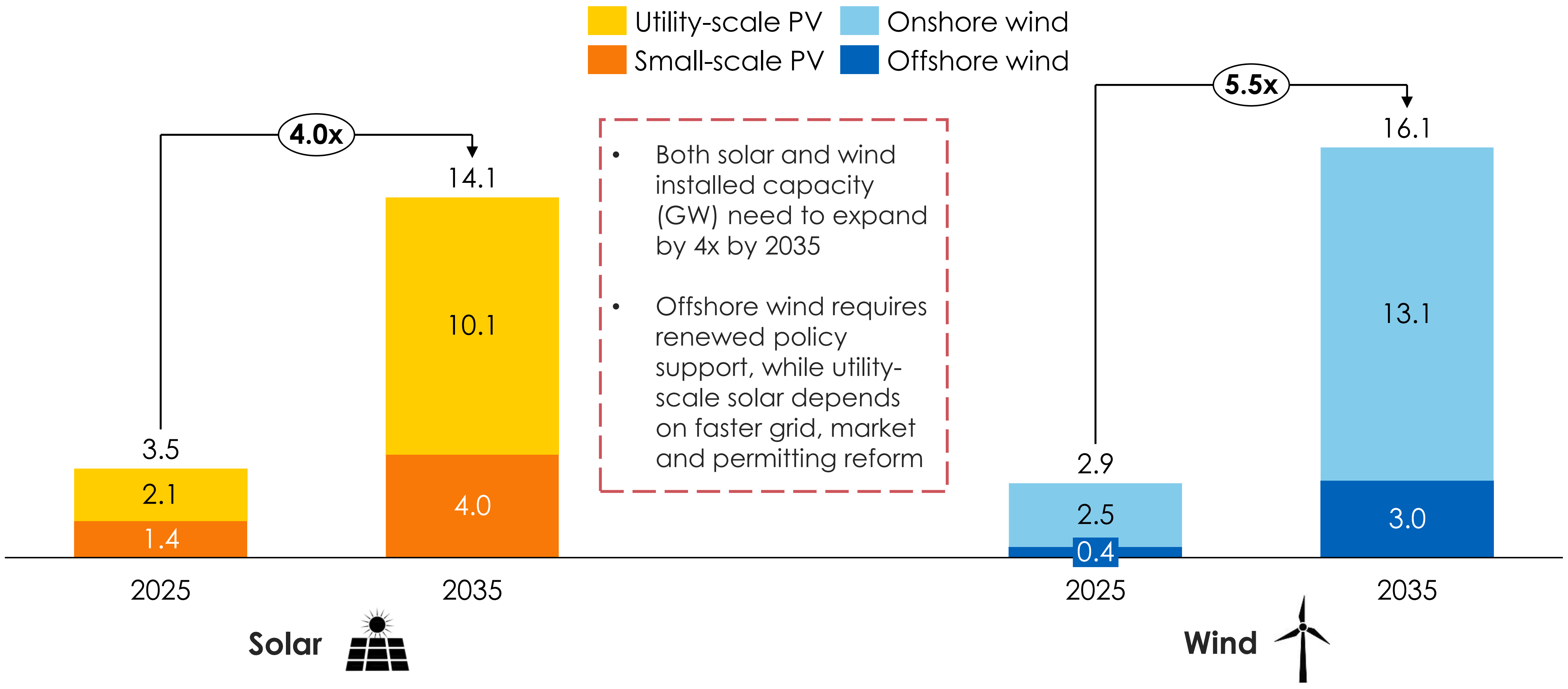
Continued slow growth for wind ex-China due to supply chain, land allocation, and permitting barriers

Note: [1] The COP28 presidency has a target to treble renewables (incl. solar, wind, hydropower, bioenergy, geothermal) by 2030. This would involve a roughly 5x increase in solar PV and 3x increase in wind from 2022.
Source: Systemiq analysis for the ETC; BNEF (2022/23/24/25) *Global Installed Capacity*

Policy should target 4x solar and 5.5x wind generation by 2035 to align with net zero buildout rates; offshore wind and utility-scale solar require support

Global generation change in BNEF NZS broken down by wind and solar

‘000 TWh



- Both solar and wind installed capacity (GW) need to expand by 4x by 2035
- Offshore wind requires renewed policy support, while utility-scale solar depends on faster grid, market and permitting reform

Source: BNEF (2025), *New Energy Outlook*

ETC work on power systems transformation provides confidence that solar and wind dominated systems are technically and economically feasible

1

Managing System Balancing

Meeting balancing needs as the penetration of wind and solar grows

2

Building and optimising grids

Ensuring grids can increase 2-3 times in size and modernise to support demand growth and new generation

3

Ensuring low costs

Ensuring future clean power system costs are no higher than today's

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

- Flexible dispatchable generation
- Long-distance transmission
- Energy storage
- Demand-side flexibility
- Innovative grid technologies

5 new insights from this report

1. It is technically and economically possible to operate and balance power systems with high shares of wind and solar (e.g. 70-80%+) through technologies existing today. **The cost of each system varies significantly based on whether it is wind ("wind belt") or solar ("sun belt") dominated**

2. The **lowest total system costs will be in sun belt countries** with large solar resources and short duration balancing. **Costs will be higher in high latitude countries**, which are dependent on wind resources and have significant seasonal balancing requirements

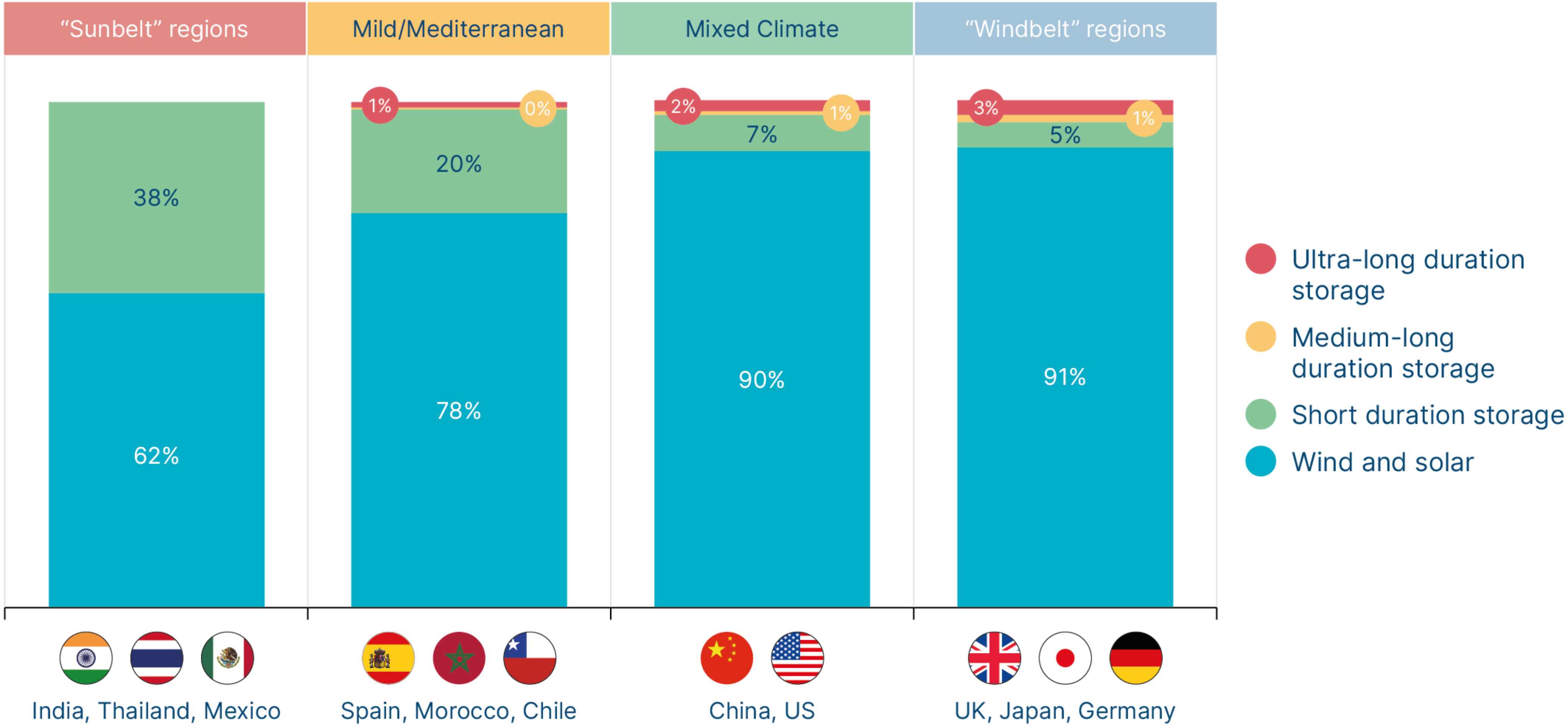
    - The **final stages of power system decarbonisation will be the most complex and costly**; careful planning is needed to minimize additional costs for consumers

3. **Up to 30% of all global power demand could be a flexible system asset (through demand-side flexibility)**, key bottleneck is how to incentivise deployment and adoption, and guarantee reliability

4. **Long-distance transmission from low-cost renewable regions can be a cost-effective source of flexibility where politically feasible**

5. **Grid costs per kWh are unlikely to materially change despite investments potentially increasing by 2-3x over the next 25 years**, as long as the user base expands in line with planning and innovative grid technologies and demand side flex are utilised. Need to ensure pace of electrification at same pace as decarbonisation.

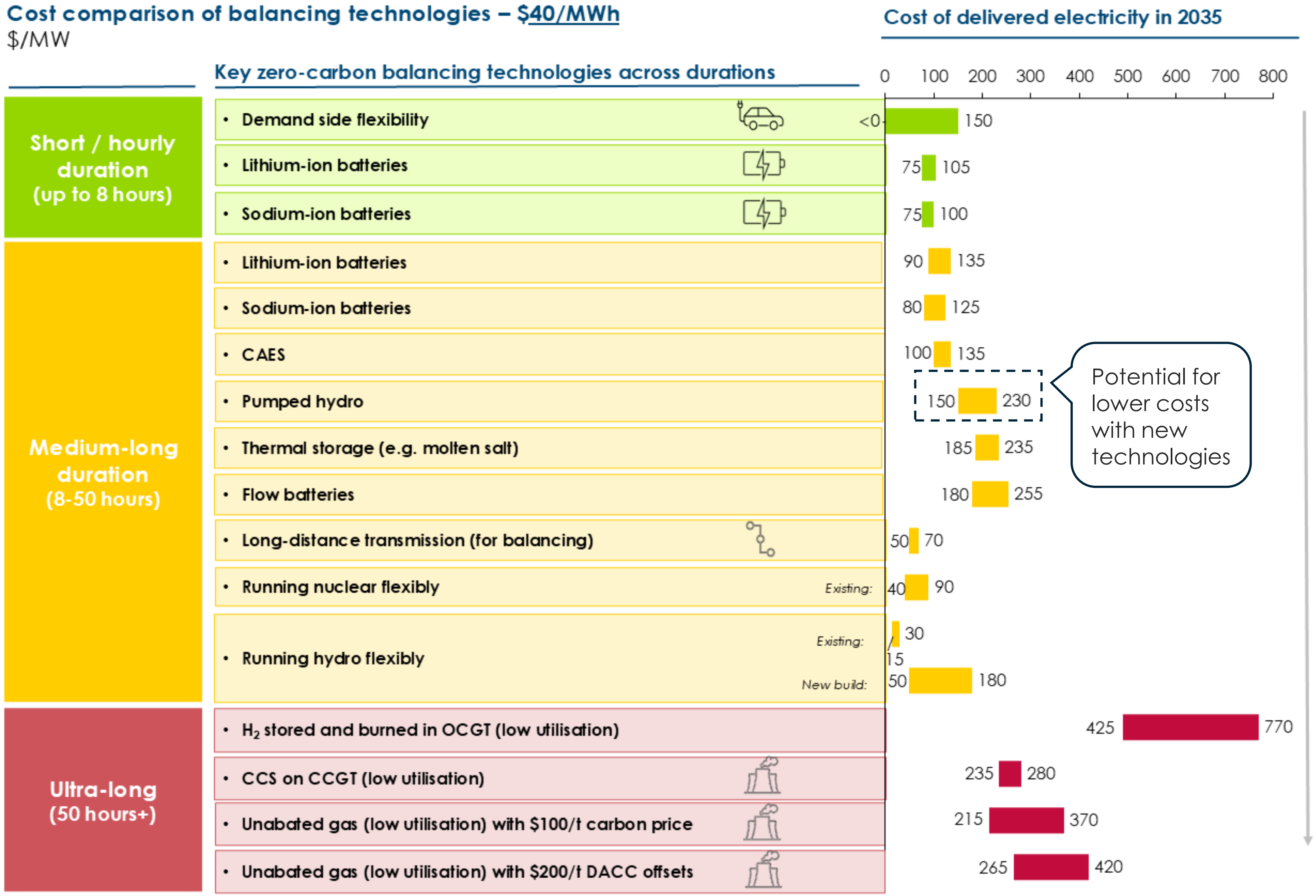
Balancing needs will vary across regions



Source: Systemiq analysis for the ETC (2025)

Balancing costs will vary by duration

Cost comparison of balancing technologies – $40/MWh
$/MW



Short / hourly duration (up to 8 hours)	Demand side flexibility		<0	150
	Lithium-ion batteries		75	105
	Sodium-ion batteries		75	100
Medium-long duration (8-50 hours)	Lithium-ion batteries		90	135
	Sodium-ion batteries		80	125
	CAES		100	135
	Pumped hydro		150	230
	Thermal storage (e.g. molten salt)		185	235
	Flow batteries		180	255
	Long-distance transmission (for balancing)		50	70
	Running nuclear flexibly	Existing:	40	90
	Running hydro flexibly	Existing:	15	30
		New build:	50	180
Ultra-long (50 hours+)	H_2 stored and burned in OCGT (low utilisation)		425	770
	CCS on CCGT (low utilisation)		235	280
	Unabated gas (low utilisation) with $100/t carbon price		215	370
	Unabated gas (low utilisation) with $200/t DACC offsets		265	420

Potential for lower costs with new technologies

Key takeaways

- **Short duration**: Demand-side flexibility and lithium-ion batteries already cost competitive vs fossil in some cases
- **Medium-long duration**: mix of options, pumped hydro and long-distance transmission could be most competitive
- **Ultra-long duration**: Costly, as high capex assets at low utilisation; a restricted role for unabated gas with clear guidelines may be the most pragmatic near-term path.

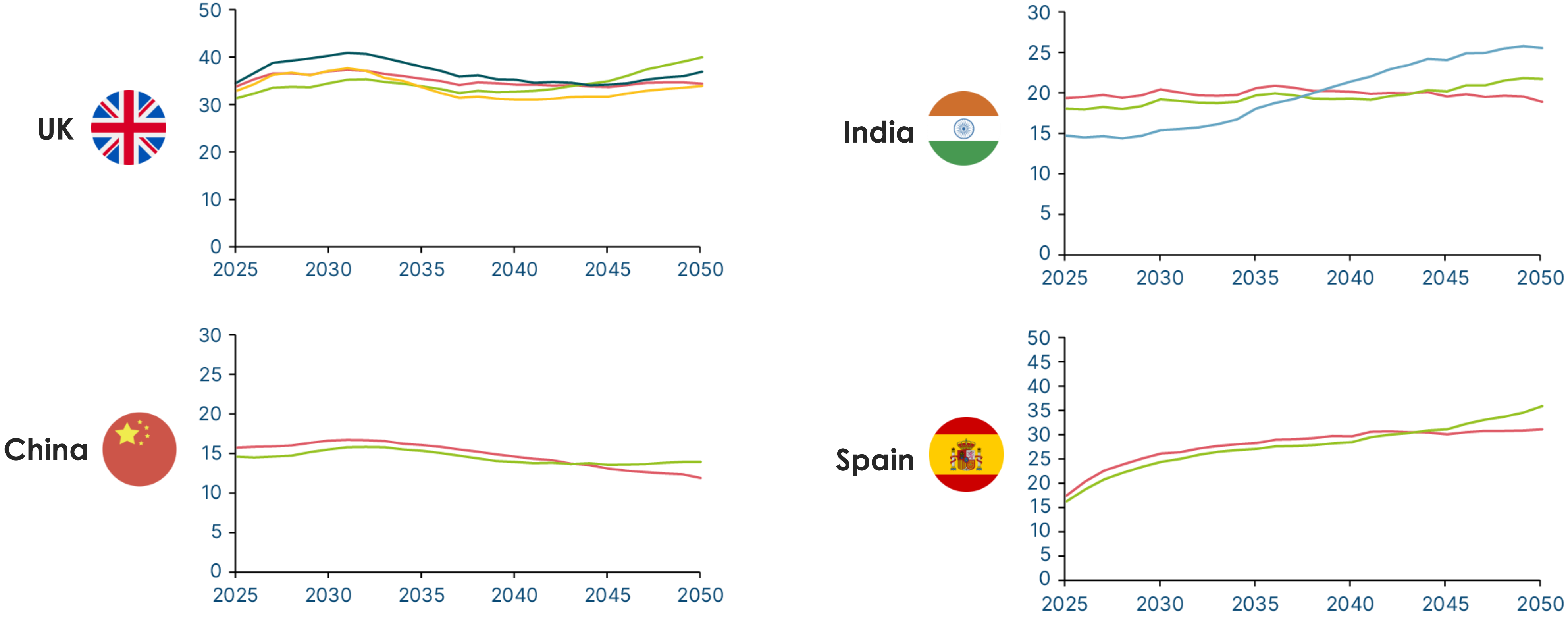
Note: The following assumptions are used for the following technologies: Hydrogen based on a 5% utilisation factor for OCGTs and a 50% electrolyser utilisation rate. Interconnectors assume no electricity cost input. **Source:** Systemiq analysis for the ETC; BNEF (2024), *Energy Storage System Cost Survey*; BNEF (2024), *Long duration energy storage cost survey*; PNNL (2025), *Pumped Hydro Energy Storage*; BNEF (2024), *Electrolysis System Cost Forecast 2050: Higher for Longer*; BNEF (2025), *LCOE Data Viewer*; Liu et al. (2021), *Development status and prospect of salt cavern energy storage technology*; D. Mullen (2024), *On the cost of zero carbon electricity: A techno–economic analysis of combined cycle gas turbines with post–combustion CO_2 capture.*

