Energy
Transitions
Commission

Power systems transformation & role of ‘firm’ power: latest ETC insights

ETC Representatives meeting

18 September 2025

Agenda

- **Power Systems Transformation report launch & key messages**
- Next steps: Nuclear & Geothermal

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

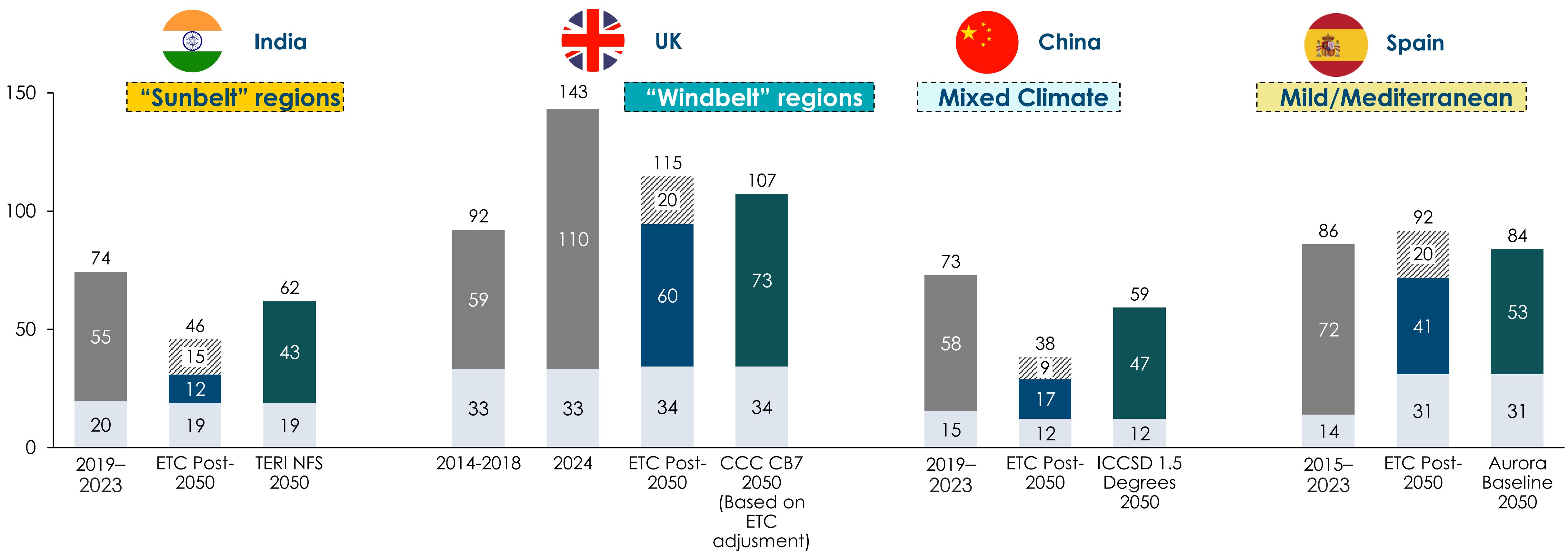
4. **Long-distance transmission from low-cost renewable regions can be a cost-effective source of flexibility where politically feasible**

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.

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

Total system costs (generation, balancing, and grids), recent vs post-2050
$/MWh (real 2024$)

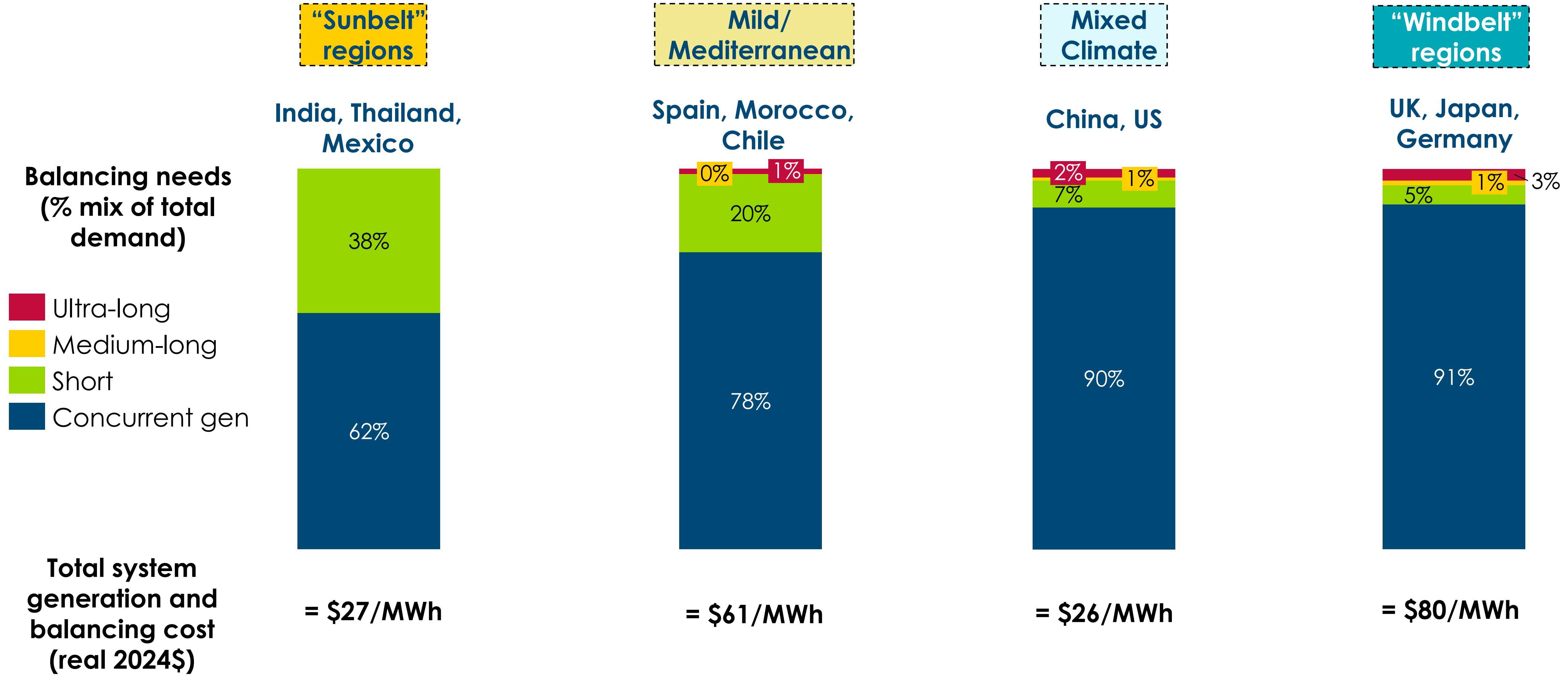
Average wholesale power prices
Cost of meeting balancing needs
Wind/solar
Dispatch model generation and balancing
T&D costs (ETC est.)



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*.

1 System balancing needs and costs differ in sunbelt vs. windbelt regions

Balancing needs and costs differ by region and resource type:

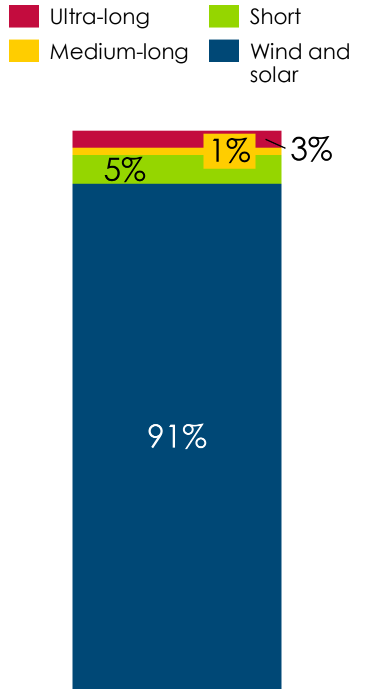
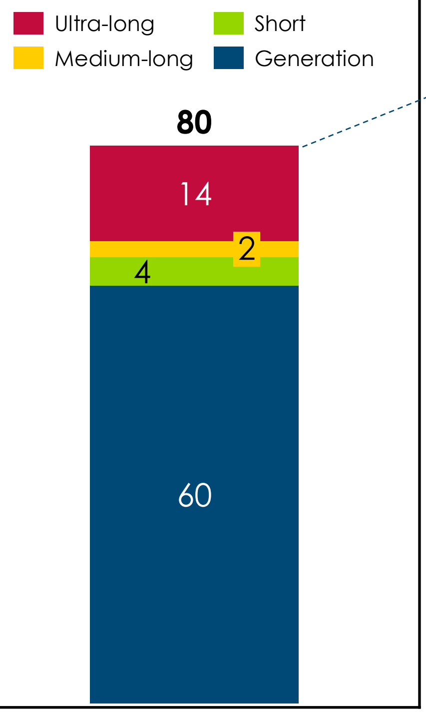


Source: Systemiq analysis for the ETC (2025)

2 Ultra-long duration balancing costs add significantly to wind dominated systems

Total system generation costs for a 2050 system, Northern Latitude

$/MWh (real 2024$)

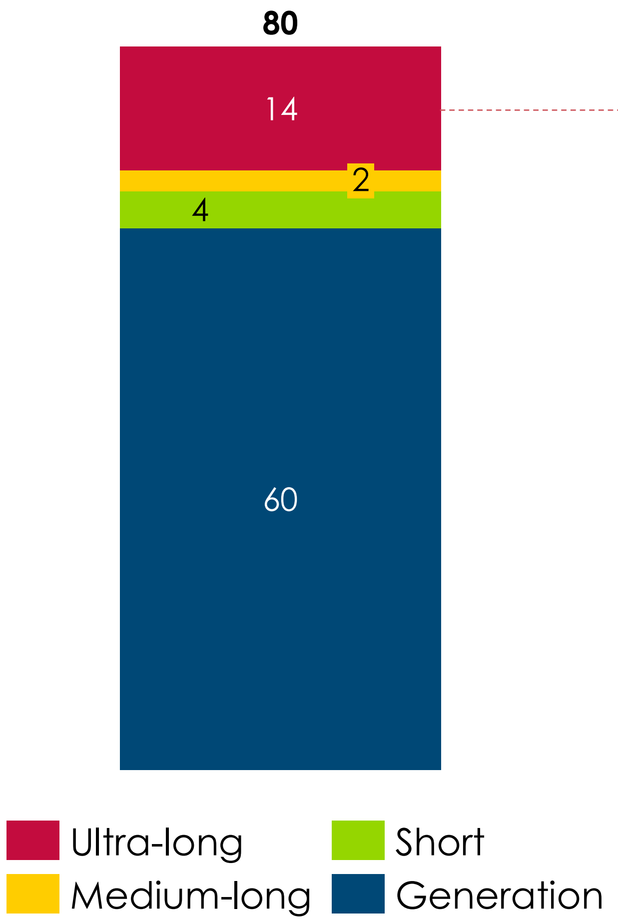
Scenario	Balancing variability (% mix of total demand)	Generation and storage deployment and costs	System generation cost ($/MWh, real 2024$)
Core scenario, UK		**Generation:** 778 TWh at **$45/MWh** **Short storage:** 26 TWh at **$80/MWh** **Medium-long:** 7 TWh at **$170/MWh** **Ultra-long:** 16 TWh at **$460/MWh**	

While ultra-long duration **only makes up 3%** of the balancing requirement in this archetype, **it makes a significant addition ($14/MWh) to final generation costs**

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 this report, with the input electricity cost for all storage technologies set to be the archetype's generation cost per MWh. Efficiency losses for storage technologies are included (assumed efficiencies are 90% for short, 60% for medium-long, 40% for ultra-long). Surplus generation arises from overbuild required to meet balancing needs and is included in both energy and cost calculations. 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.*

2 High-costs of ultra-long duration presents a challenge around the costs of a fully clean system in wind belt countries

System generation and balancing cost in wind belt countries, UK case study
($/MWh, real 2024$)



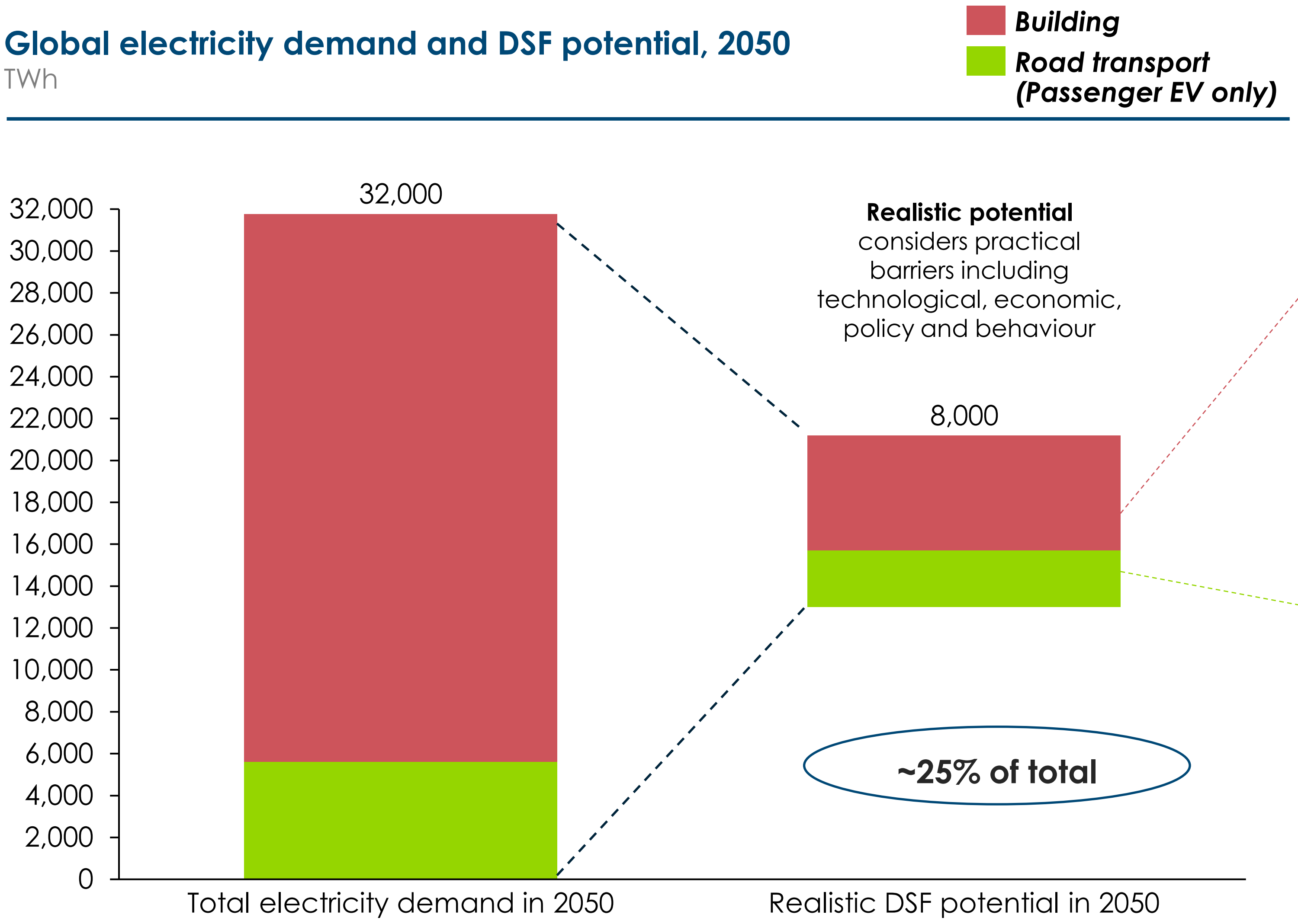
- Though ultra-long duration balancing contributes a small numbers of necessary hours (16 TWh), it **contributes to 18% of generation and balancing cost**s
- This raises the question of whether you accept higher total system costs for an 100% clean system

A more pragmatic approach would be to pursue a system that is 93-95% clean and use unabated gas, with offsets via carbon removals elsewhere in the system

~25% of building + passenger EV electricity demand in 2050 could be flexible

3

Global electricity demand and DSF potential, 2050
TWh



Buildings

- In our realistic scenario, 20% of building electricity demand could become flexible by 2050.
- Savings made by:
  - Heating and cooling, lighting and appliance flexibility