Grid costs per unit likely to be at similar level or only slightly higher over time, as size of the electricity system grows

Grid CAPEX costs (Tx and Dx) per demand unit, 2025-2050

$/MWh (real 2024$) for payments per kWh of demand

- ● ETC – Accelerated But Clearly Feasible (ACF) Scenario
- ● NESO – Future Energy Scenario: Holistic Transition (UK)
- ● Climate Change Committee Sixth Carbon Budget (UK)
- ● BNEF – New Energy Outlook 2024 Scenario
- ● TERI – Domestic Energy Scenario (India)

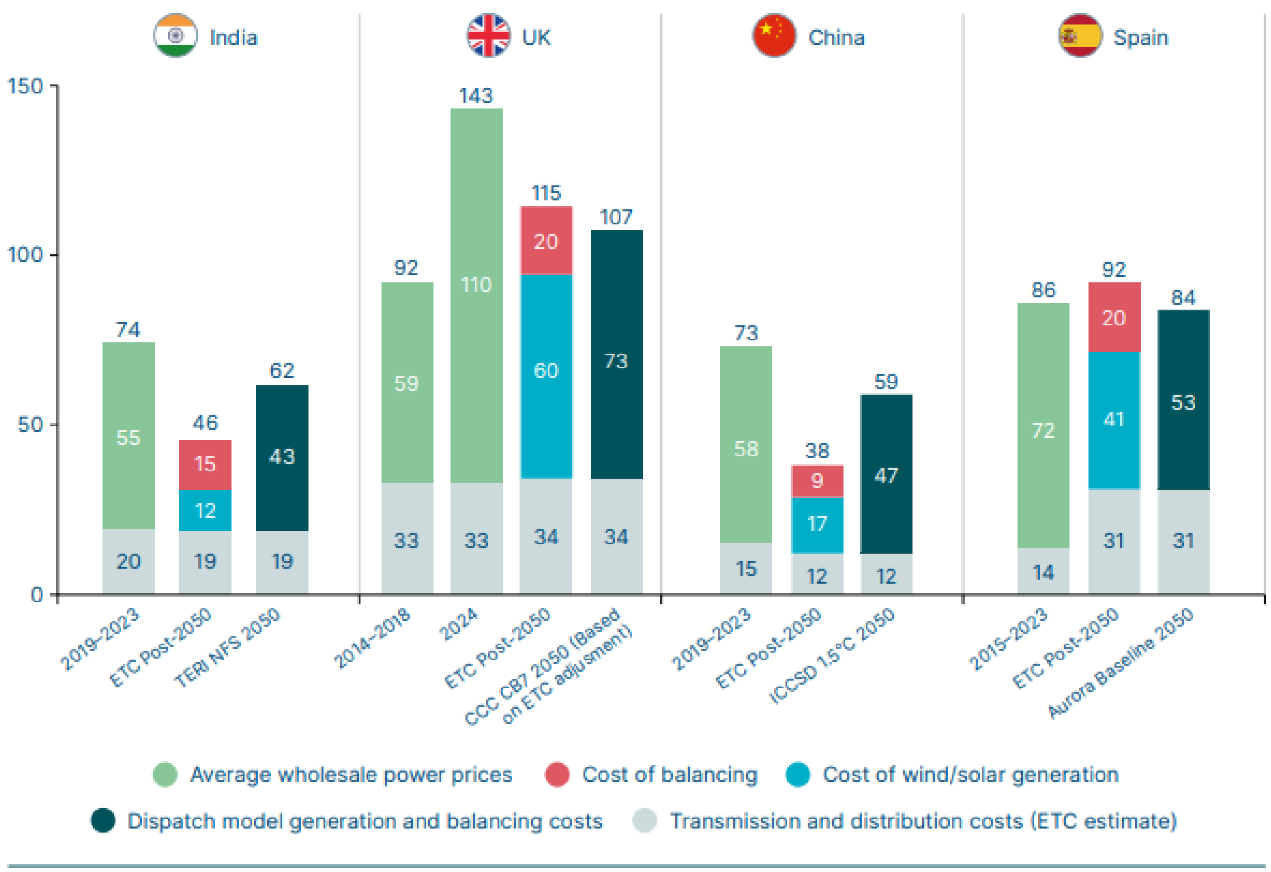


Source: IEA (2023), Investment in transmission and distribution grids in selected countries, 2015-2022; BNEF (2024), New Energy Outlook 2024; CCC (2020), The Sixth Carbon Budget; NESO (2024), Future Energy Scenarios; TERI (2024), Electricity Transition Pathways to 2050.

System generation, balancing, and grid costs could be lower or competitive with current wholesale prices

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

$/MWh (real 2024$)



Generation and balancing

- The **lowest system costs will be in sun belt countries** thanks to low-cost solar and batteries; **costs will be higher in high latitude countries**, which are dependent on wind resources and have significant seasonal balancing requirements

Grid costs

- Grid costs per unit likely to be at **similar level or only slightly higher** over time

Note: Generation costs are derived based on the generation mix using BNEF 2050 mid CAPEX and OPEX estimates, alongside capacity factors from the average weather year supply scenario (representing the long-term average), 30-year project lifetimes, and real WACC of 4%, 5%, and 6% for solar, onshore wind, and offshore wind, respectively. Storage costs are derived using the LCOS methodology outlined in the Power report. Cost estimates are in 2024 US$/MWh and reflect levelised costs of generation and storage, including contributions from surplus energy **Source:** Systemiq analysis for the ETC; BNEF (2025), *LCOE: Data Viewer*; 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;* Ember (2025), Wholesale electricity prices in Europe; CCC (2025), *The Seventh Carbon Budget*; TERI (2024), *India's Electricity Transition Pathways to 2050: Scenarios and Insights;* ICCSD (2022), *China's Long-Term Low-Carbon Development Strategies and Pathways;* Aurora (2023), *Long Duration Energy Storage in Spain.*

Deepdive on two key focus areas

Sunbelt opportunity

- There is a massive decarbonisation opportunity in the **sunbelt region**
- **Barriers to tackle**: grids, capital costs, bankable market design and policy stability

Grid build optimisation through innovative grid technologies (IGTs)

- Grid build can be optimised using innovative grid technologies
- **Barriers to tackle**: grid financing mechanisms, partnerships between grid operators and tech providers

ETC has released a short briefing note on **Innovative Grid Technologies**, first of a series that will expand on key topics in *Power Systems Transformation*

ETC Briefing – Power Systems Transformation

Innovative Grid Technologies:
a fast-track to cheaper, resilient grids

October 2025

Around the world, grids will need to grow and modernise. As the world electrifies, both rapidly growing electricity demand, as well as rising wind and solar generation, will require large scale investment in both transmission and distribution grids. **Innovative Grid Technologies (IGTs) can offer a vital solution for optimising grid build.** IGTs, which can be either software solutions (such as dynamic line rating) or hardware solutions (such as advanced conductors), optimise use of existing infrastructure by maximising the network capacity and reducing losses, lowering investment needs, speeding connection queues, and accelerating renewable integration. To scale, they require coordinated action across the value chain to reform regulation, align incentives, and ease supply chain bottlenecks.

1. The world needs to massively expand and invest in grids

Upgrading global grids is one of the defining challenges of the energy transition. Overall, the Energy Transitions Commission estimates that the total global grid length must grow by 2–4 times from today to 2050, growing from around 82 million km of grid in 2025 to around 150–200 million km in 2050, with growth across all regions.[1] To put this in perspective, 150 million km is around 1.1x the distance from the Earth to the sun. The challenge is fundamentally different around the world. In countries such as India, this simply represents a continuation of the pace of grid built out seen in the last decade. In Western Europe and the US, the increase will be a step change after a period of relatively slow investment.

These expansion needs are matched by a similar order of needs of investment. Total global investment in grids needs to grow from around $370 billion in 2024 to a peak of $870 billion per annum in the 2030s and 2040s. About 55% of the total is required in the distribution network and 45% in transmission. This is not just about adding more copper wires – it involves replacing aging grid assets and modernising grid infrastructure and capabilities, such as enabling two-ways flows.

2. IGTs can reduce grid investments by up to 35%

IGTs are both software and hardware solutions that can optimise the use of existing grid infrastructure by maximising network capacity and reducing losses. Commercially ready IGTs include hardware solutions such as advanced conductors, voltage upgrades and "storage as transmission assets" which can boost network capacity by 40% to over 400%. On the software side, technologies like flexible AC transmission systems, dynamic line rating (DLR) and grid inertia and flexibility measurements can increase network capacity by around 30% through real-time visibility and response.[2] Advances in artificial intelligence are now making these tools more powerful, improving automation, precision and integration into grid operations. Emerging applications include self-healing grid systems that automatically detect and isolate faults.[3]

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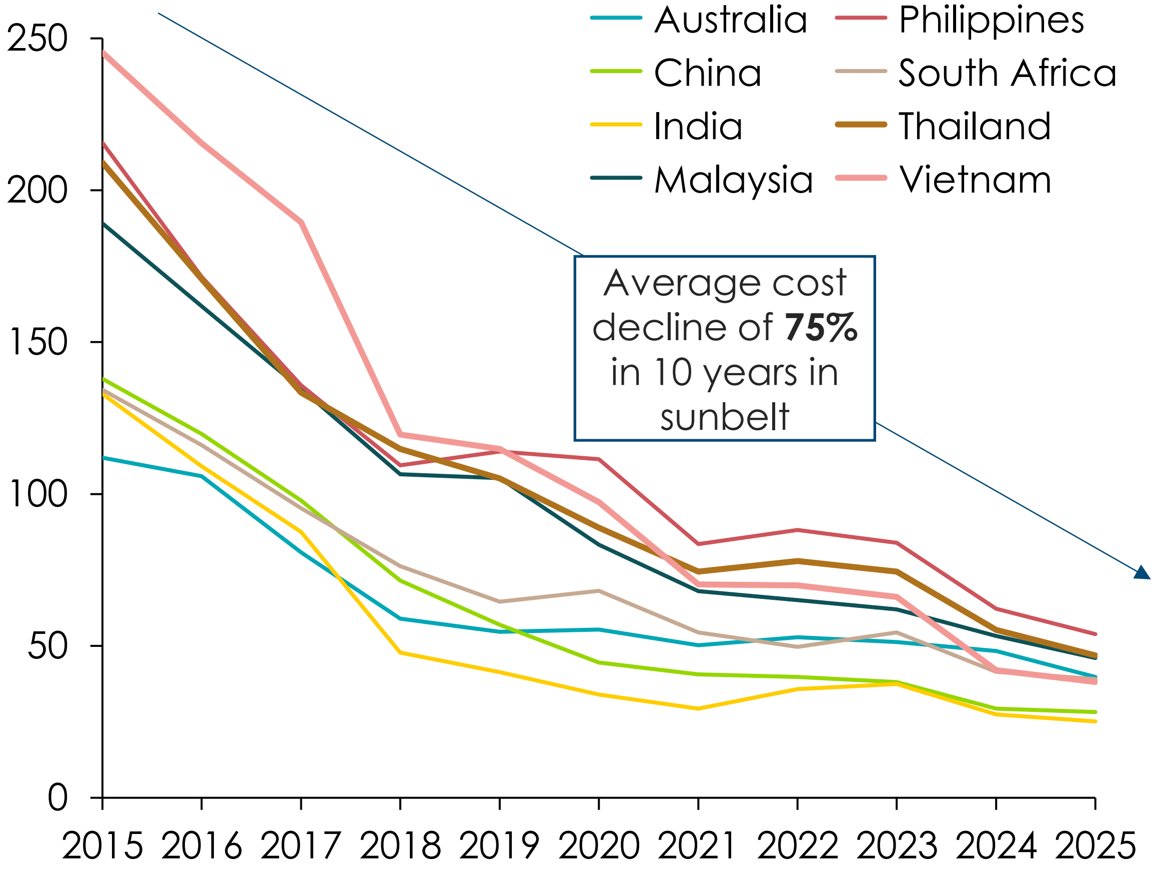
[1] IEA (2023), Electricity Grids and Secure Energy Transitions; BNEF (2024), NEO grids.
[2] IEA (2023), Electricity Grids and Secure Energy Transitions; BNEF (2024), NEO grids;
[3] Alam et al (2025), Artificial intelligence integrated grid systems: Technologies, potential frameworks, challenges and research directions

Energy Transitions Commission | powered by SYSTEMIQ

Sunbelt: Rapidly declining solar and battery costs present a major opportunity for electrification in markets using these technologies