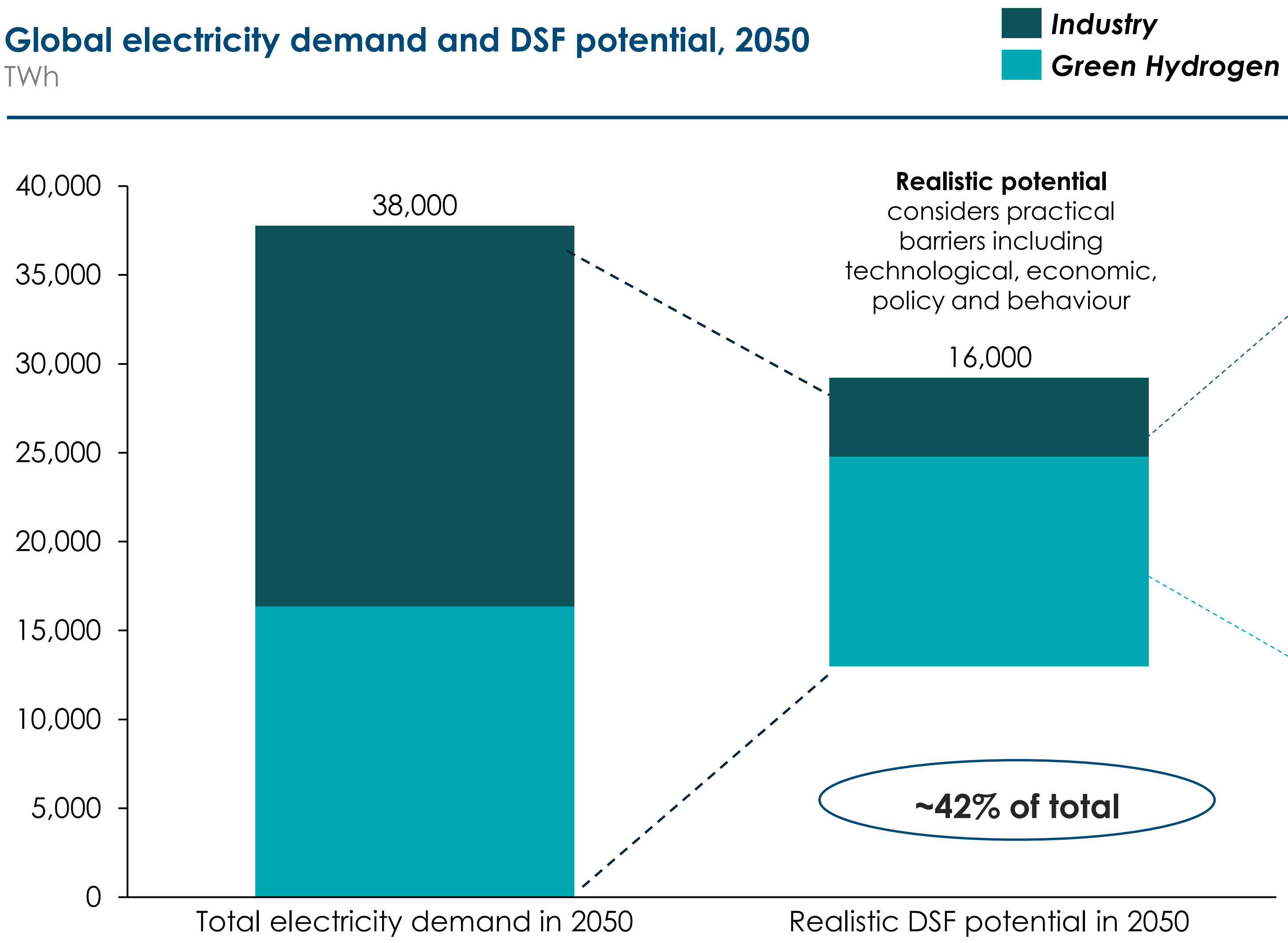
Electric Vehicles

- By 2050, ~50% of demand could be flexible with smart charging and V2G tech.
- Enabled by:
  - Smart charging solutions
  - Vehicle-2-grid technology, but has less potential as more costly

Note: In our DSF Briefing Note, we look at two scenarios "realistic" and "theoretical" to consider the ideal possibilities and what can be realistically achievable. In this analysis, we focus on the realistic potential of DSF, as it provides a more grounded and actionable view of what can be delivered given today's technological, policy, economic and behavioural constraints — and therefore offers a more reliable basis for system planning. Source: Systemiq analysis for the ETC; IEA (2024), *World Energy Outlook 2024;* RMI (2023), *Unlocking demand-side flexibility in China*; Macquarie (2020), *Flexibility of Hydrogen Electrolysers;* IEA (2024), *Global EV Outlook 2024;* World Electric Vehicle Journal (2019), *Flexibility of EV demand.*

3 ~40% of industry and green hydrogen demand in 2050 could be flexible

Global electricity demand and DSF potential, 2050
TWh

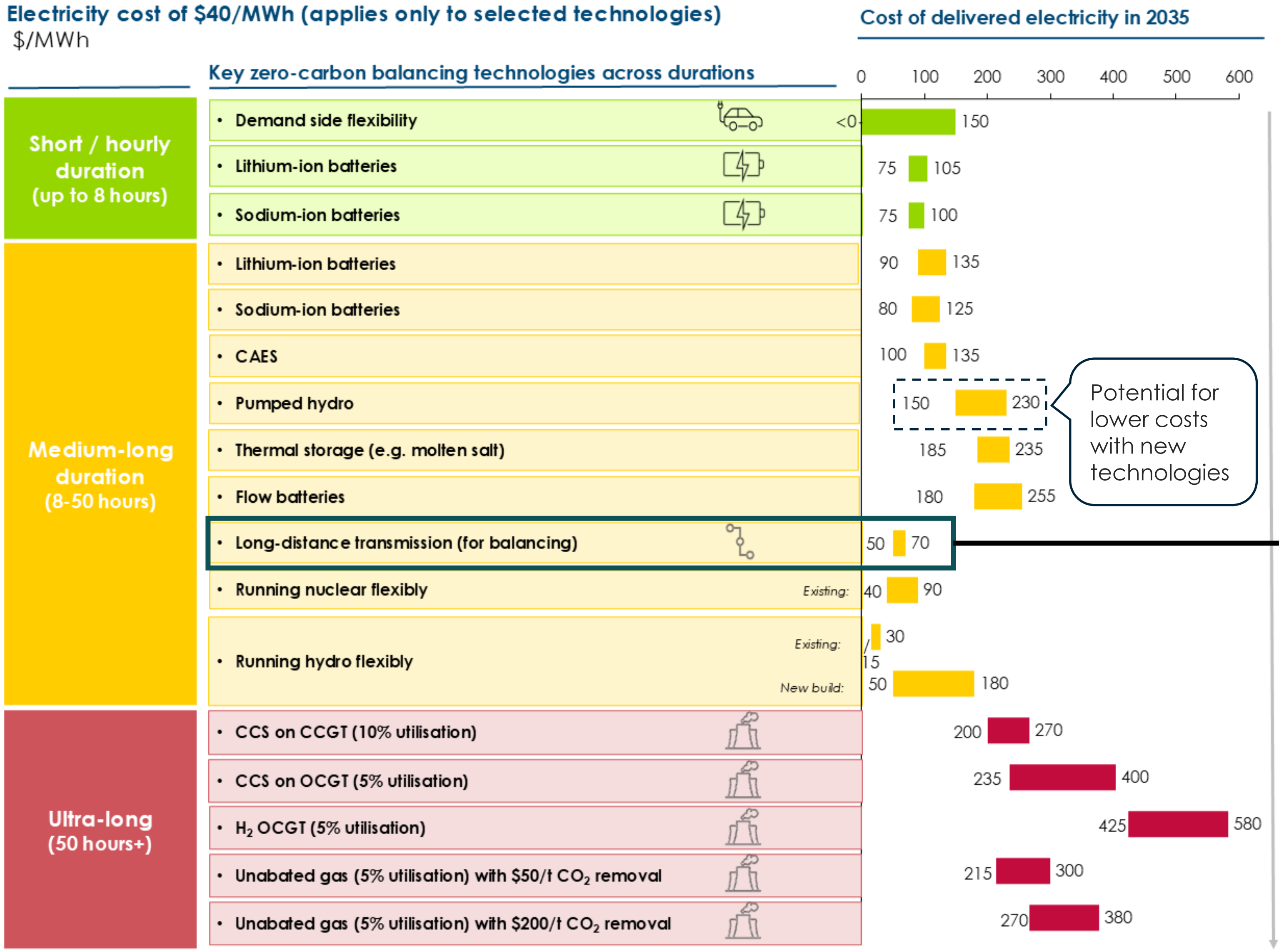


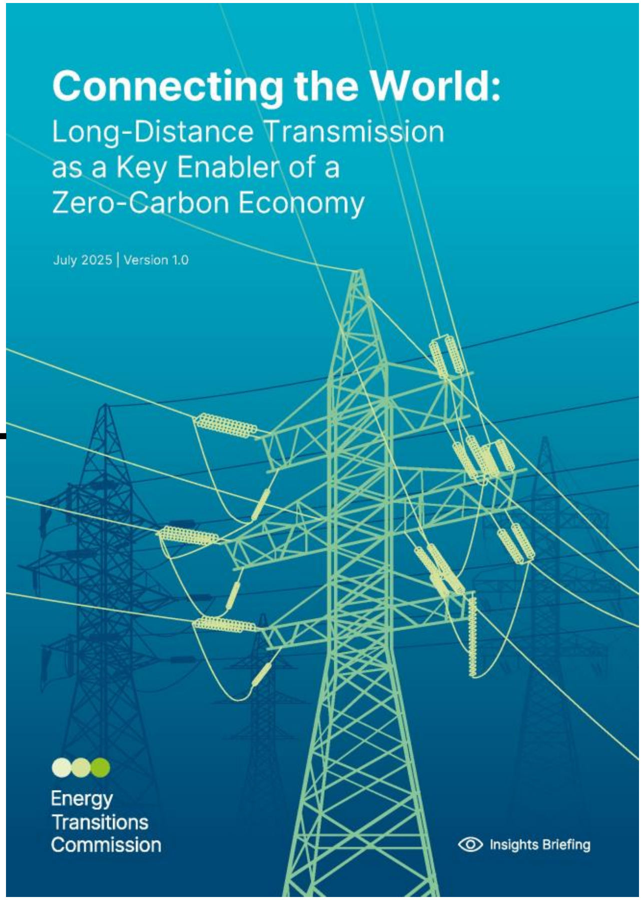
Industry
- In our realistic scenario, 20% of industrial demand could be flexible by 2050, largely driven by hydrogen production.
- Savings made by:
    - Electrified industrial heat
    - Batch processes
    - Data centres shifting energy use

Green Hydrogen
- 75% of potential industrial flexibility by enabling green hydrogen production to be flexible.
- This is due to 80–90% of hydrogen electrolysis load being flexible.
- Enabled by:
    - Ramping electrolysers up or down based on grid needs.

Note: In our DSF Briefing Note, we look at two scenarios "realistic' and "theoretical" to consider the ideal possibilities and what can be realistically achievable. In this analysis, we focus on the realistic potential of DSF, as it provides a more grounded and actionable view of what can be delivered given today's technological, policy, economic and behavioural constraints — and therefore offers a more reliable basis for system planning. Source: Systemiq analysis for the ETC; IEA (2024), *World Energy Outlook 2024;* RMI (2023), *Unlocking demand-side flexibility in China*; Macquarie (2020), *Flexibility of Hydrogen Electrolysers;* IEA (2024), *Global EV Outlook 2024;* World Electric Vehicle Journal (2019), *Flexibility of EV demand.*

4 Long-distance interconnection, batteries and pumped hydro are a very cost-effective flexibility source at longer durations, if feasible

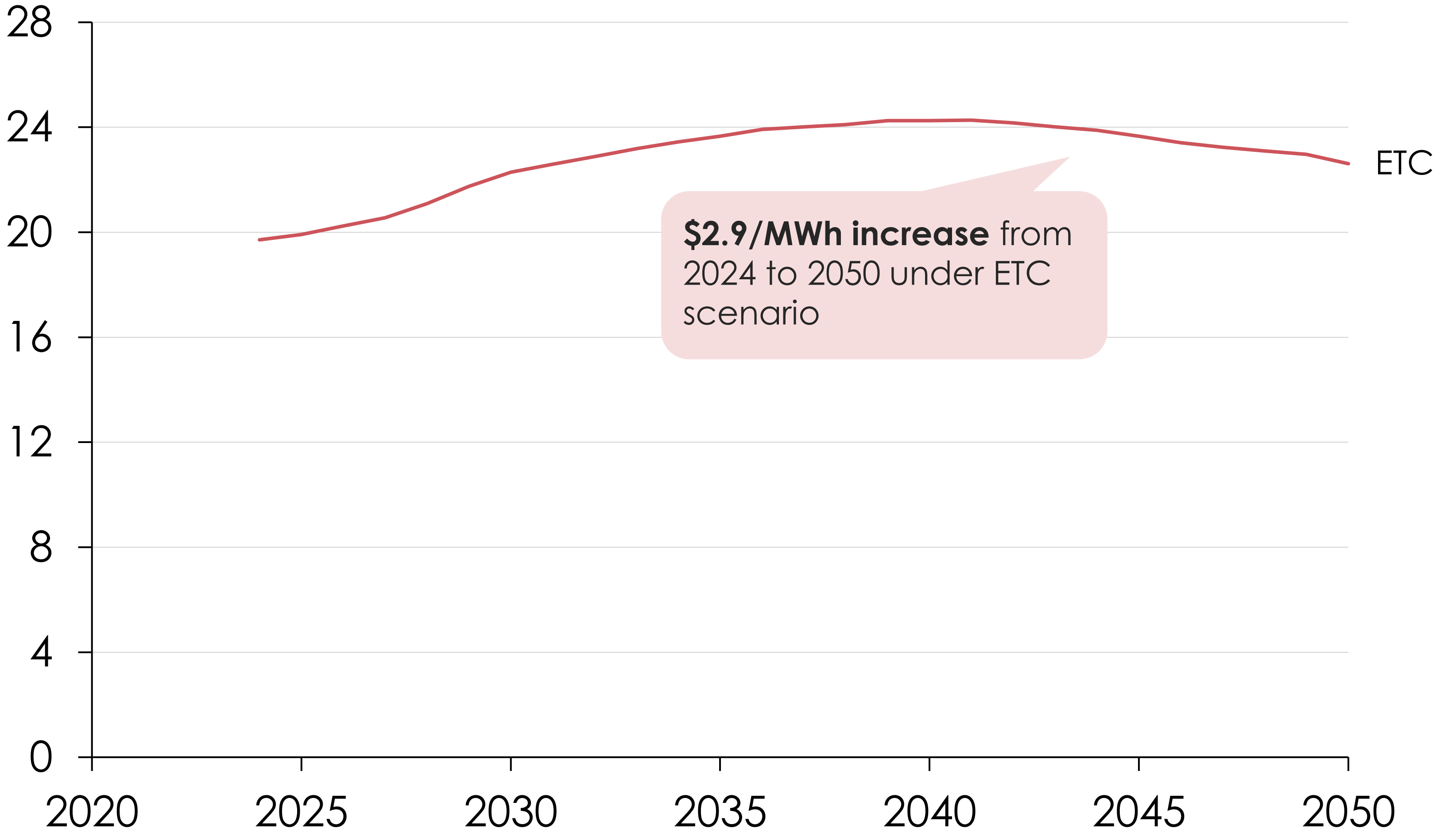




5 Grids will need to expand, optimisation is key: costs per MWh will only increase slightly to 2050, but can be reduced if we maximise flexibility

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

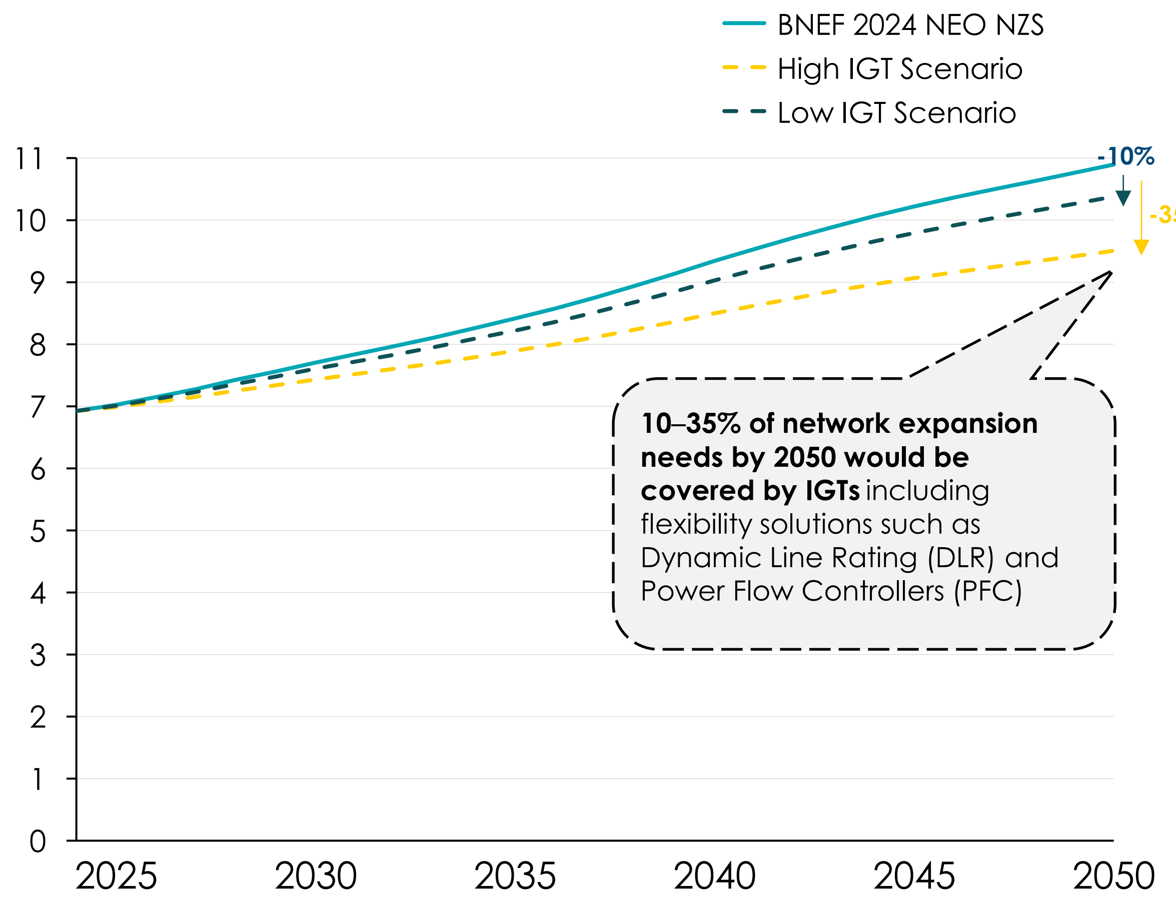


- **Grid capacity must grow by at least 50% by 2050** to meet electrification needs, even with all efficiency and optimisation measures in place
- The **initial increase in cost per unit of demand** is due to the upfront investments needed to build and reinforce the grid infrastructure in line with rising 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.