PV fixed-axis LCOE, mid-scenario, by sunbelt country

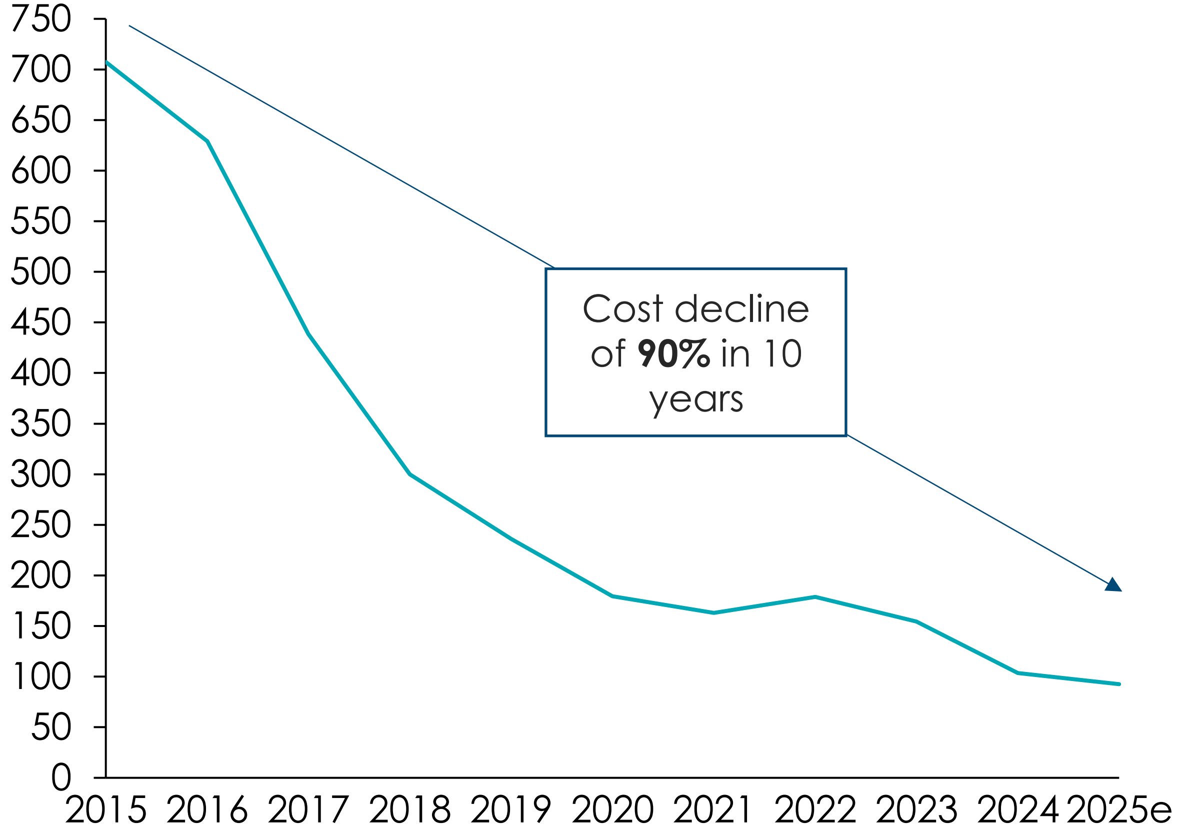
$/MWh



Average cost decline of **75%** in 10 years in sunbelt

Utility-scale battery LCOE, 4-hour duration

$ bn, 30th April 2025



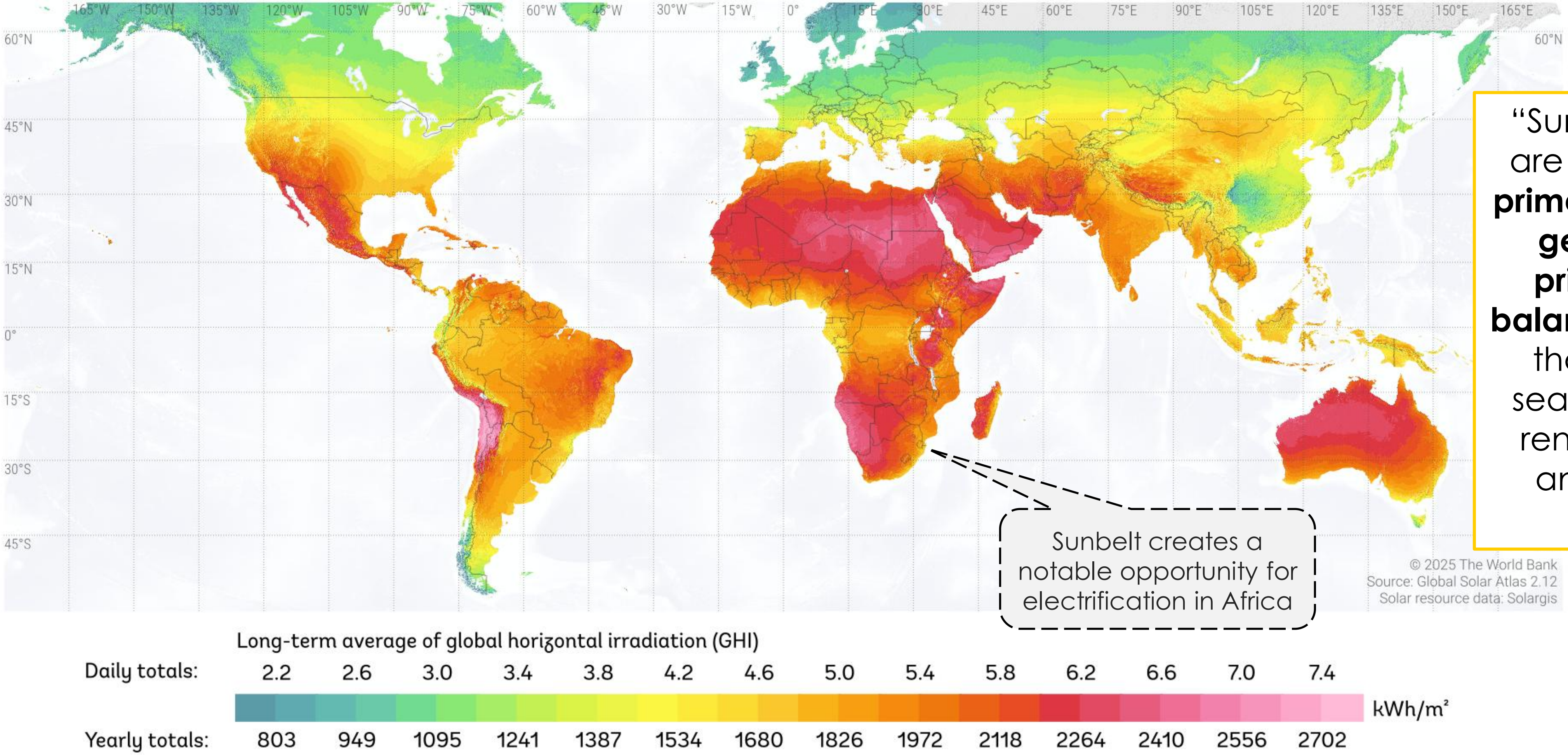
Cost decline of **90%** in 10 years

Source: BNEF (2025), LCOE Data

This particularly benefits countries in the ‘Sunbelt’, spanning Africa, Oceania, Middle East, Latin America and South-East Asia regions

Irradiation varies across the globe

Long-term yearly average of daily and yearly GHI totals



© 2025 The World Bank
Source: Global Solar Atlas 2.12
Solar resource data: Solargis

Sunbelt creates a notable opportunity for electrification in Africa

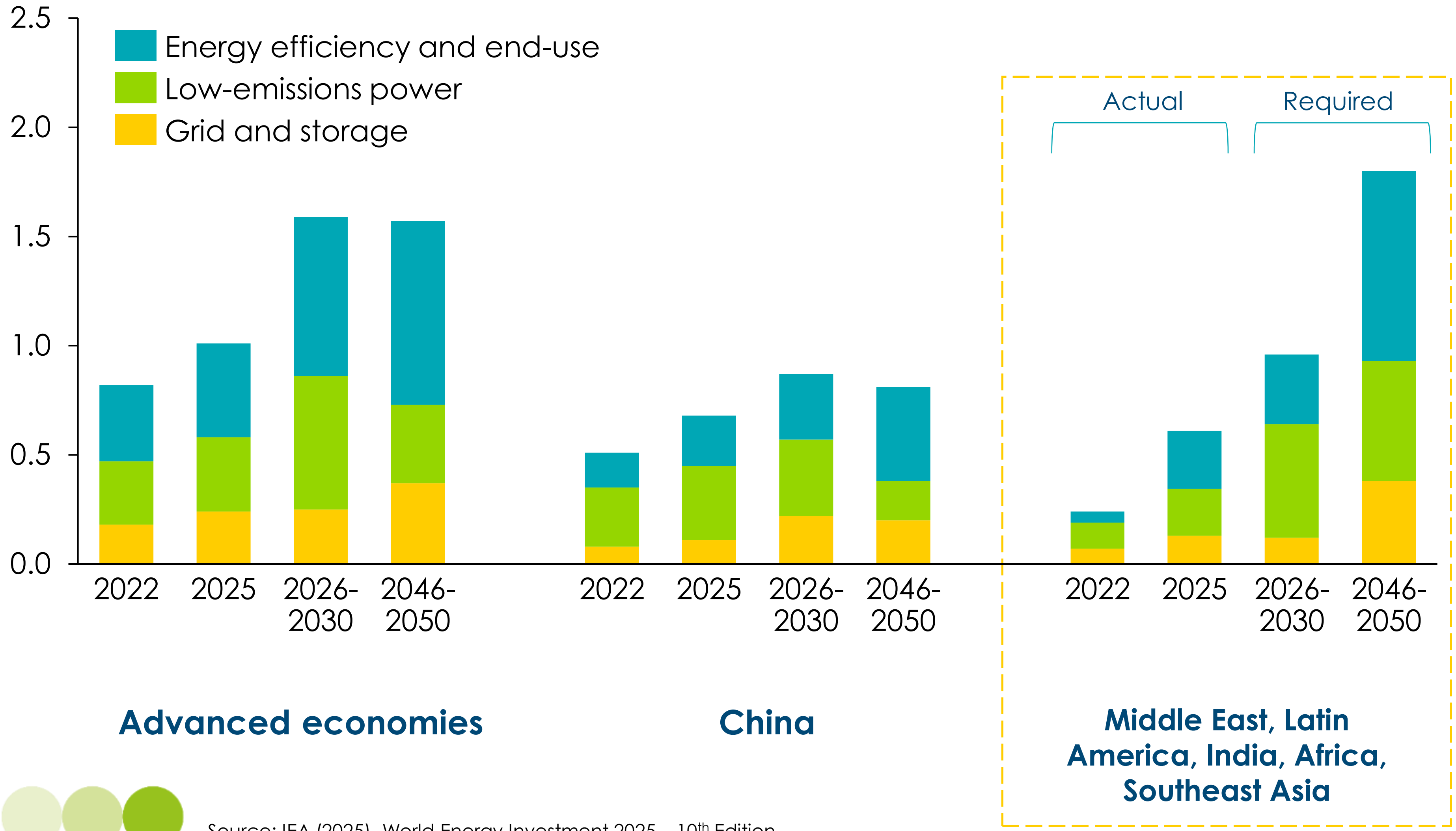
“Sunbelt” countries are categorised by **primarily solar-based generation** and **primarily a daily balancing challenge**, thanks to limited seasonality of both renewable supply and of demand patterns

Note: GHI refers to Global Horizontal Irradiance - the total amount of solar radiation received on a horizontal surface. Source: World Bank (2025), *Global Solar Atlas*, available at https://globalsolaratlas.info/map?c=11.609193,8.4375,3.

However, many Sunbelt regions facing an investment gap vs other geographies and vs Net-Zero pathway

Clean energy investment needs by region/country in the Net Zero Scenario, 2022-2050

trillion USD (2022)

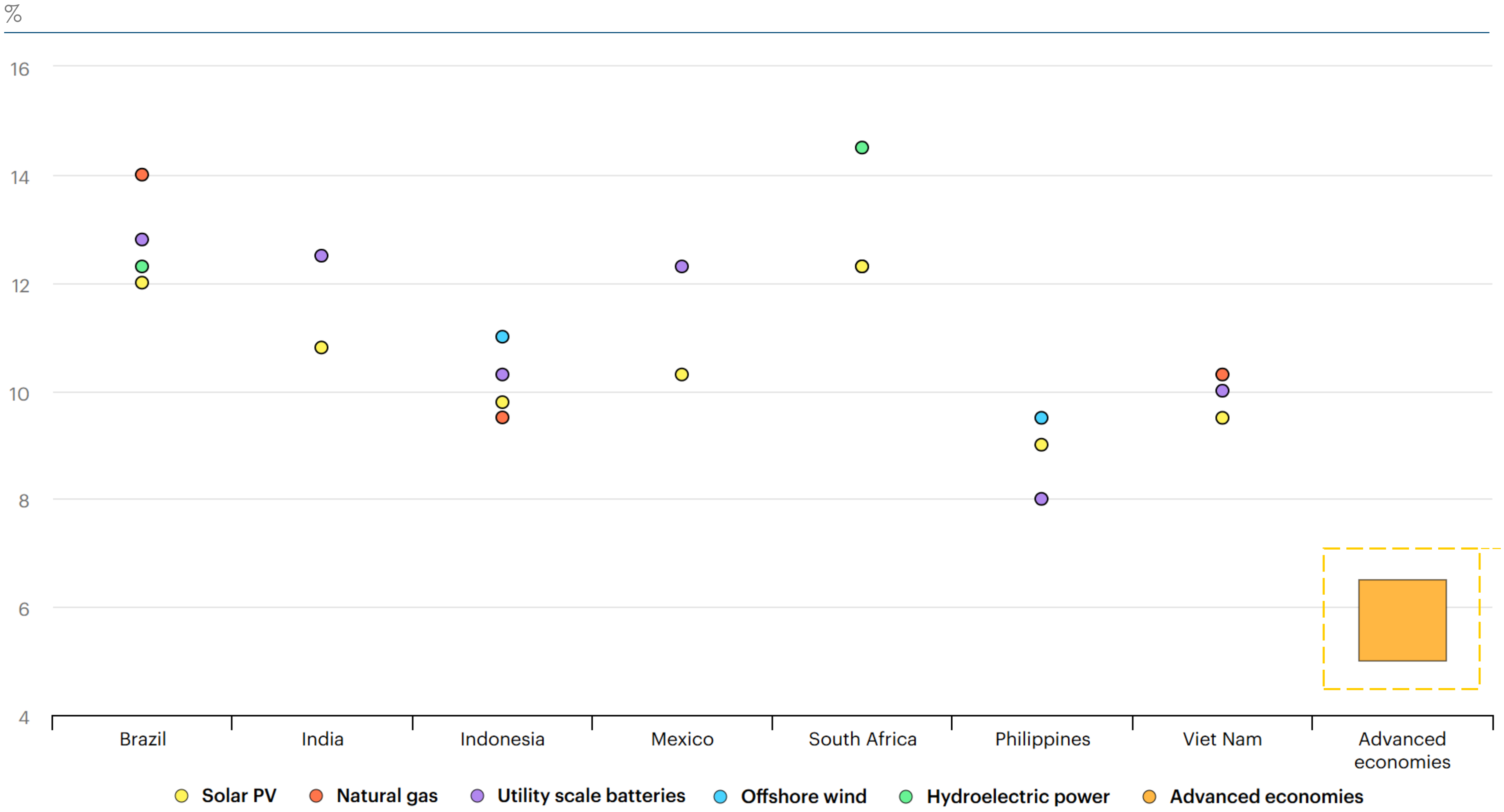


- Clean energy investment in the sunbelt is **rising but far below what is needed** to meet growing electricity demand and decarbonisation targets.
- **Southeast Asia, Africa, and Latin America** remain underfunded relative to their potential and needs.

Source: IEA (2025), World Energy Investment 2025 – 10th Edition

Slow investments into these markets is explained by continual high cost of capital compared to advanced economies

Cost of capital by project type in selected emerging markets and developing economies countries, 2024



Cost of capital still notably higher in emerging markets compared to advanced economies

Source: IEA (2025) Cost of capital expectations for 2025 diverge amid rising uncertainty

Sunbelt opportunity requires addressing cost of capital, grids and stable revenue frameworks

Cost of capital

- **Blended and concessional finance** lower risk premia and unlock international capital.
- Domestic lenders dominate clean energy finance (~75%), **but additional ~$50 bn/yr needed** by 2035 in Southeast Asia.

Grids

- **Grid build-out is the primary bottleneck**: investment must double from ~USD 400 bn
- **Faster permitting**, standardised equipment procurement, and co-located storage are critical.

Stable revenue frameworks

- **Stable revenue frameworks** (PPAs, FX hedges, corporate PPAs) attract private capital.
- **Policy instability** (e.g. Viet Nam tariff revisions) has stranded >USD 13 bn in renewables.

Other key barriers include: supply chain localisation, land and permitting constraints, currency and macroeconomic volatility

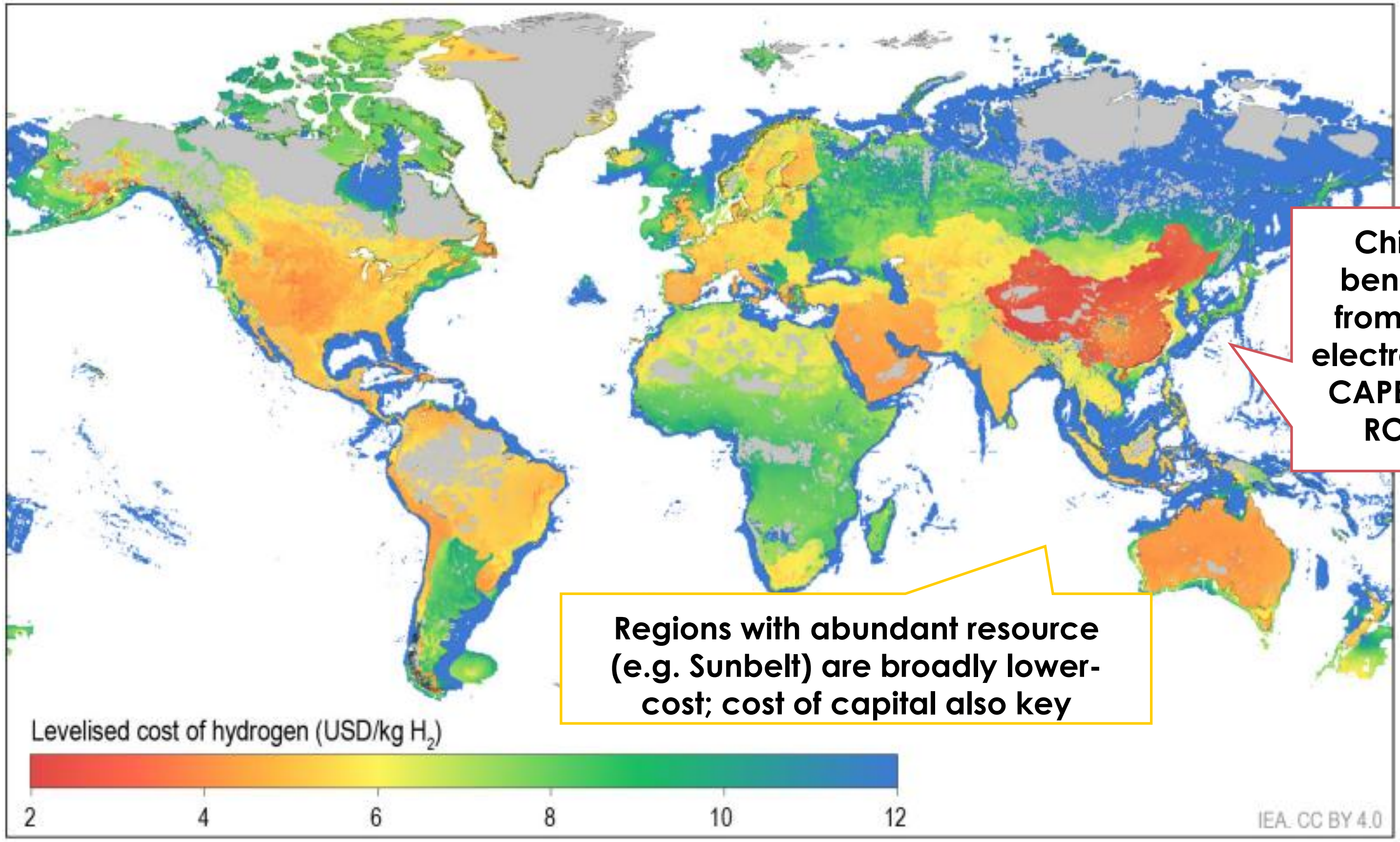
These factors compound risk, keeping private finance out of high-potential sunbelt markets

Source: MPP (2025), Clean industry: transformational trends; IEA (2025), World Energy Investment 2025 – 10th Edition; BNEF (2025), 3Q Global PV Market Outlook: Growth Is Slowing Down

Clean power costs are a key driver of hydrogen costs

Green hydrogen production cost using hybrid solar PV and onshore wind, and from offshore wind, in the IEA Stated Policies Scenario, 2030

$/kg H2



China benefits from low electrolyser CAPEX vs ROW

Regions with abundant resource (e.g. Sunbelt) are broadly lower-cost; cost of capital also key

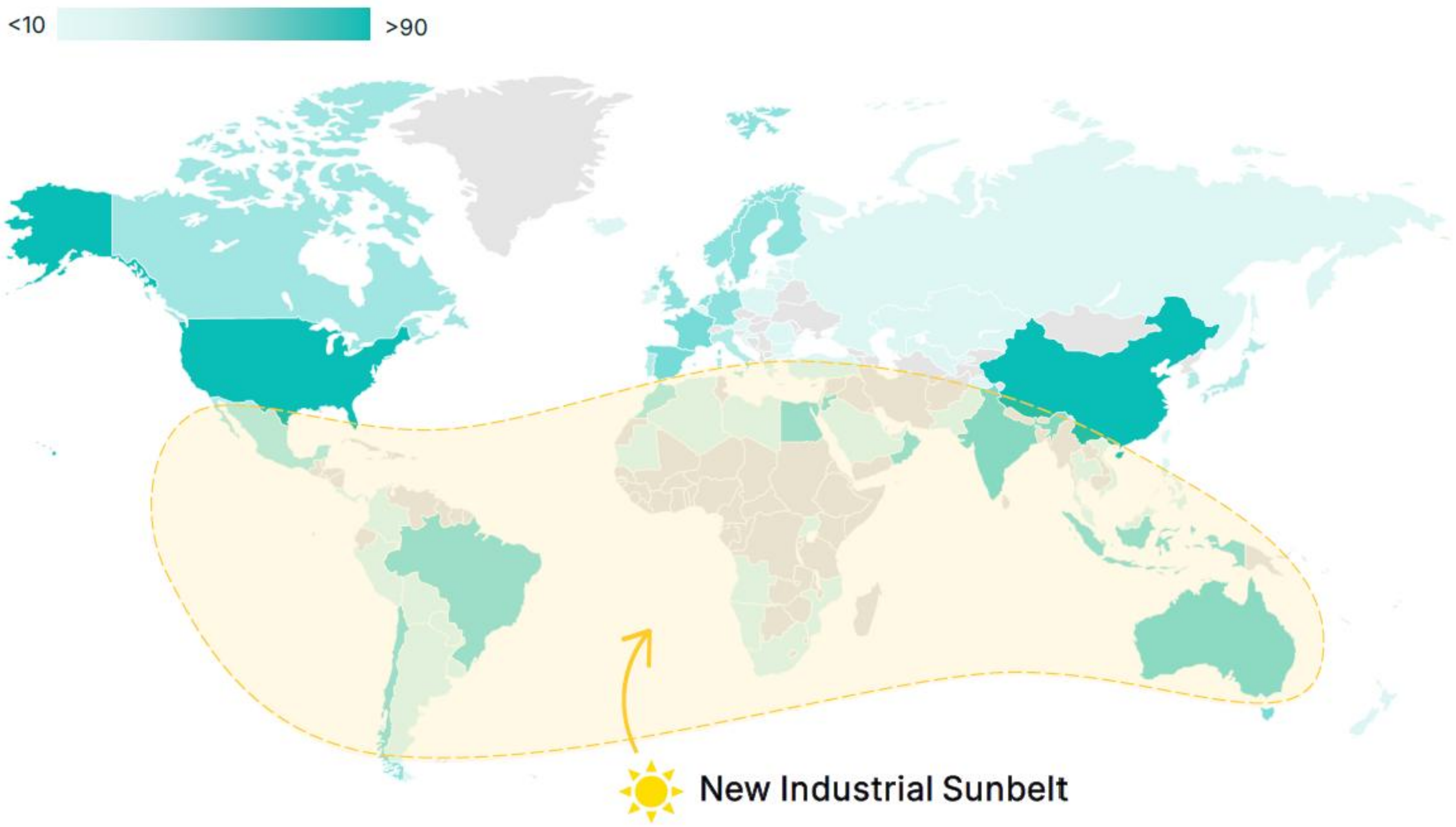
- **$2/kg only possible with LCOE of $20-25/MWh** and electrolyser capex of ~$500-700/kW - i.e. only in China
- **In EU/US Hydrogen is ~ $5/kg – based on LCOEs of $50-65/MWh,** with electrolyser capex of ~$1,500/kW
- Potential for electrolyser cost reductions beyond 2030 would further reduce costs

Notes: Assuming optimal oversizing of the renewable plant in each location to minimise the levelised cost of hydrogen production. Solar PV CAPEX is USD 400-1 250/kW, Onshore Wind CAPEX is USD 950-2 300/kW, Offshore Wind CAPEX is USD 1 720-4 850/kW. The cost of capital is assumed to be between 6-10% across different locations in this map. Water cost is not included. Source: IEA (2025) Hydrogen Tracker; Analysis by Jülich Systems Analysis at Forschungszentrum Jülich using the ETHOS model suite.

Low-cost clean power creates an opportunity for the "Industrial Sunbelt"

Clean industrial transformation is happening in 70 countries around the world

Announced projects per country, 30th April 2025



The Sunbelt is attracting a fifth of secured financing and over half of potential financing in the pipeline

Significant opportunities for EMDEs; Sunbelt EMDEs now account for ~30% of the total planned and realised clean industry project base.

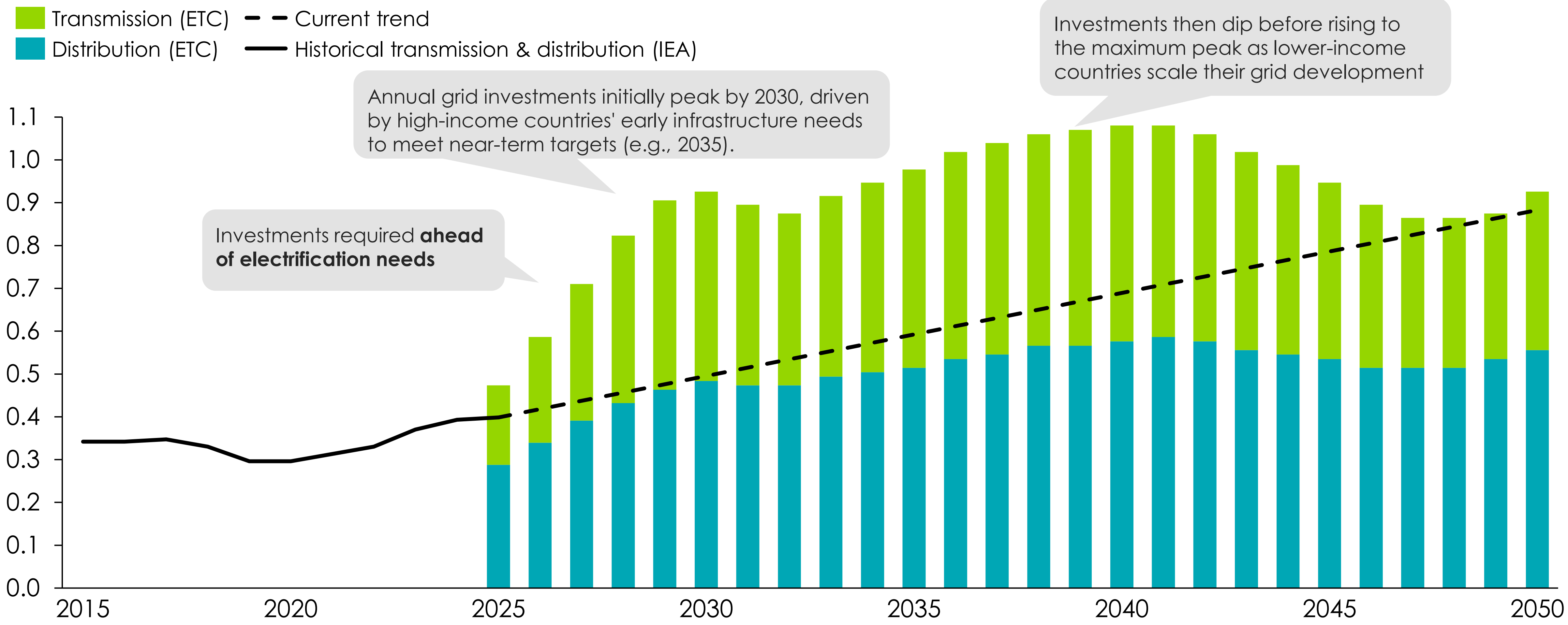
However, enhanced efforts are needed to **scale investment** – with higher financing costs being a key blocker for EMDEs

Note: Includes projects that are at the announced, reached final investment decision (FID) and operational stages. Source: MPP (2025), Clean industry: transformational trends

While grid investment has been growing at 5-10% per year in the first half of this decade, this remains significantly lower than the required levels identified by the ETC

Annual investment in new power grid system, global, ETC average, 2024–2050

Trillion USD (real 2024)



Annual grid investments initially peak by 2030, driven by high-income countries' early infrastructure needs to meet near-term targets (e.g., 2035).

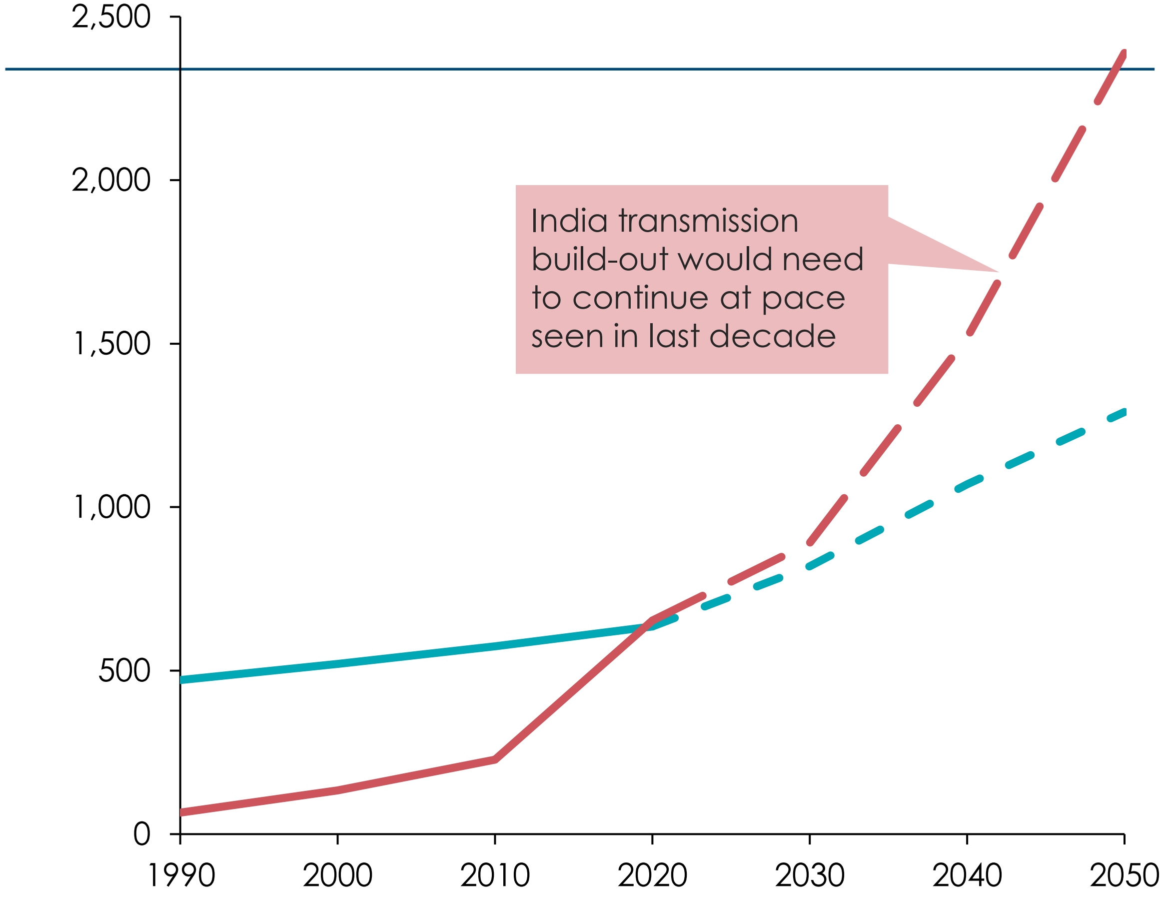
Investments then dip before rising to the maximum peak as lower-income countries scale their grid development

Investments required **ahead of electrification needs**

Notes: We have included 50% of hydrogen demand in these estimates. The "Current trend" is an extrapolation which assumes that the average growth rate shown from 2023 – 2025 continues.
Source: Systemiq Analysis for the ETC (2025); IEA (2025) *World Energy Investment 2025*.

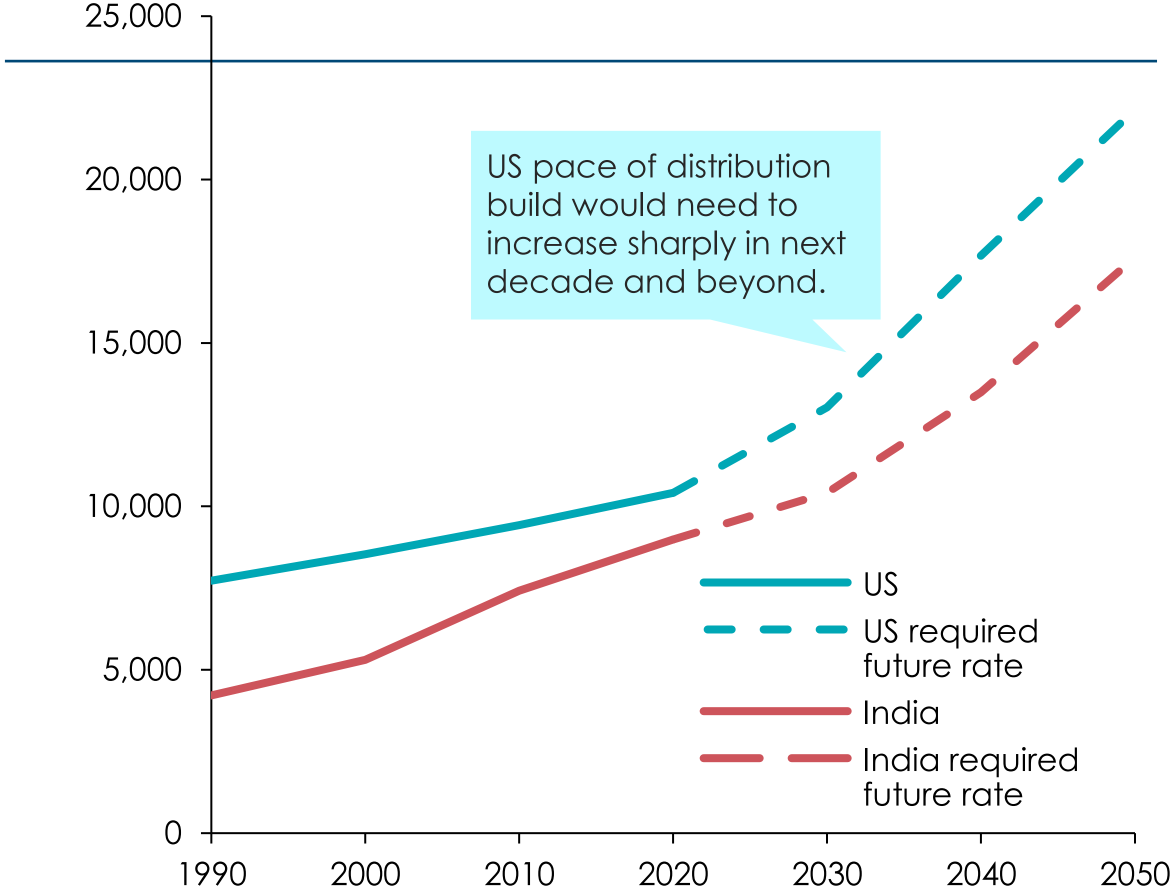
Grid growth in many developed markets (US, Europe) has been very slow for decades, whilst others (India/China) are building at record pace

Historical and forecast transmission build rate, US and India
Thousand km of wires



India transmission build-out would need to continue at pace seen in last decade

Historical and forecast distribution build rate, US and India
Thousand km of wires



US pace of distribution build would need to increase sharply in next decade and beyond.