5 Innovative Grid Technologies could significantly reduce grid build & CAPEX

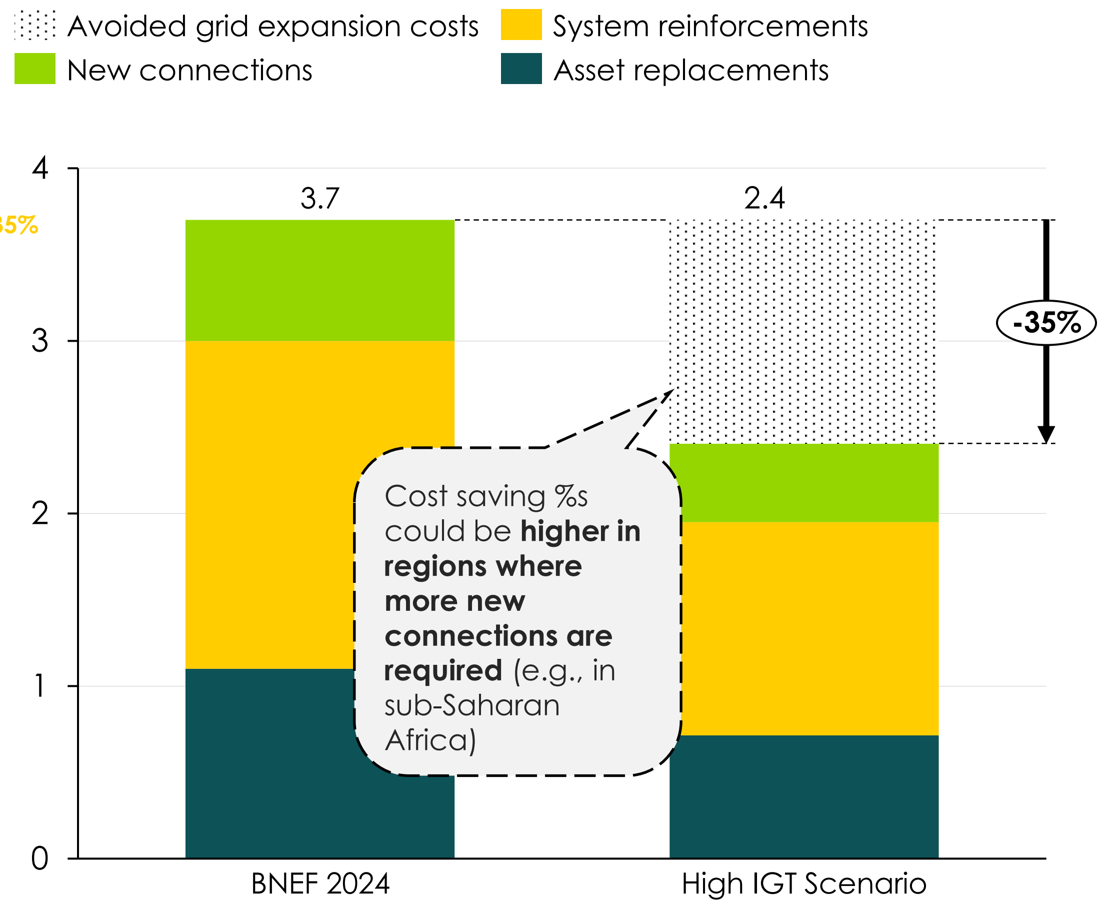
Benefits of IGTs compared to network expansion needs

Million km, Europe, 2024–2050



Cumulative investment in new power grid system, Europe

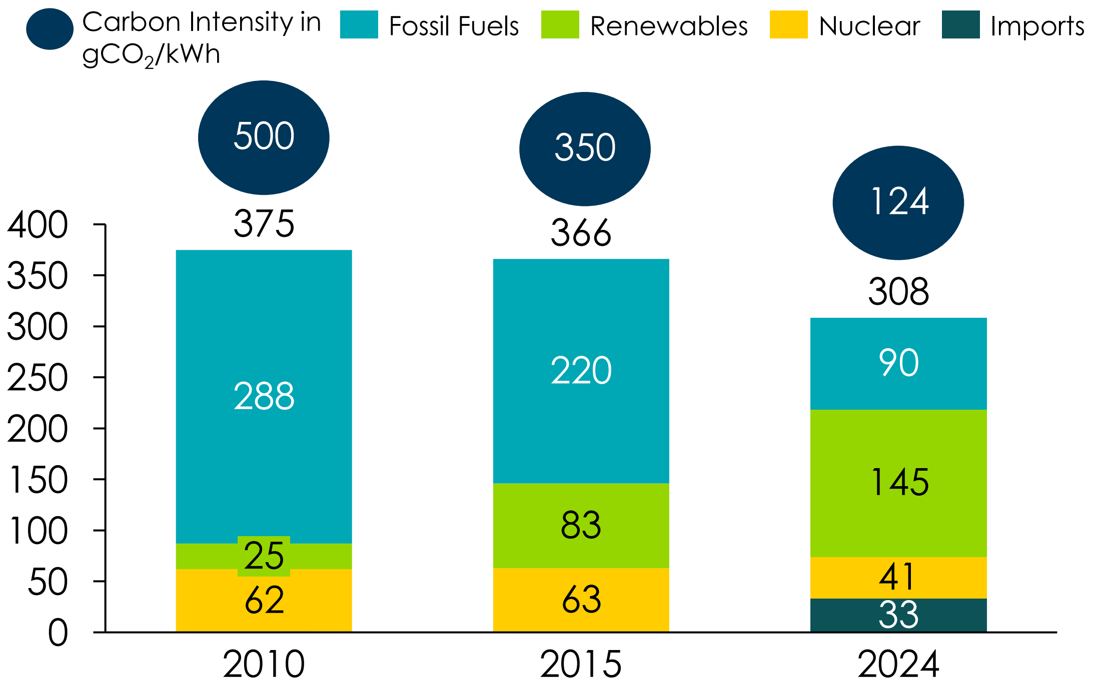
$ trillion (real 2024$), 2024–2050, based on BNEF



5 Balancing electrification and decarbonisation: the risks of a mismatch

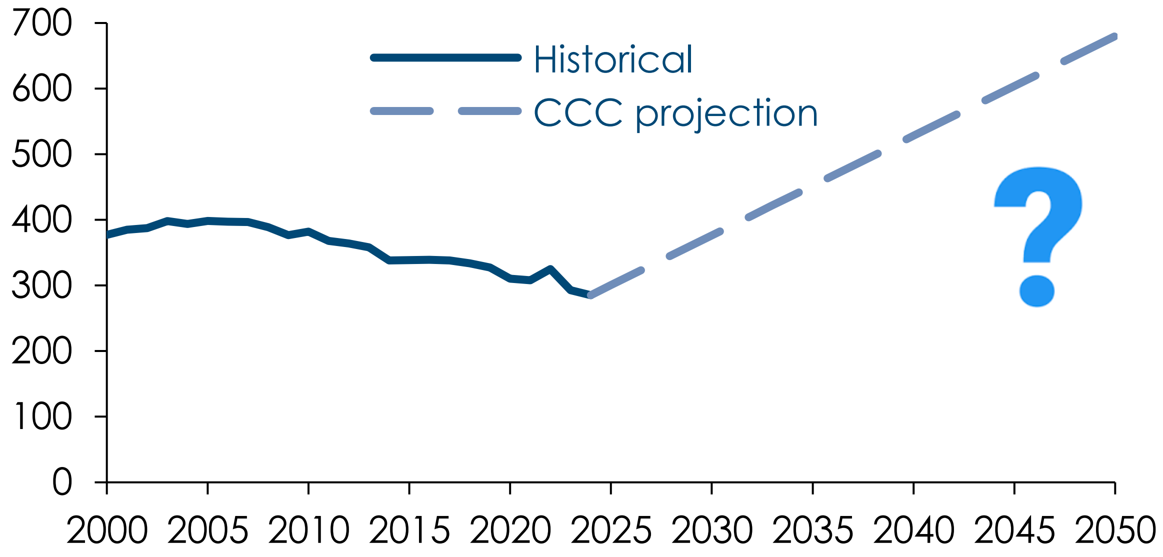
Developed Countries e.g. UK

UK electricity generation and average emissions intensity, 2010–2024
TWh



- **Decarbonisation occurring rapidly** in countries like the UK from 500g CO_2 per kWh in 2010 to 125g in 2025…

UK changes in electricity generation, 2000-2050
TWh



- …However, **electricity demand is stagnant** – from ~380 TWh in 2010 to ~300 TWh in 2024
- **CCC forecast UK demand to grow to ~680 TWh** by 2050, but will this really happen?

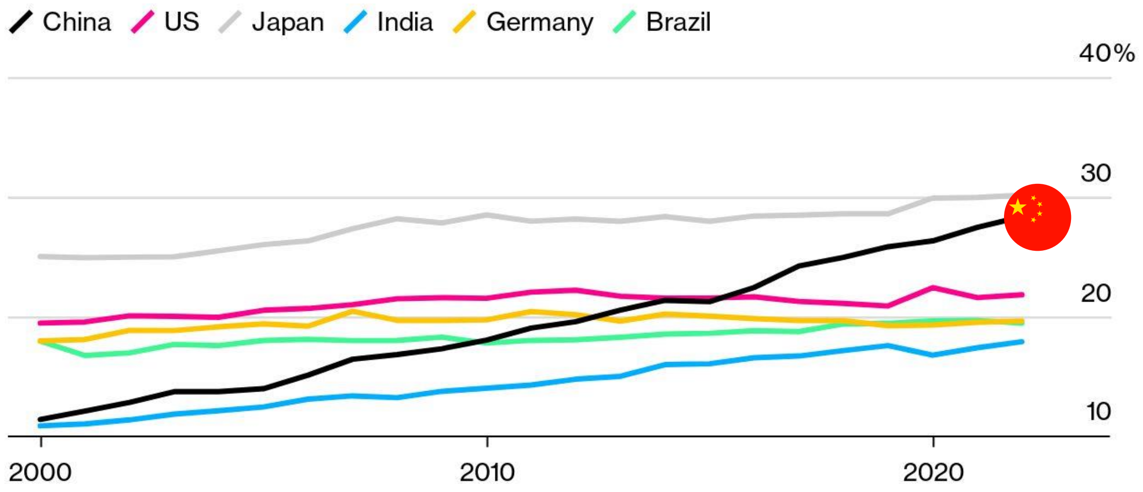
The risk – grid costs spread over fewer units, rising unit costs risk disincentivising electrification

Notes: CCC balanced pathway forecast only includes direct electrification, line extrapolated from 2050 value. Source: Carbon Brief (2024), Analysis: UK emissions in 2023 fell to lowest level since 1879; Ember (2025) Electricity data explorer; CCC (2025) Seventh Carbon Budget

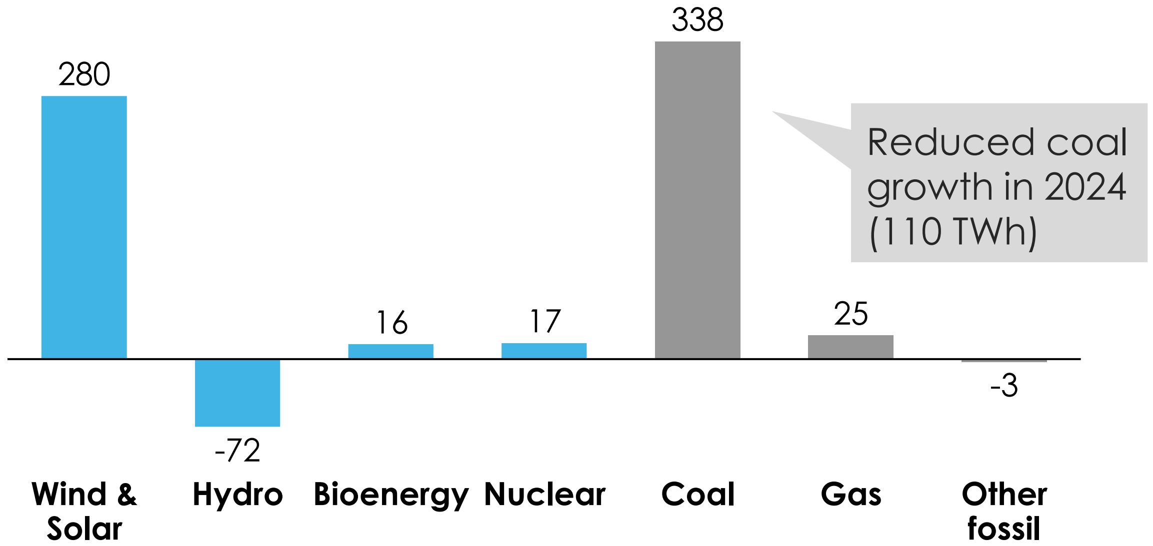
5 Balancing electrification and decarbonisation: the risks of a mismatch

Developing Countries e.g. China

Electricity's share of final energy consumption
%



China changes in electricity generation, 2023
TWh



- **Electrification rising** due to industrialisation and adaptation (e.g. rising AC use)

- But **supply is not yet decarbonised**, with China's power intensity remaining over 500g CO_2/kWh
- In recent years **additional generation from coal has outpaced** clean energy sources

The risk – growing demand locks in high emissions unless supply transition accelerates

Source: Ember (2023) 2023 Electricity Report

Six key enablers for power systems transformation

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).
- **Anticipatory funding** – shifting from short-term reactive investment to anticipatory, long-term whole-system planning.

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 and workforce

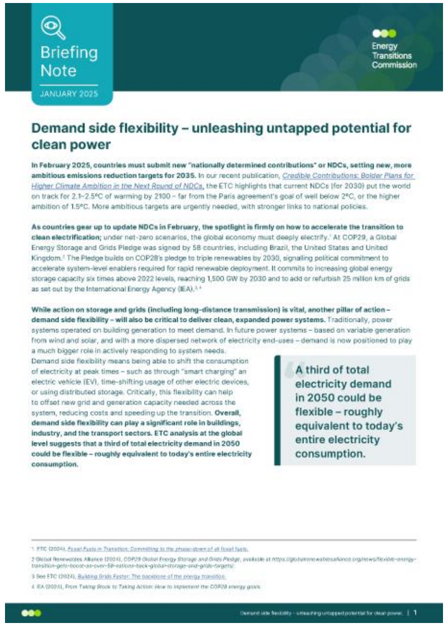
- Supply chain concerns
- Workforce education

Consumers

- Consumer engagement and trust-building

Demand Side Flexibility Campaign

February


Briefing Note

Energy Transitions Commission

JANUARY 2025

Demand side flexibility – unleashing untapped potential for clean power

In February 2025, countries must submit new "nationally determined contributions" or NDCs, setting new, more ambitious emissions reduction targets for 2035. In our recent publication, Credible Contributions: Bolder Plans for Higher Climate Ambition in the Next Round of NDCs, the ETC highlights that current NDCs (for 2030) put the world on track for 2.1–2.5°C of warming by 2100 – far from the Paris agreement's goal of well below 2°C, or the higher ambition of 1.5°C. More ambitious targets are urgently needed, with stronger links to national policies.

As countries gear up to update NDCs in February, the spotlight is firmly on how to accelerate the transition to clean electrification; under net-zero scenarios, the global economy must deeply electrify.[1] At COP29, a Global Energy Storage and Grids Pledge was signed by 58 countries, including Brazil, the United States and United Kingdom.[2] The Pledge builds on COP28's pledge to triple renewables by 2030, signaling political commitment to accelerate system-level enablers required for rapid renewable deployment. It commits to increasing global energy storage capacity six times above 2022 levels, reaching 1,500 GW by 2030 and to add or refurbish 25 million km of grids as set out by the International Energy Agency (IEA).[3,4]

While action on storage and grids (including long-distance transmission) is vital, another pillar of action – demand side flexibility – will also be critical to deliver clean, expanded power systems. Traditionally, power systems operated on building generation to meet demand. In future power systems – based on variable generation from wind and solar, and with a more dispersed network of electricity end-uses – demand is now positioned to play a much bigger role in actively responding to system needs.

Demand side flexibility means being able to shift the consumption of electricity at peak times – such as through "smart charging" an electric vehicle (EV), time-shifting usage of other electric devices, or using distributed storage. Critically, this flexibility can help to offset new grid and generation capacity needed across the system, reducing costs and speeding up the transition. **Overall, demand side flexibility can play a significant role in buildings, industry, and the transport sectors. ETC analysis at the global level suggests that a third of total electricity demand in 2050 could be flexible – roughly equivalent to today's entire electricity consumption.**

> A third of total electricity demand in 2050 could be flexible – roughly equivalent to today's entire electricity consumption.

ETC highlights the critical role of demand side flexibility in delivering clean, expanded power systems as countries gear up to increase ambition of Nationally Determined Contributions (NDCs)

Short blog post on demand-side flexibility published ahead of the briefing note led to additional work and funding with Pool fund on International Energy (PIE) – European Climate Foundation.

Demand side flexibility: unleashing untapped potential alongside electricity grids and storage

The trajectory to net-zero relies on massive clean electrification: Electricity will grow from 20% of all energy used today to over 60% by 2050. The ETC's latest scenarios estimate at least a doubling of global electricity use by 2050, potentially reaching over 75,000 TWh compared to today's approximate 28,000 TWh.[1] **To achieve this in just 25 years, the power system must expand in scale and transform how electrons flow through the system.**