Notes: US historical build rate calculated on assumption of 1% grid growth in transmission and distribution per year from 1990 – 2022; Princeton modelling outlines that from 2013 to 2020 transmission lines have expanded at only 1% per year. Source: BNEF (2021) Power Grid Long Term Outlook 2021; BNEF (2023) New Energy Outlook Grids; Princeton Zero Lab (2022) *Preview: Final REPEAT Project Findings on the Emissions Impacts of the Inflation Reduction Act and Infrastructure Investment and Jobs Act*

There are three main opportunities to reduce grid investment needs

Innovative grid technologies

Deployment of IGTs can:

- Increase efficiency of **existing** grid assets
- Reducing required **new** grid investment

Demand-side flexibility

Demand-side flexibility can:

- Reduce **peak** electricity demand
- Reducing required **distribution system investment** by 40%

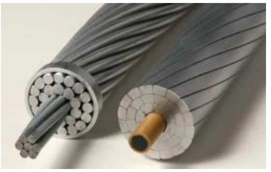
Optimal siting

Optimal siting of assets can:

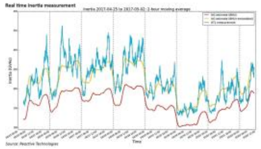
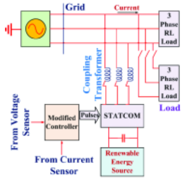
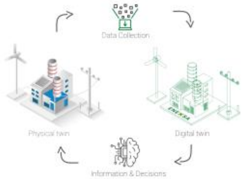
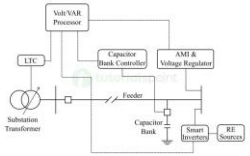
- Maximise use of **existing grid connections**
- Reduce grid **expansion** needs

Eight innovative grid technologies, including hardware and software, critical to optimising the grids and reducing investment needs

Hardware

			Network capacity increase
1	Advanced conductors		100-300%
2	Superconductors		400-1000%
3	Voltage upgrade		30-400+%
4	Storage as a Transmission Asset		40%

Software

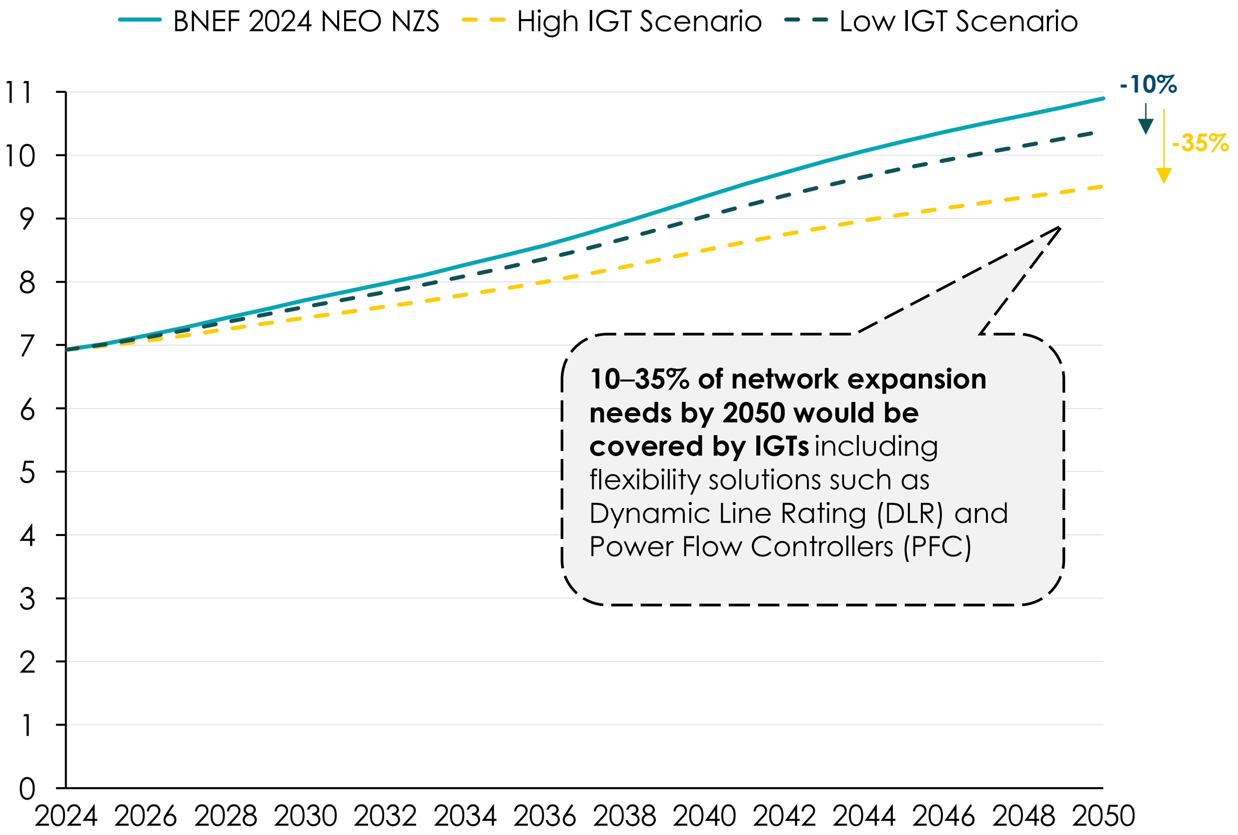
			Network capacity increase
1	Grid Inertia Measurements		30%
2	Flexible AC Transmission Systems		30%
3	Dynamic Line Rating		30%
4	Flexibility management software		30%
5	Volt/VAR Management Systems		NA*

Note: * = Volt/VAR Management Systems controls reactive power by improving reliability and reducing losses, but it does not increase how much real power the grid can transmit, hence there is no increase to the network capacity. Source: ETC (2025), Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems

Innovative grid technologies could significantly reduce grid build and reduce CAPEX spending

Benefits of IGTs compared to network expansion needs

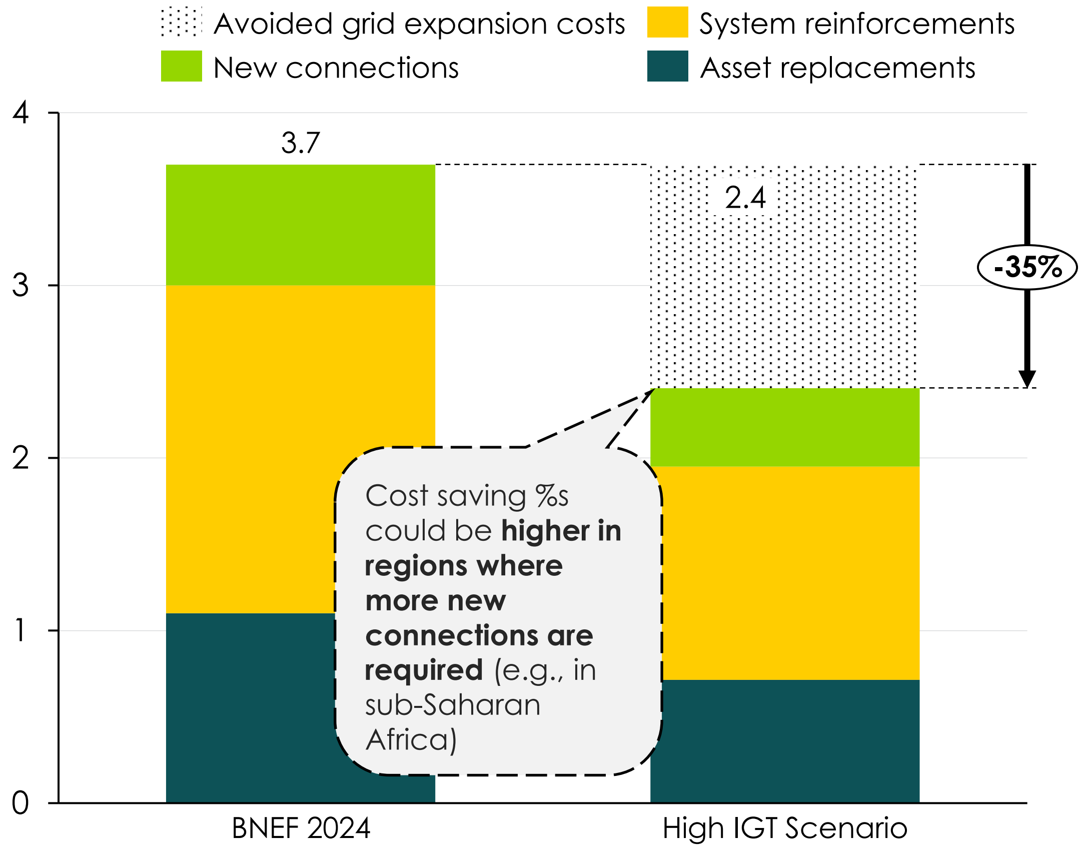
Million km, Europe, 2024–2050



10–35% of network expansion needs by 2050 would be covered by IGTs including flexibility solutions such as Dynamic Line Rating (DLR) and Power Flow Controllers (PFC)

Cumulative investment in new power grid system, Europe

$ trillion (real 2024$), 2024–2050, based on BNEF



Cost saving %s could be **higher in regions where more new connections are required** (e.g., in sub-Saharan Africa)

Note: We have assumed that IGTs impact all three investment categories: IGTs lower new connection needs by maximising existing and new infrastructure use (though some remote renewables still need connections, new connections leveraging IGTs will require fewer upgrades in future); IGTs delay system replacements by extending grid asset life; and IGTs reduce reinforcement requirements by improving line capacity and utilisation.

Source: Systemiq analysis for the ETC; CurrENT (2024), *Prospects for innovative power grid technologies*; BNEF (2024), *New Energy Outlook.*

Four key areas to scale innovative grid technologies

1 **Reform regulation to reward optimisation**

- Move from cost-minimisation to performance-based incentives.
- Create mechanisms that make new grid technologies bankable.

2 **Deploy software-based grid technologies early**

- Pilot and scale "low-regret" digital solutions to prove benefits and accelerate adoption.

3 **Integrate system operators and data**

- Build interoperable data platforms so information flows efficiently across grids.

4 **Use AI and automation for smarter grids**

- Apply AI for fault detection, self-healing, and automated re-routing to boost visibility, reliability, and recovery.

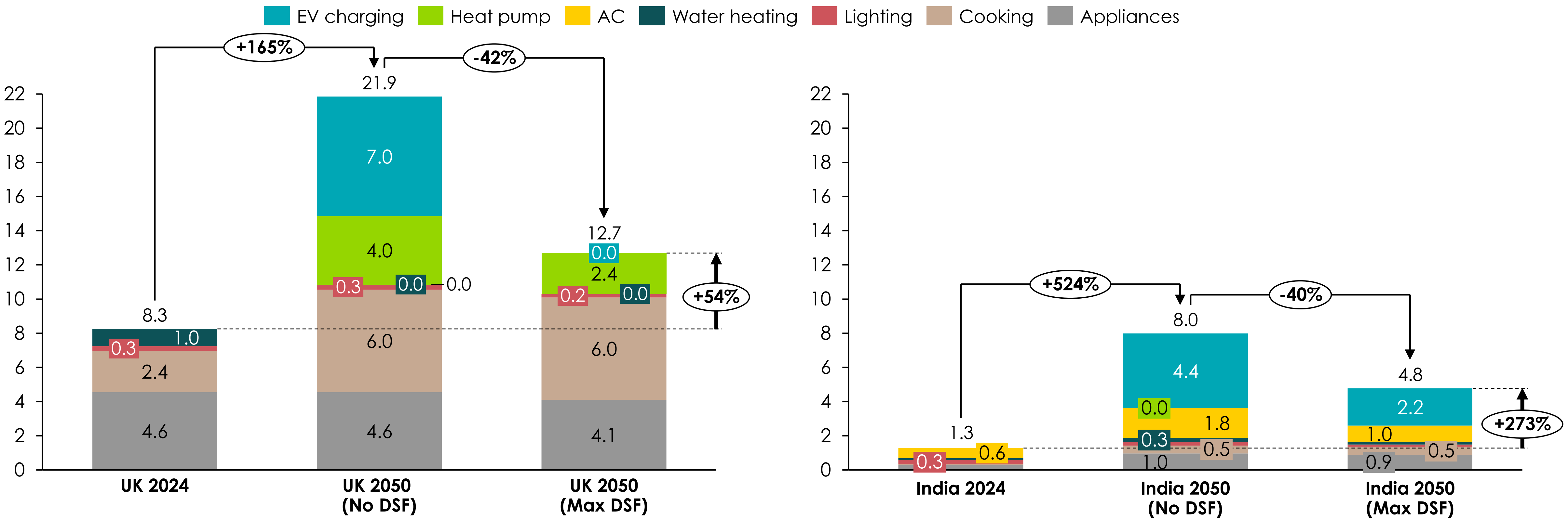
Increases in household-level peak power demand are expected, however demand-side flexibility can offset some peak demand increase

DSF potential to reduce UK winter peak

Potential Winter Peak (kW)

DSF potential to reduce India summer peak

Potential Summer Peak (kW)



Driven by the electrification of:

- Household heating: heat pumps draw approximately 4 kW of flexible demand.
- Personal vehicles: EV charging could contribute around 7 kW of flexible demand.

Driven by increased appliance penetration and electrification:

- AC: AC units draw around 3 kW of flexible demand
- Personal vehicles: EV charging could contribute around 4 kW of flexible demand (accounting for high proportion of three-and-two-wheelers).

Note: Indian data accounts for penetration, therefore each stack doesn't directly correlate with appliance consumptions.
Source: Systemiq analysis for the ETC; TERI (2024), *India's Electricity Transition Pathways to 2050;* US Department of Energy (2018), *Department of Energy Announces $19 Million for Advanced Battery and Electrification Research to Enable Extreme Fast Charging;* Contemporary Structures (2023), *How Much Electricity Does a Heat Pump Use?*

Three key areas required to scale demand-side flexibility

1

Build the enabling infrastructure

- Roll out **smart meters, automated controls, and data-sharing platforms.**
- Establish **interoperability standards** and data protocols.
- Strengthen **cybersecurity and data privacy.**

2

Align markets and pricing signals

- Introduce **dynamic network tariffs and flexibility markets**.
- Support **aggregation models** and fair market access for smaller loads.
- Use **real-time and time-of-use price signals.**

3

Empower and engage consumers

- Build **trust and awareness** through clear offers and visible rewards.
- **Pilot** behavioural and automated programmes
- Leverage **digital tools** for ease of participation.

Next steps of the ETC’s Clean Power work programme

1

Power Systems Transformation Briefing notes series

Topic	Publication date
Innovative Grid Technologies (IGTs)	October
Sunbelt opportunity	November

2

Region-specific engagement

Indonesia New Energy Systems

Africa Sunbelt opportunity

India AgriPV

UK balance sheet

INTERNATIONAL SOLAR ALLIANCE

Digital grids

3

New workstream on low-carbon firm power generation

Understanding the role of clean baseload technologies in power systems, including:

- Nuclear
- Geothermal

2026 – the Power team will be conducting a deep-dive into Market Design and Consumer Bills

Agenda

- What is ETC doing at COP30?
- COP28 energy efficiency target: opportunity to meet in next two decades
- Tripling Renewables: focus on Sunbelt opportunity and optimizing grids
- **The role of Carbon Molecules in the Energy Transition**

COP28 focused on three headline areas: tripling renewables, doubling energy efficiency, and a "transition away" from fossil fuel consumption

3x

Renewable Power

Target 11,000 GW+ by 2030, growing:

- Solar ×5
- Wind onshore ×4
- Wind offshore ×8
- Geothermal ×7

Renewables to reach 62% of installed capacity by 2030

2x

Energy Efficiency

Doubling the global rate of energy efficiency improvement to 4% per year

Key to limiting energy demand growth and keeping 1.5°C within reach

Fossil fuels. "Transition away from fossil fuels in energy systems, in a just, orderly and equitable manner … "

Carbon in an electrified future: The steps in our analysis

1. How large a role can and should direct electrification play in a zero-emission economy?

- Develop an **unconstrained scenario** which identifies how much of the economy could **in principle be electrified** if zero carbon electricity were available at a very low cost and on the required scale

2. The role of hydrogen and non-carbon H_2 derivatives

- Update the projections for the **role of hydrogen**, exploring in particular the balance between hydrogen and non-carbon H_2 derivatives relative to carbon and hydrocarbon molecules in different sectors

3. The potential to recycle and reuse carbon molecules

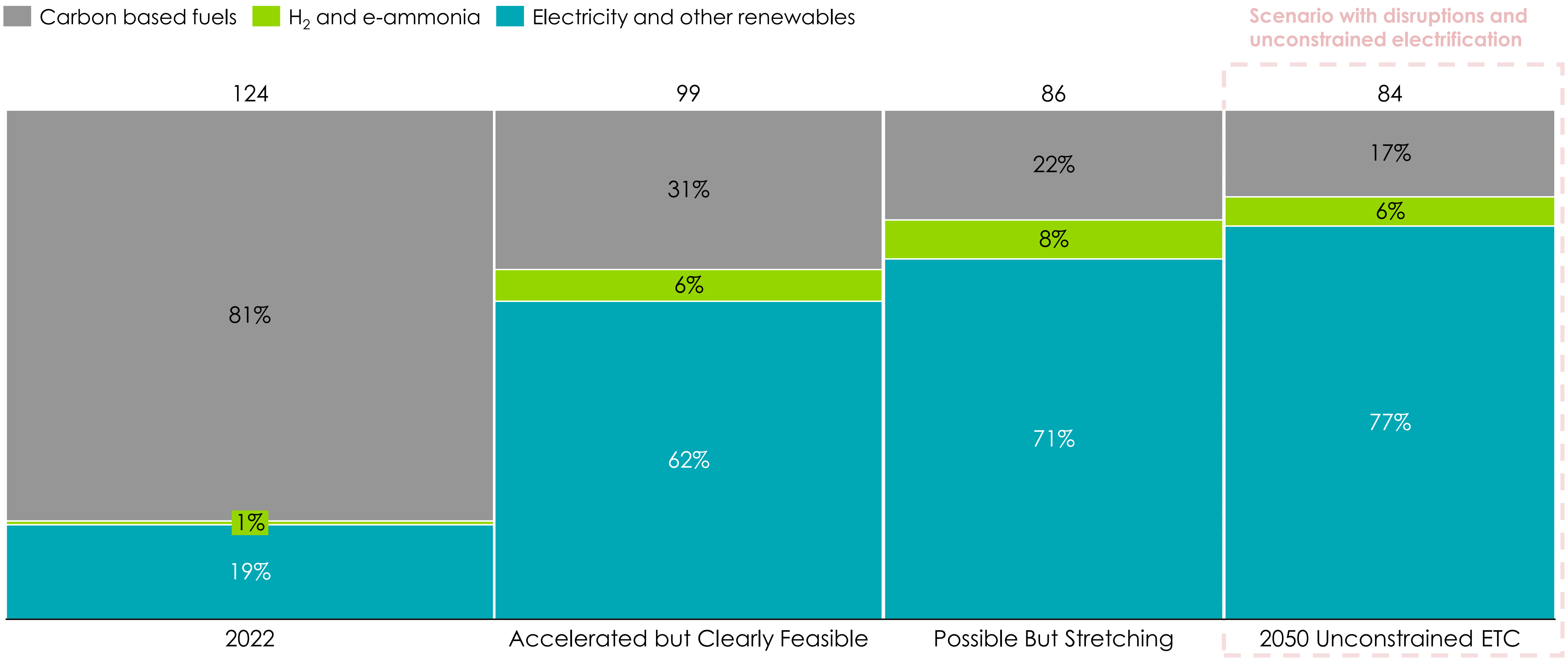
- **Explore how close to total recycling** of all carbon molecules it would be possible to get, and with what implications for the primary supply of new carbon still required to support a prosperous global economy