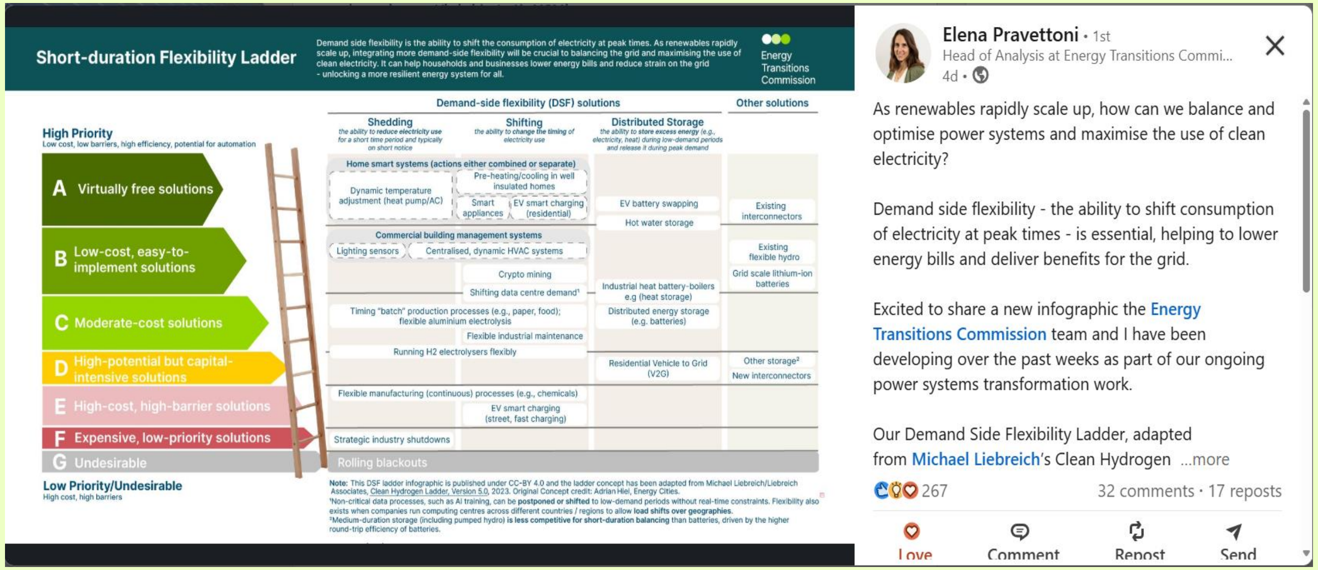
3 op-eds placed in relevant trade publications

BusinessGreen™

ENERGY VOICE
Leading the global energy conversation

NEW ENERGY WORLD
The magazine of the Energy Institute

Short-duration flexibility ladder drew over 70,000 impressions, 600 reactions, and 60 comments from the energy sector on social media



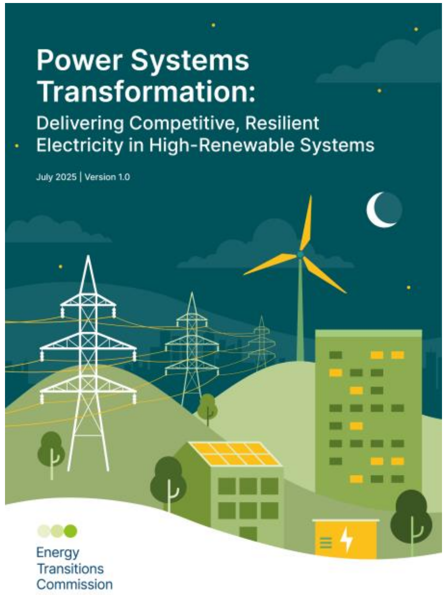
Michael Liebreich "This is great… to understand that there are smarter and dumber solutions, and to get the discussion focused."

Likes from across the world at senior levels, including:

- Head of UK Clean Power Taskforce
- Chair of UK Government's Energy Digitalisation Taskforce
- Executive Director of Australian Net Zero Commission

Power Systems Transformation Campaign: Pre-launch

June, Pre-launch



ETC underscores that 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, delivering system stability and round-the-clock electricity.

Spain and Portugal blackouts put grid resilience high on the news agenda. ETC commented as a "trusted" source and previewed the Power Systems work

Iberia mess places timely focus on grid resilience — Reuters

Europe's first grid crisis may not be its last — FT Financial Times

Massive blackout reignites culture war over the future of nuclear energy in Spain — El País

The great Iberian power cut need not spell disaster for renewables — The Economist

We briefed:

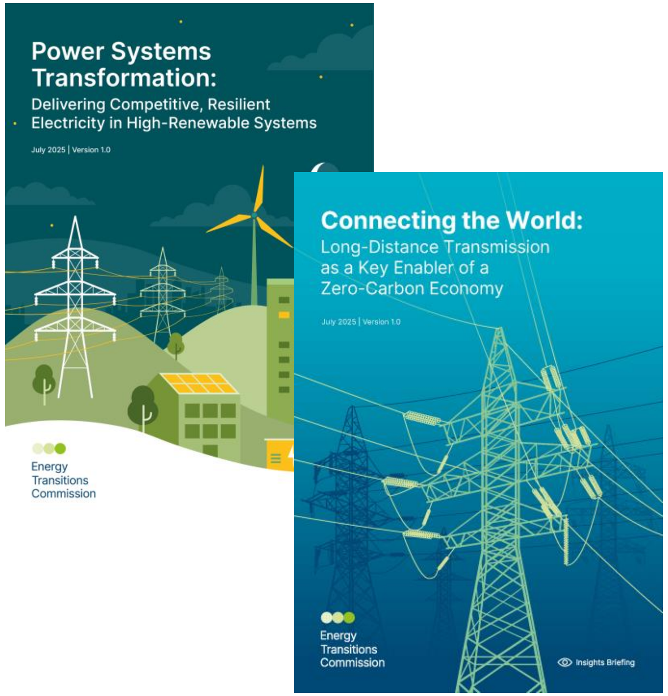
- **Journalists**, including The Economist, Financial Times & Reuters
- **Media panel with GSCC - 30 Tier 1/European media**

And spoke about this report to:

- **Chris Stark**, Head of UK's Mission for Clean Power and DESNZ
- Climate Action's **Global Clean Power Taskforce**

Power Systems Transformation Campaign

July



Social media performance in first month

~40K impressions | 500+ reactions | 15% engagement

Media

- **450+ news stories published** in China, Japan, Vietnam, Singapore, UAE, Germany, France, US, UK, Australia, Norway, Spain and **strong pick-up in India** (coverage in 15+ outlets)
- **Tier 1 highlights:** *Business Green*, Reuters, *Energy Intelligence*, CGTN &FT

India could cut power costs to $50/MWh with solar-wind system by 2050 — pv magazine

TROPICAL COUNTRIES CAN HALVE POWER COSTS BY 2050 BY RELYING ON SOLAR: — CarbonCopy, Making Climate Sense

India Can Halve Power Costs by 2050 with Solar-Led System — energetica India

Engagement & Partnerships

- **20+ partners briefed**, including Oxford Institute, Mission 2025, Global Solar Council, Ember, LDES Council, GSCC, GRA, OECD
- Potential YouTube collaboration with *Just Have a Think* (700k subscribers)
- Modo Energy podcast recorded and launching soon

EMBER | Global Solar Council | The Oxford Institute | LDES Long Duration Energy Storage Council | Mission 2025 | Global Strategic Communications Council

Next steps in the power systems campaign

Region-specific engagement

- Indonesia New Energy Systems
- Africa Sunbelt opportunity
- India AgriPV
- UK balance sheet

Short-form content development, topic focus

- Innovative Grid Technologies: 1-2 page briefing & op-ed
- Baseload optimisation tool
- Key messages video

Second wave of media and engagement (Sep-Nov)

Global Renewables Alliance · CLIMATE WEEK NYC · CLIMATE GROUP · FT FINANCIAL TIMES · COP30 BRASIL AMAZÔNIA BELÉM 2025

- Targeted media push: Briefing Financial Times on a 12-article series on clean electrification
- Collaborating with partners at Climate Week NYC on Sun Day and COP30
- Extracted LATAM data from the report for Brazil and Latam briefings before COP30
- Social media data campaign continues

"Clean electrification is very much the backbone of the energy transition," says Elena Pravettoni, head of analysis at the Energy Transitions Commission think-tank. "It's going to do a lot of the heavy lifting."

FT FINANCIAL TIMES

Questions for discussion

- How can ETC target higher-level stakeholder engagement (policymakers) across power system themes?

Agenda

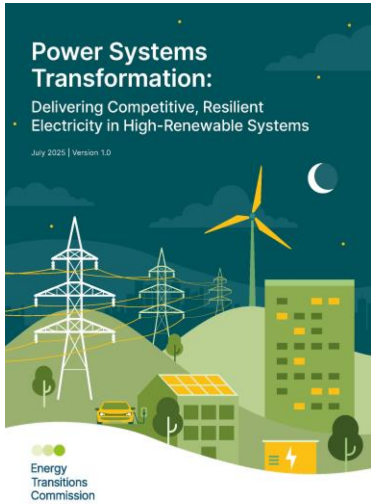
- Power Systems Transformation report launch & key messages
- **Next steps: Nuclear & Geothermal**

There are several key, live debates around power systems decarbonisation; unanswered questions to be addressed in 2025 and 2026

Ongoing debates that we've addressed

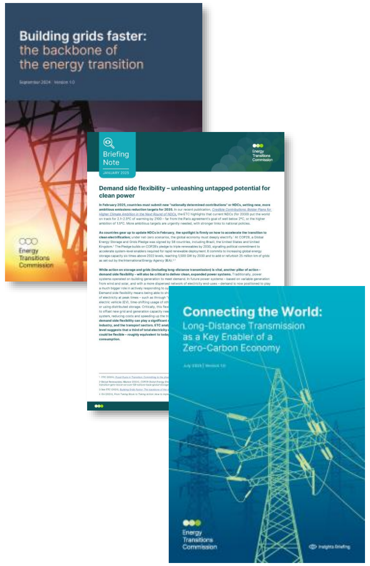
- **How can system reliability be maintained and flexibility scaled at high wind and solar shares?**
- **How can grids be expanded at speed?**
- **How can we enable rapid electrification while balancing with decarbonisation?**
- **What is the cost of "clean firm" vs fossil around the world?**

2025



2024/5

2024/5



Other debates addressed by new work

What is the role of nuclear and geothermal in clean power systems?	To be addressed in a new ETC workstream in 2025 with a report published in 2026
How can we enable low costs to pass through to consumers?	Partly addressed in *Power Systems Transformation*; deeper work planned for 2026 on retail pricing

Why is the conversation on nuclear and geothermal topical today?