4. Sources of primary carbon: costs and sustainability

- Review the latest **technology development** and **cost trends** in point source capture and direct air capture of CO_2 (DACCS)
- Assess **advances in potential sustainable bioresource supply** and **engage with Brazil's distinctive viewpoint** around maximising 2nd generation biofuel production

Electrification will play a key role in decarbonised energy systems; ETC scenarios show electricity growing from 20% to 60%+ in 2050

Global final energy demand by energy source and scenario
Thousand TWh (%), 2022 and 2050

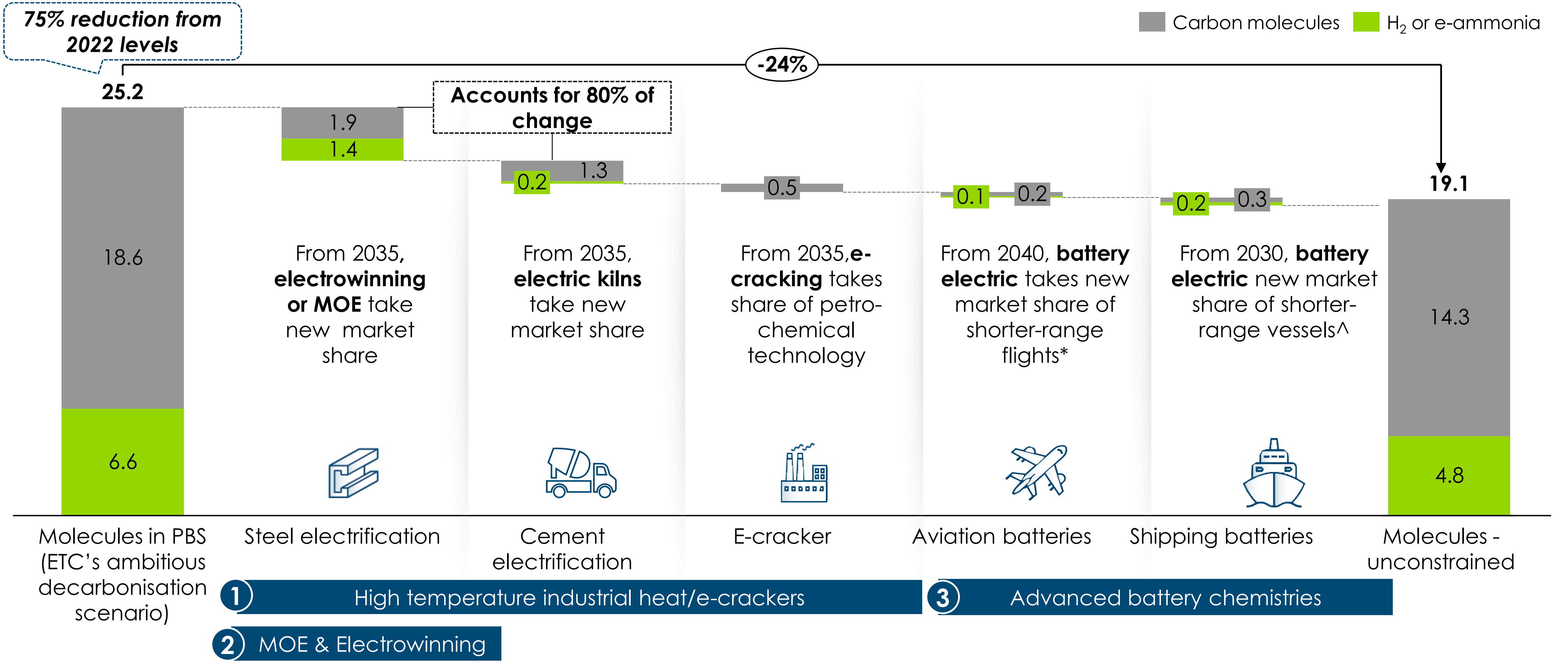


Note: ACF = Accelerated but Clearly Feasible; PBS = Possible but Stretching
Sources: 2022 scenario, and PBS scenario based on ETC (2023) Fossil Fuels in Transition report

Several key innovations could lead to a greater role of electrification, reducing the role of molecules

Molecules in the energy system – Possible But Stretching (PBS) to Unconstrained share 2050

Final Energy Consumption, Thousand TWh

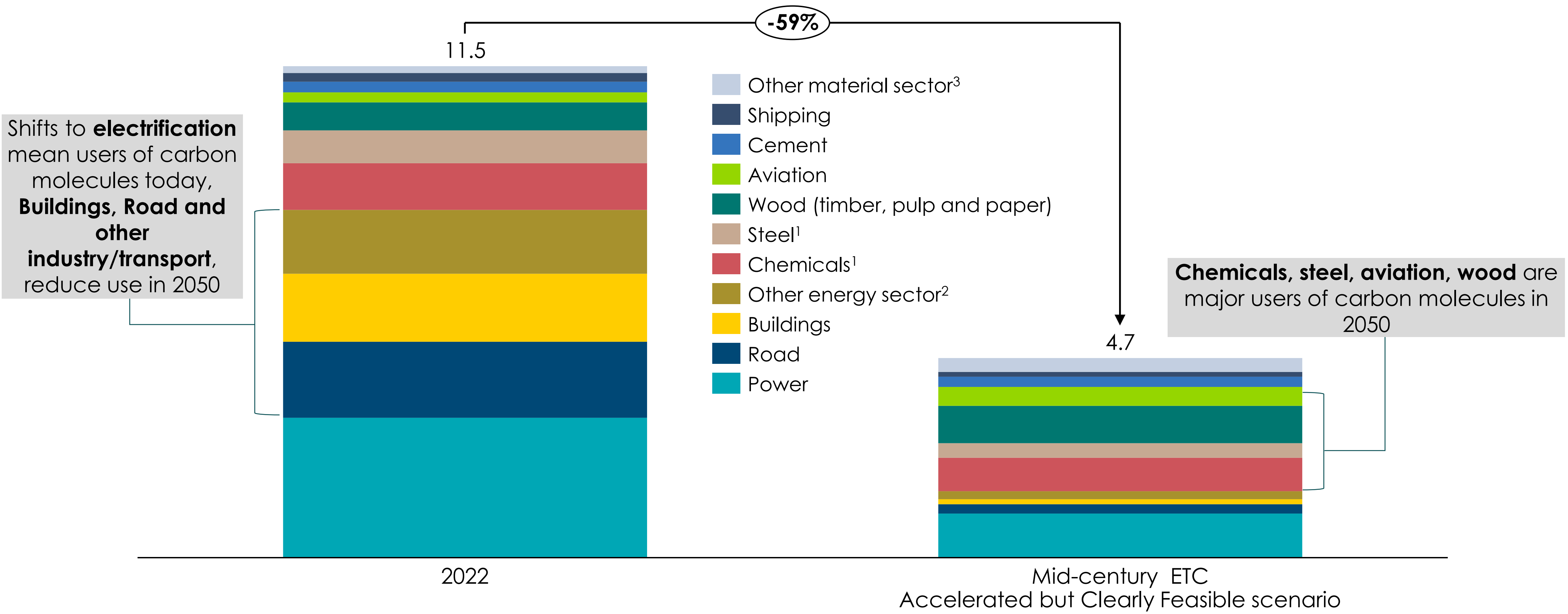


Source: Systemiq analysis for ETC (2024) based on Fossil Fuels in Transition (2023), Planet Positive Chemicals Report (Systemiq, 2022, BAU Net-Zero scenario); Steel: MPP STS (2022) Aviation: MPP STS (2022) Notes: PBS = Possible But Stretching ETC decarbonization scenario. *estimated at 15% of all nautical miles travelled, ^estimated at 20% of energy demanded

Carbon demand will persist even in a decarbonized world: 1) in sectors which cannot be electrified and 2) in sectors where carbon is essential feedstock

Carbon Demand Across the Energy and Material Sectors

Gigatons of carbon (C)



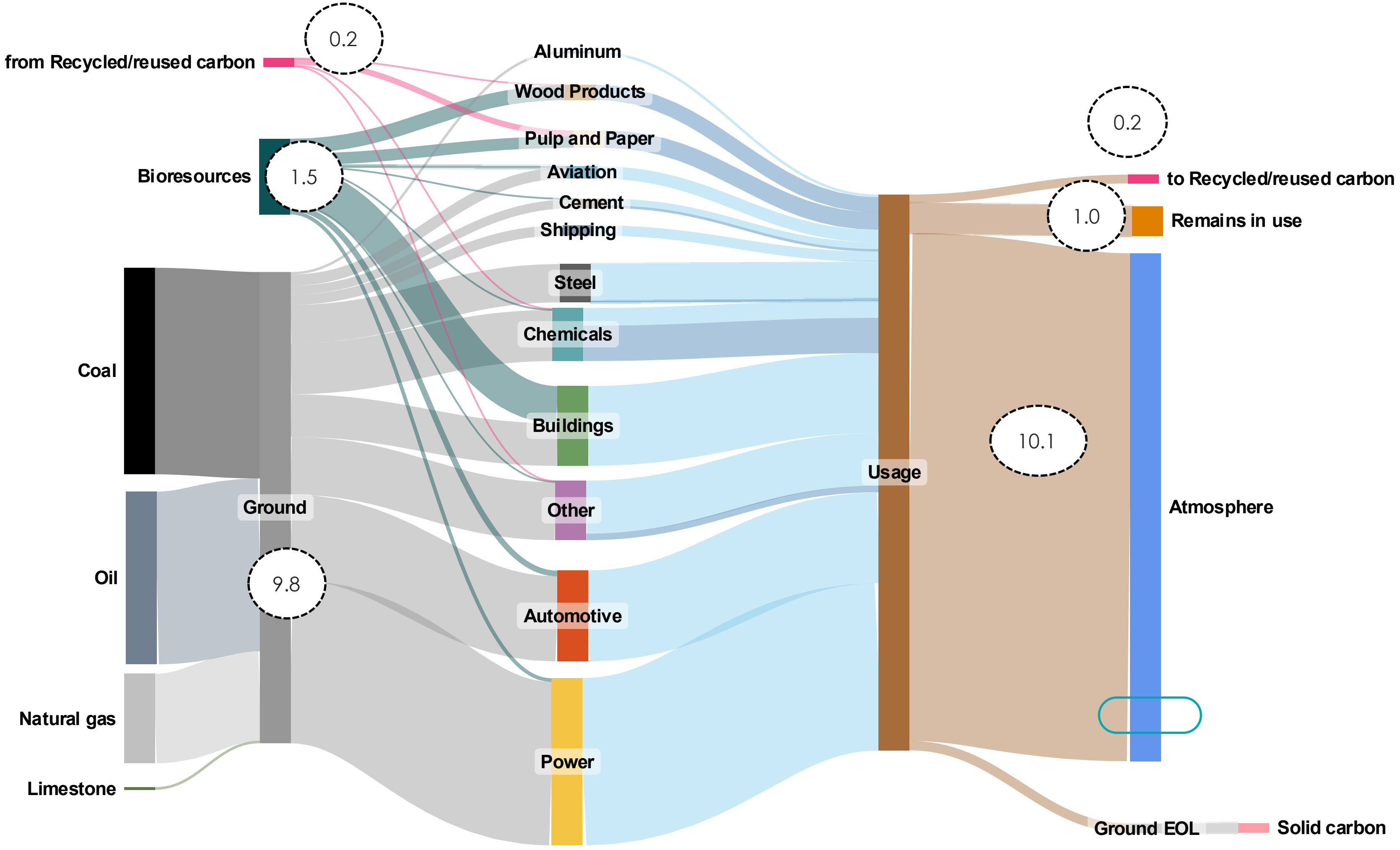
Shifts to **electrification** mean users of carbon molecules today, **Buildings, Road and other industry/transport**, reduce use in 2050

Chemicals, steel, aviation, wood are major users of carbon molecules in 2050

Notes: *ACF = Accelerated but Clearly Feasible scenario, based on ETC Fossil Fuels in Transition (2023) with minor updates. Sources: Chemicals: Planet Positive Chemicals Report (Systemiq, 2022, BAU Net-Zero scenario); Biomass: ETC Bioresources report (2021); Steel: MPP STS (2022); Cotton, Bitumen and Soda Ash: Systemiq analysis (2025) . 1. Include energy based carbon feedstocks, a proportion of which which end in the final products (e.g. chemicals for plastics and steel), and others end in process emissions. 2. Includes remaining demand remaining sectors, primarily other industry and other transport. 3) Other material sectors include non-wood biomass, limestone, carbon ash, biochar, carbon fibre and charcoal Carbon-based fuels include those fuels that also require carbon sources, e.g. e-methanol and synthetic aviation fuels.

The majority of carbon today comes from fossil fuels and ends up in the atmosphere

Carbon source and destination for the Energy and Materials Sectors, today – Gt C



It is essential that this carbon is used, sourced and managed at end-of-life in a way which results in zero net emissions

1) Use: Via carbon circularity levers that reuse, reallocate or recycle carbon

- Reduced demand
- Recycled material (mechanical recycling)
- Recycled carbon (chemical recycling, carbon utilisation)

2) Source: via sustainable sources of primary carbon

- Atmospheric (DAC)
- Oceanic (ocean-based capture)
- Biomass (sustainable biomass)
- Ground (fossil fuels)

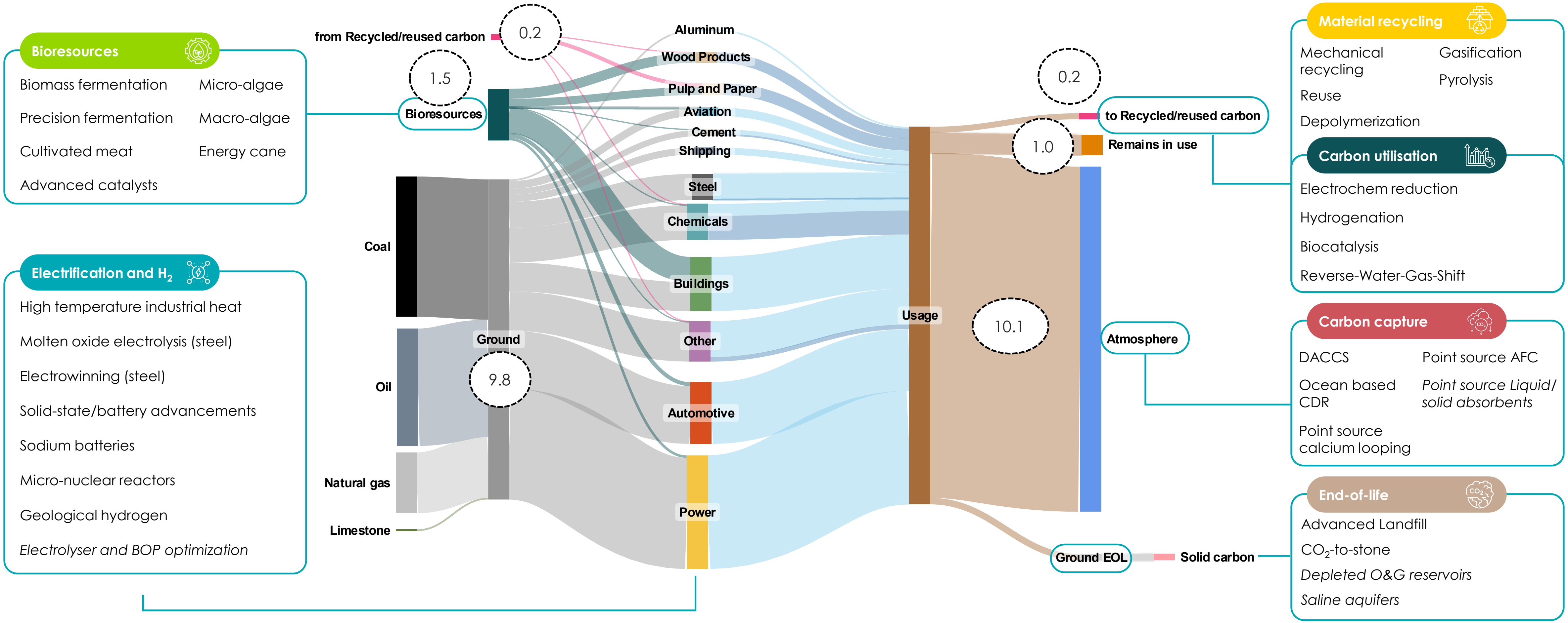
3) End-of-life: via carbon management of linear solutions

- Carbon capture and storage
- Solid carbon storage

While there is a significant potential to scale sustainable sources of primary carbon, strategic usage of abated fossil and carbon removals will be necessary

30+ emerging technologies were explored that shape the way carbon is sourced, used and managed at end of life

Carbon source and destination for the Energy and Materials Sectors, today – Gt C



Bioresources

- Biomass fermentation
- Precision fermentation
- Cultivated meat
- Advanced catalysts
- Micro-algae
- Macro-algae
- Energy cane

Electrification and H_2

- High temperature industrial heat
- Molten oxide electrolysis (steel)
- Electrowinning (steel)
- Solid-state/battery advancements
- Sodium batteries
- Micro-nuclear reactors
- Geological hydrogen
- *Electrolyser and BOP optimization*

Material recycling

- Mechanical recycling
- Reuse
- Depolymerization
- Gasification
- Pyrolysis

Carbon utilisation

- Electrochem reduction
- Hydrogenation
- Biocatalysis
- Reverse-Water-Gas-Shift

Carbon capture

- DACCS
- Ocean based CDR
- Point source calcium looping
- Point source AFC
- *Point source Liquid/ solid absorbents*

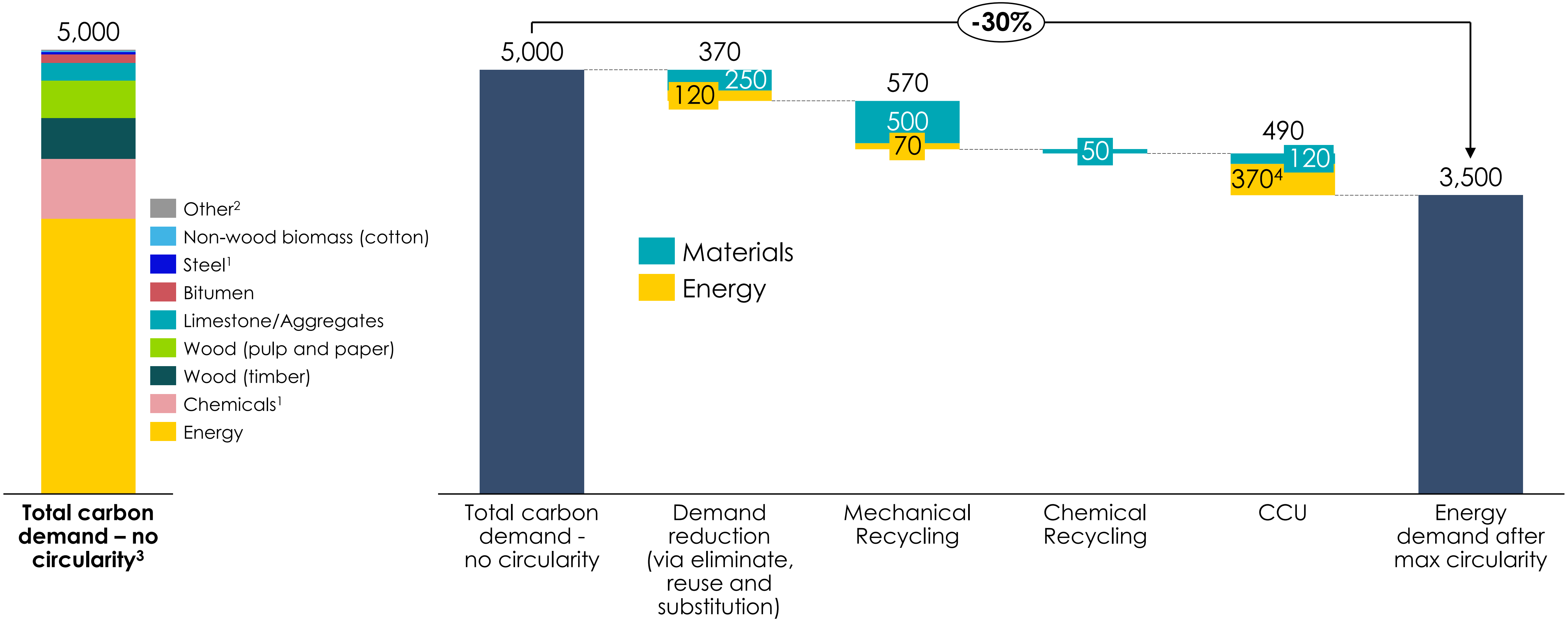
End-of-life

- Advanced Landfill
- CO_2-to-stone
- *Depleted O&G reservoirs*
- *Saline aquifers*

Maximum circularity of plastics and captured carbon can reduce primary carbon demand in 2050 by 30%

Carbon Demand Across the Energy and Material Sectors, 2050

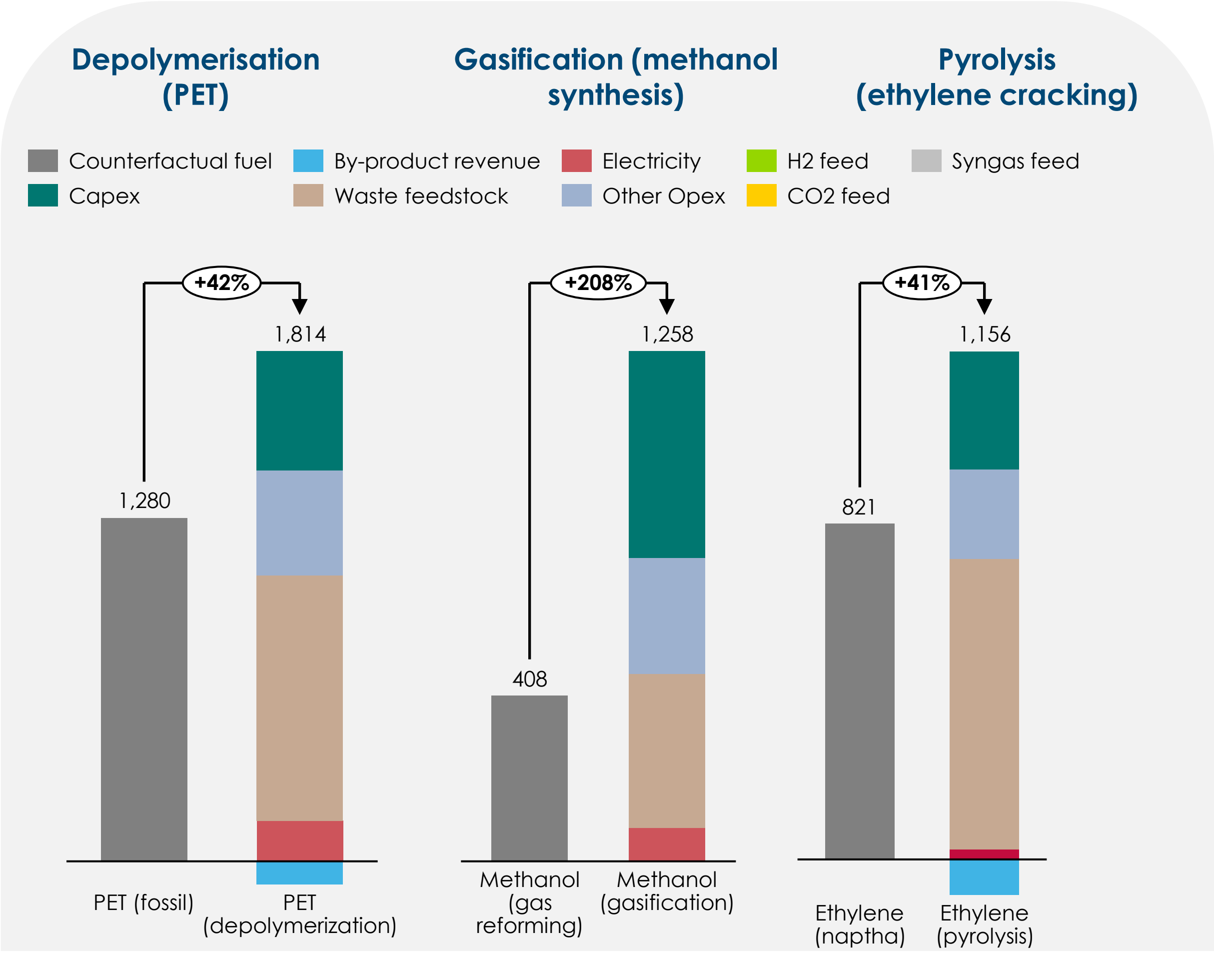
Million tons of carbon (C)



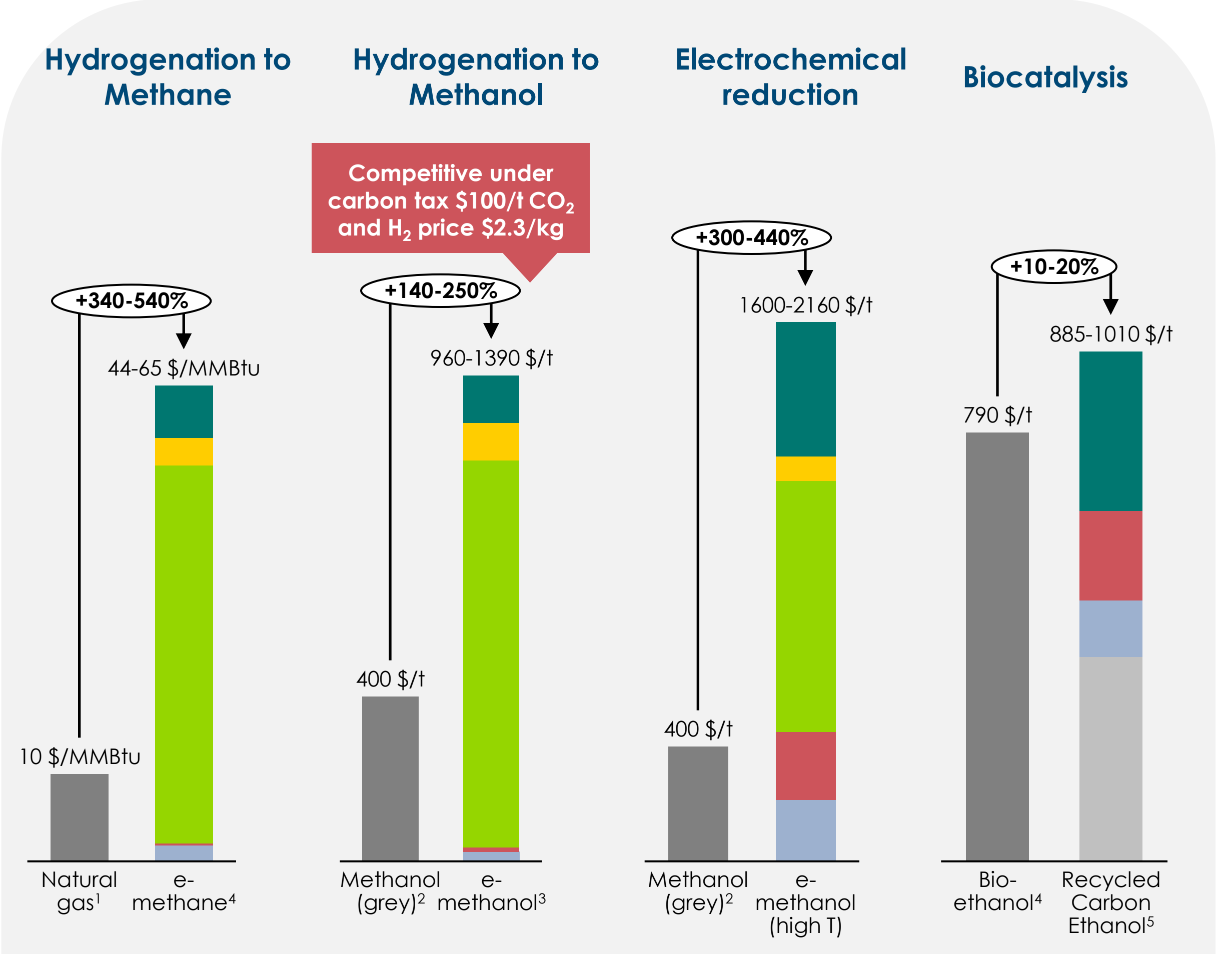
Notes: 1) Chemicals and steel include the feedstock from the energy system that has remained in material, i.e. plastic, in order to show the circularity levers. 2) Other includes carbon ash, biochar, carbon fibre, charcoal based on range in Systemiq reports. 3) Total carbon demand is shown without applying the circularity levers of ACF. 4) EOR is not reducing the carbon demand. Sources: Energy: Systemiq analysis (2025), based on Fossil Fuels in Transition (ETC, 2023); Chemicals: Planet Positive Chemicals Report (Systemiq, 2022, BAU Net-Zero scenario), and Systemiq (2024) Plastic Treaty Futures.; Biomass: ETC Bioresources report (2021); Steel: MPP STS (2022); Cotton, Bitumen and Soda Ash: Systemiq analysis (2025)

However, the business case is challenging for chemical recycling and carbon utilisation technologies

Chemical recycling and thermo-conversion
Levelised cost of production $/tonne (2025)



Carbon utilisation technologies
Levelised cost of production $/tonne (2025)



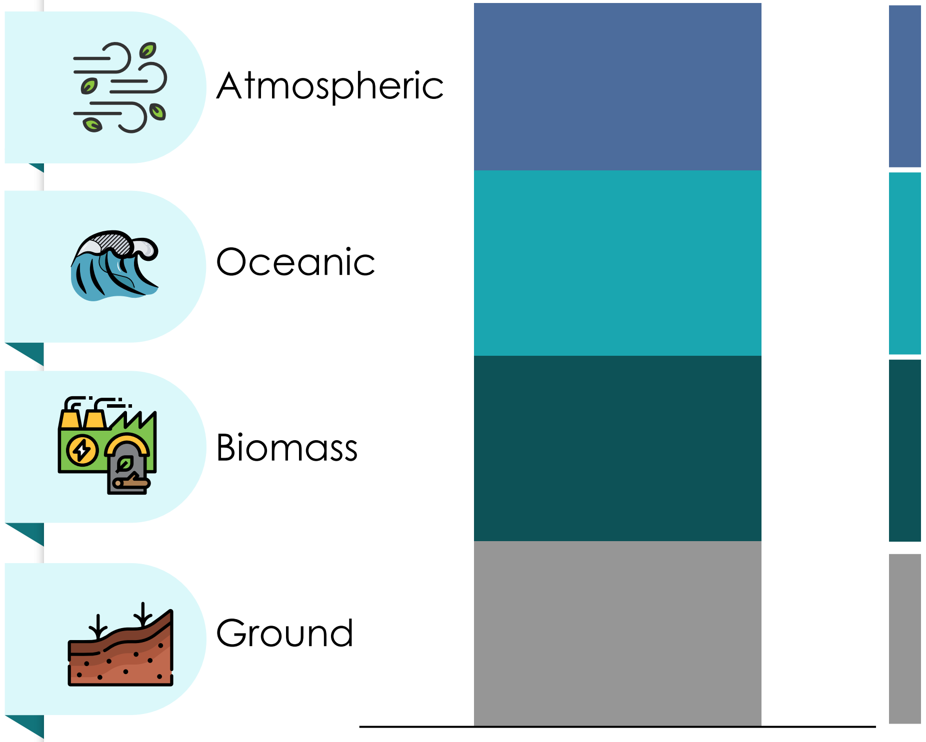
Competitive under carbon tax $100/t CO_2 and H_2 price $2.3/kg

Sources/Notes: 1) Ten-year historical mean of EU Natural Gas TTF. 2) 20-year historical mean (Methanex). 3) EU PtX modelling (MPP, 2024). 4) Conventional ethanol from corn (IRENA). 5) Capex from LanzaTech (EIC presentation, 2022; IEA Bioenergy, 2020); Depolymerisation estimation is based on published data: Singh et al. (2021). Gasification and pyrolysis based on BEIS, NREL and Systemiq PCC model.

Sustainable primary carbon is constrained (biomass), or still emerging (DAC, ocean-based capture)

Sources of primary carbon supply

Illustrative



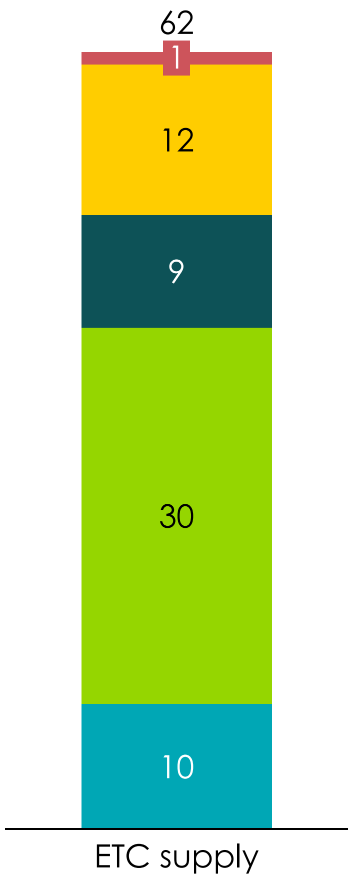
Status

- DAC technologies still emerging and **expensive at 480 $/tonne**[1] projected for 2030.
- Ocean-based capture **still at TRL 6**, with only small numbers of plant at pilot[2]
- Sustainable biomass[3] that does not encroach on food production and nature **limited to 40-60EJ**[4]
- Carbon capture required to allow for fossil carbon to be sustainable, but **does not address upstream emissions**

Notes/sources: 1) Revised ETC projections (2025) 2) Prince Aleta (2024) Direct ocean capture: the emergence of electrochemical processes for oceanic carbon removal 3) The term 'sustainable biomass' is used to describe organic material that is renewable, has a lifecycle carbon footprint equal or close to zero (including considerations for the opportunity cost of land), and for which the cultivation and harvesting practices used are mindful of ecological considerations such as biodiversity and health of the land. 4) SYSTEMIQ analysis for ETC (2021).

Biomass: potential upside to availability from biotech and use of degraded land for crops, if land-use if governed appropriately

Biomass supply potential, EJ primary biomass



Every additional hectare for bioenergy **competes with food production or ecosystem restoration**

⬇

Deployment must stay within ecological and food security limits

Technological advances that could extend sustainable potential

Agricultural innovation
Improvements in yields and the growth of alternative proteins could reduce land pressure, freeing-up land for biomass supply.

Aquatic biomass
Macro- and microalgae could provide low-land, low-carbon feedstocks

Residue utilization
Better harvesting and processing of residues could boost sustainable biomass use without harming soil health or carbon stocks.

Marginal land management
Degraded land use approaches could deliver additional biomass

Indicative measures to manage degraded land-use for biomass

Measures

1. Eligibility baseline & definition
2. Geo-registration & continuous satellite MRV[3]
3. Digital chain of custody & traceability
4. Restoration review & performance linked incentives
5. Enforcement, exclusions & transparency

Notes/sources: 1) From total unprocessed residues, 70% are left on ground and a recoverability of ~50% is assumed. Production from 2023 is taken and extrapolated to 2050 using the same CAGR for the 2003 – 2023 period. 2) 0.9 CAGR taken from 2019 to 2050 plus an additional 12% increase by 2050 due to technological advancements yields a total of 40% increased productivity. This frees up 640 million ha, which is split in the same way as freed land from Alternative Proteins or Macroalgae, yielding additional 30 EJ
Sources: Systemiq Analysis (2025) using FAO data, ETC analysis; ETC (2021), Bioresources Within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible.

Full circularity cannot be achieved; therefore linear end-of-life solutions, such as CCS and landfill to waste are being advanced

Emerging point-source capture technologies

Calcium looping: Captures CO_2 using a looping cycle of limestone-based reactions

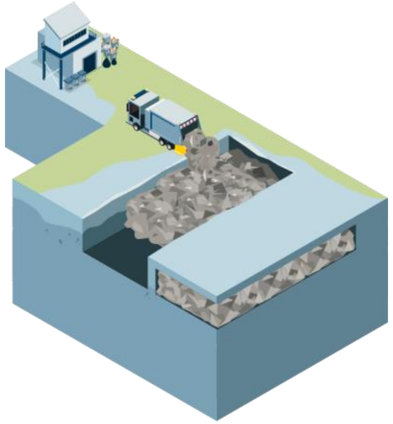
Suitable for cement:
High tolerance in impurities and integration with existing infrastructure[1]

Process modification: Captures CO_2 and utilizes it in the power production process via Allam-Fetvedt Cycle

Suitable for power: Enables 99% capture rate and fully integrates CO_2 capture within its core thermodynamic process

They can both be economically viable in 2030 with carbon price of 90 $/tCO_2$

Advanced landfilling technology



Pre-landfill material recovery and biological treatment (MRBT)

Waste is stabilised via aerobic processing (e.g. composting) to reduce methane-generating potential before landfilling.[3]

- Advanced landfill **reduces emissions from MSW by 90%** compared to managed landfill, and it could be implemented at a **marginal additional cost** of ~$30/tWaste
- It is almost as effective as incineration + CCS but can be more affordable with higher TRL

Notes/sources: MRBT = Material Recovery and Biological Treatment. MSW managed to advanced landfill abated 1,9 tonnes for incremental $30/t waste. Incineration + CCS abates 1tonne for incremental $130/t waste. This results in cost of abatemement equal to $16 per tonne for advanced landfill and $130 per tonne for incineration + CCS.
1) Arias et al. (2024) 2) FutureBridge (2022) Allam- Fetvedt Cycle 3) "Reducing waste management's contribution to climate change" (Zero Waste Europe, 2024).

Emerging-tech innovation is required to fill the gap

Promising but early-stage technologies

Many of the most impactful solutions remain in early stages of development and deployment,

	TRL
MOE/Electrowinning	5
o-CDR	6
Cultivated meat	4
Mineralisation	6

Barriers to scaling

Barriers across technical, environmental, economic, and policy dimensions. Such as:

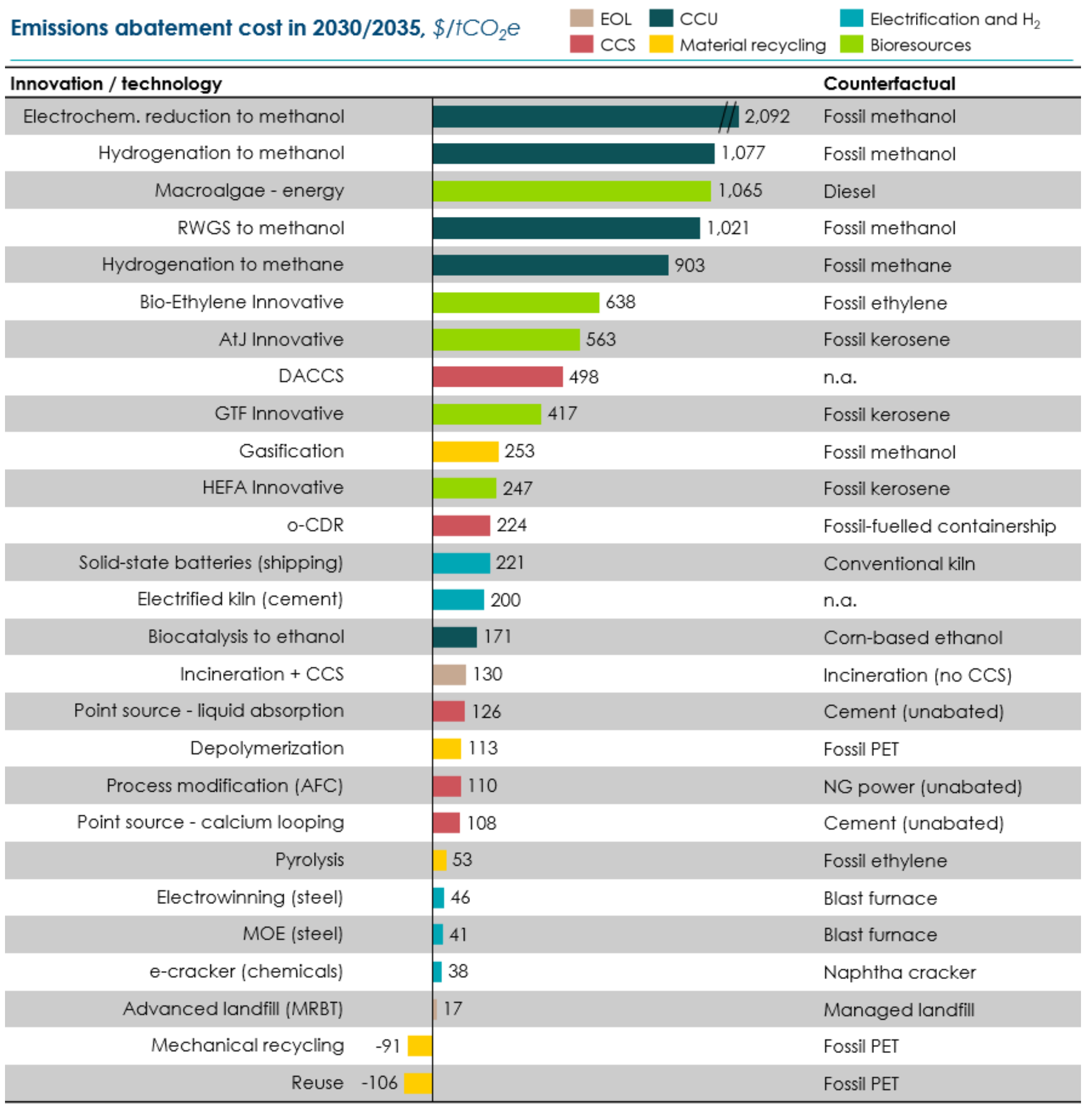
- Capacity and scalability constraints
- High costs and immature supply chains
- Environmental and safety concerns
- Need for supportive and adaptive policy frameworks

Building diverse and adaptive portfolios

No single solution can address the full challenge. The optimal mix will depend on geography, sector, and time horizon.

- Balance cost, readiness, and resource efficiency
- Stay responsive to evolving constraints and opportunities
- Combine near-term deployment of available options with investment in long-term innovation

Technologies with low energy requirements, like reuse and recycling, currently have the lowest cost of abatement.


Emissions abatement cost in 2030/2035, *$/tCO$_2$e*

Key messages

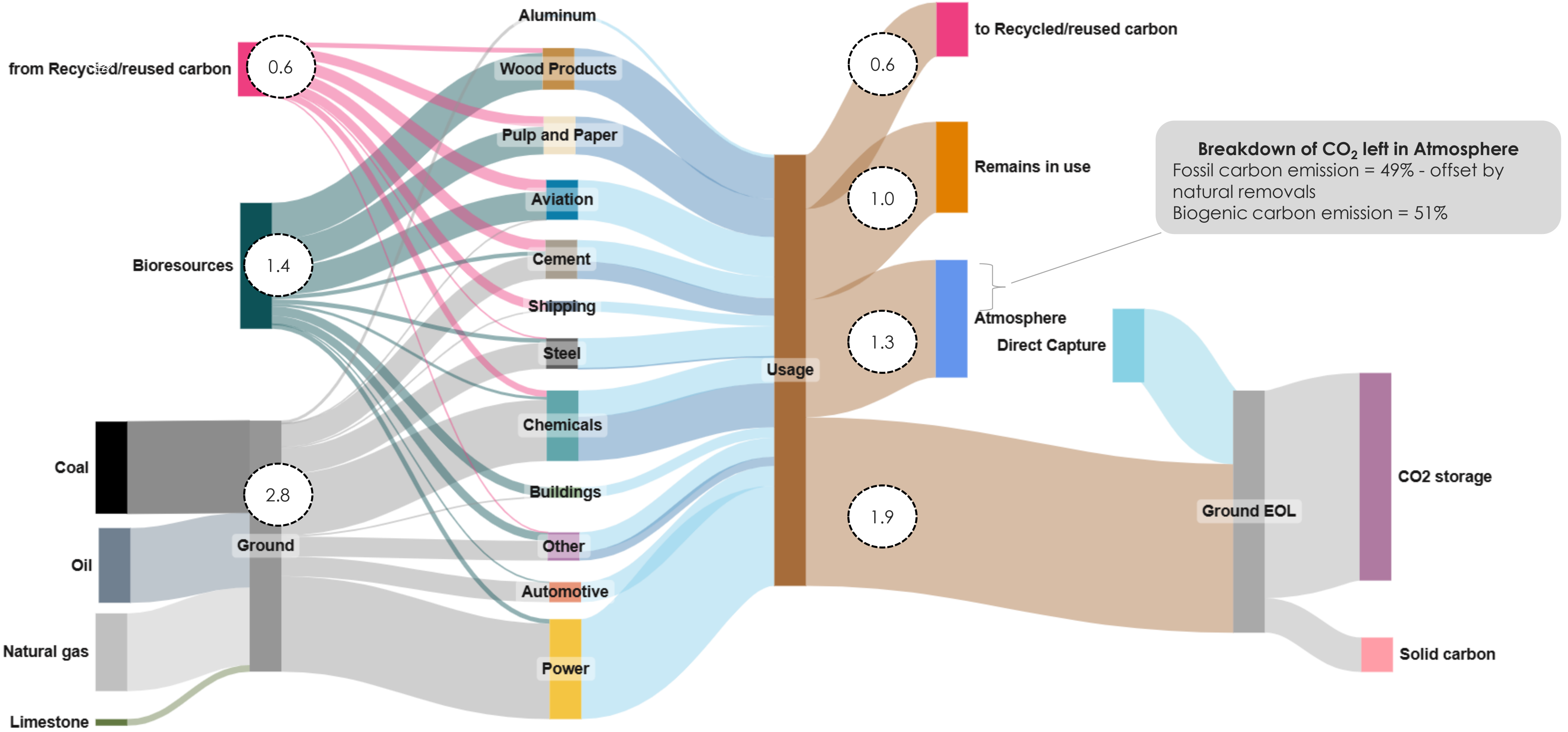
1. Reuse and recycling has negative cost of abatement
2. Direct electrification technologies(electro winning, MOE, and e-cracking) are low-cost options if they progress to a higher TRL level
3. CCS is economic, but DACCS projections for 2030 are still very expensive
4. CCU is very expensive and cannot play a major role yet

DAC, gasification and CCU **are energy intensive**.
Their competitiveness depends on cost of clean electricity

Hence, in the long term their role might be more significant than the chart suggest

Carbon supply is reduced 60% compared to today and 57% of remainder still derives from fossil fuels extracted from the ground

Carbon source and destination for the Energy and Materials Sectors, ACF scenario 2050 – Gt C



Breakdown of CO_2 left in Atmosphere
Fossil carbon emission = 49% - offset by natural removals
Biogenic carbon emission = 51%

Three more scenarios are developed to cover the whole spectrum of possible pathways

Minimum Primary Carbon

Combines ambitious electrification with strong growth in recycling

- Fossil supply corresponds to 33% of carbon supply
- Achieving this requires abundant low-cost green power and large-scale recycling systems

Results in:

Reduced dependence on removals, with storage needs less than half those in Base case

Minimise Fossil Carbon

Shows the scale of bioenergy needed if large-scale carbon storage was infeasible

- Fossil supply accounts for only 17% of carbon supply
- This scenario depends on major bioresource expansion and careful land-use management.

Elimination of DAC and minimal storage needs, as bioenergy can achieve near carbon-neutrality without CCS

Fossil Fuel in Perpetuity

Illustrates the storage needs if fossil fuel use stayed higher than in the Base Case

- Fossil supply corresponds to 70% of carbon supply
- Still fossil supply falls to 1/3 of today’s level

Increased end-of-life management needs ~10Gt CO_2 must be stored, exceeding both IEA and ETC net-zero scenarios.

Key messages of Carbon Molecules report for COP30

Key messages

01. **Carbon demand will persist** even in a decarbonized world. Around **~3-5Gt** of carbon will be needed across energy and materials sectors. It must be actively planned for and managed.

02. **Electrification technologies and re-use models are most effective for reducing carbon demand** further, and offer low abatement costs relative to sourcing and other circularity technologies

03. **Around a third of carbon used could be circular, but we need intervention to realise this,** as the business case is challenging across multiple recycling and carbon utilisation technologies

04. **Sustainable primary carbon is constrained (biomass), or emerging (DAC, ocean-based), while fossil is abundant.** While there is potential to scale sustainable sources of primary carbon, strategic usage of abated fossil will be necessary to deliver a timely transition.

05. **Linear end-of-life solutions, such as CCS and landfill to waste are being advanced,** and will play a role, especially where circularity solutions are challenged. These technologies would provide the necessary backstops, and pragmatic solutions especially in the near term.

06. **Some areas of the carbon system have commercially viable abatement solutions, but key gaps persist in the technology landscape**. Accelerating and de-risking emerging technologies is critical to build a complete, scalable carbon ecosystem.

Next steps of the ETC's *Carbon Molecules work*

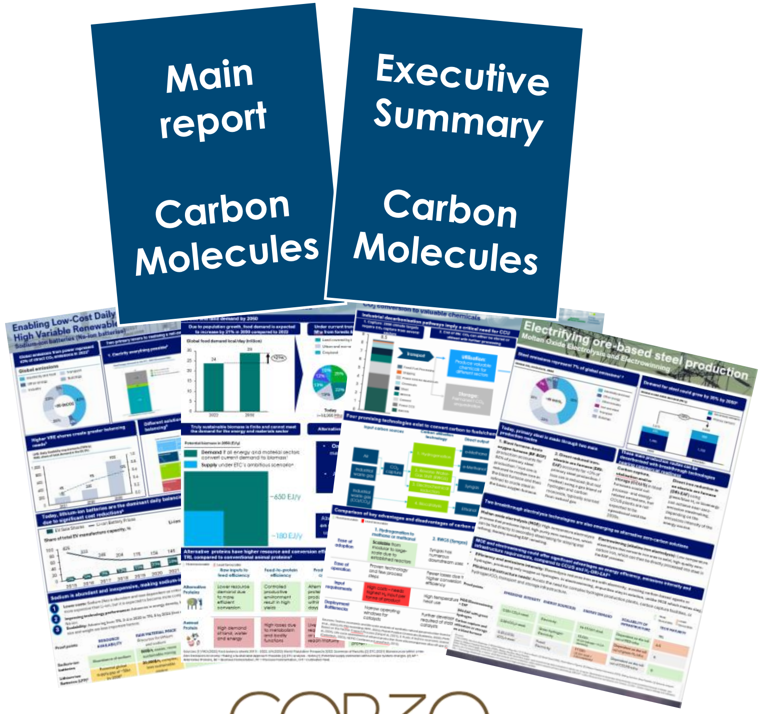
①

Media outreach and digital

- **ES launch on Nov 5th; full report publication on Nov 10th/11th** *(COP30 thematic days on bioenergy and circular economy)*
- **Press release distribution** to media contacts, with regional focus on Brazil
- **Broadcast media campaign around COP30**
- **Targeted podcast campaign**
- **Social media campaign and amplification**

②

Engagement around COP & innovation deep dives



COP30
BRASIL
AMAZÔNIA
BELÉM 2025

③

Using report as foundation of new analyses

Report serves as analytical building block for multiple strategic priorities. I.e.:

- Shifting bioenergy towards a sustainable transition
- Restatement of necessity of hydrogen
- Repurposing existing refining infrastructure for clean energy scale-up
- Country level strategies for sustainable and circular carbon
- Accelerating innovation conditions for promising innovations (i.e. beyond TRL 4-6)
- AI in carbon