- Nuclear and geothermal increasingly seen as **"clean firm" power** — reliable, carbon-free electricity
- They **face distinct opportunities and challenges**

Nuclear	Geothermal
Renewed political momentum: >20 countries pledged at COP28 to triple capacity by 2050	**Expanding as a dispatchable renewable** with "always-on" potential
Corporate buyers (Microsoft, Google) exploring nuclear	**New technologies, such as Enhanced Geothermal Systems** broadening geographic reach
Large influx of new entrants to the nuclear technology space	**US DOE "Earthshot" programme** aiming for a 90% cost reduction target by 2035
Challenges to be addressed: High upfront cost, long permitting, safety and waste concerns	**Challenges to be addressed:** Site-specific geology, drilling costs, early financing gaps

Introducing the ETC’s Nuclear & Geothermal workstream

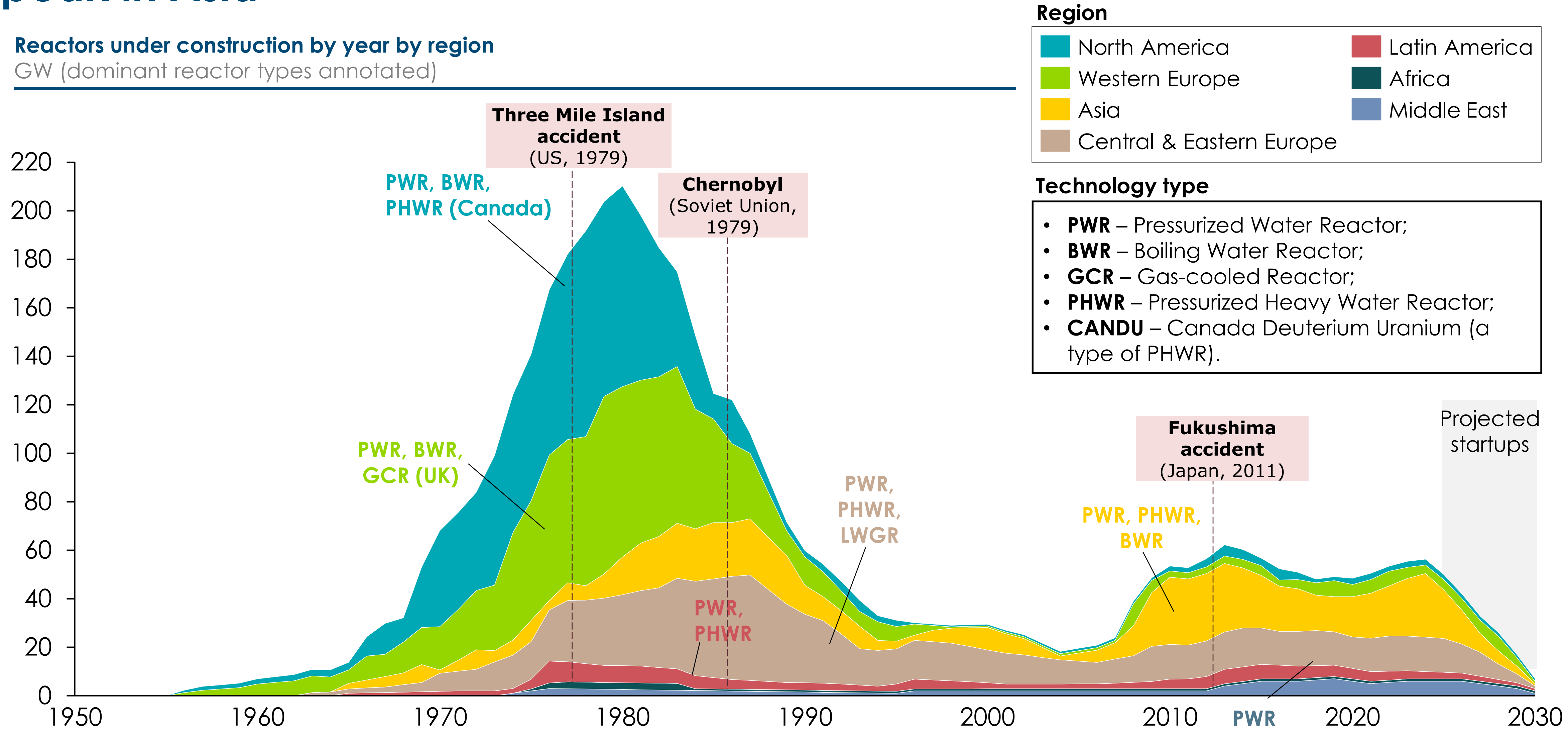
- **This new workstream explores the key question:** What is the role of nuclear & geothermal electricity in future power systems, alongside wind and solar generation, in different regions of the world? Can they be delivered at low cost? Where needed, how can their deployment be scaled faster?

- Workshop schedule
  - **Workshop 1: The role of Nuclear** (Oct 2025)
  - **Workshop 2: The role of Geothermal**
  - **Workshop 3: Key enablers to scale Nuclear and Geothermal**

Nuclear

Nuclear power deployment peaked in the 1980s in the West, with a recent peak in Asia

Reactors under construction by year by region
GW (dominant reactor types annotated)



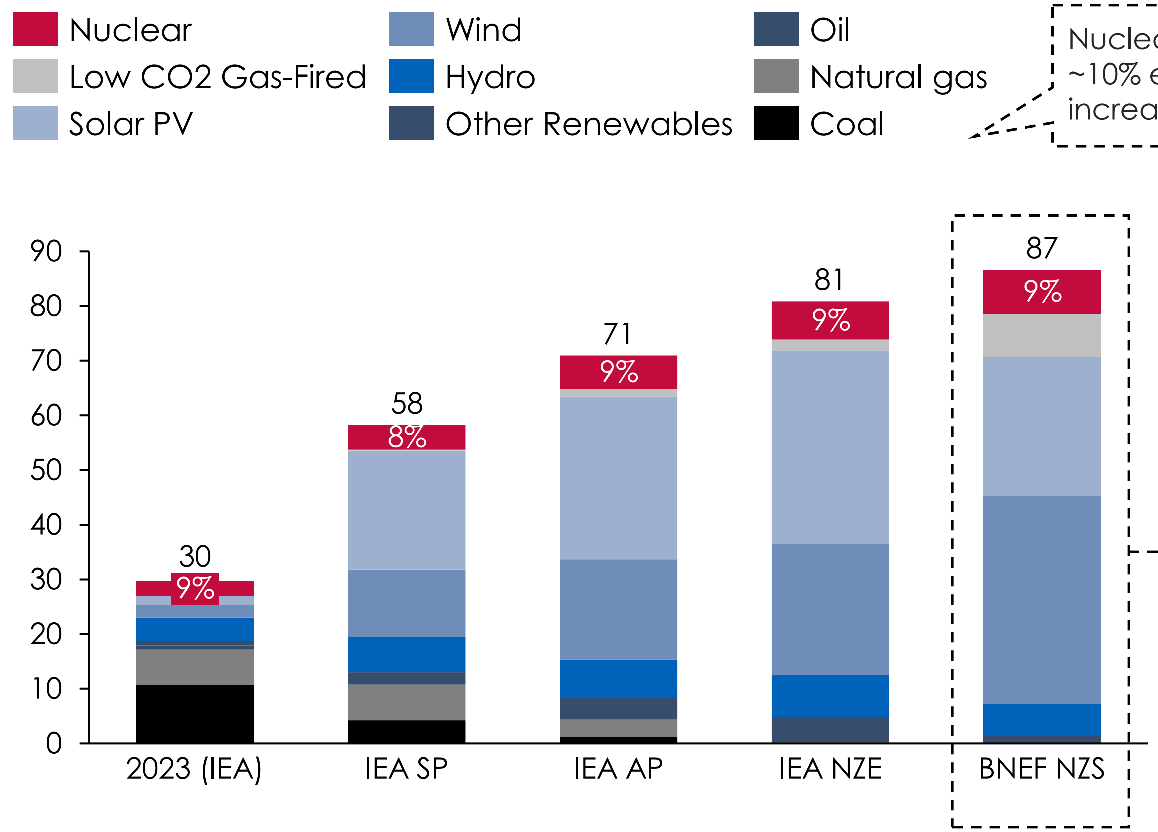
Technology type

- **PWR** – Pressurized Water Reactor;
- **BWR** – Boiling Water Reactor;
- **GCR** – Gas-cooled Reactor;
- **PHWR** – Pressurized Heavy Water Reactor;
- **CANDU** – Canada Deuterium Uranium (a type of PHWR).

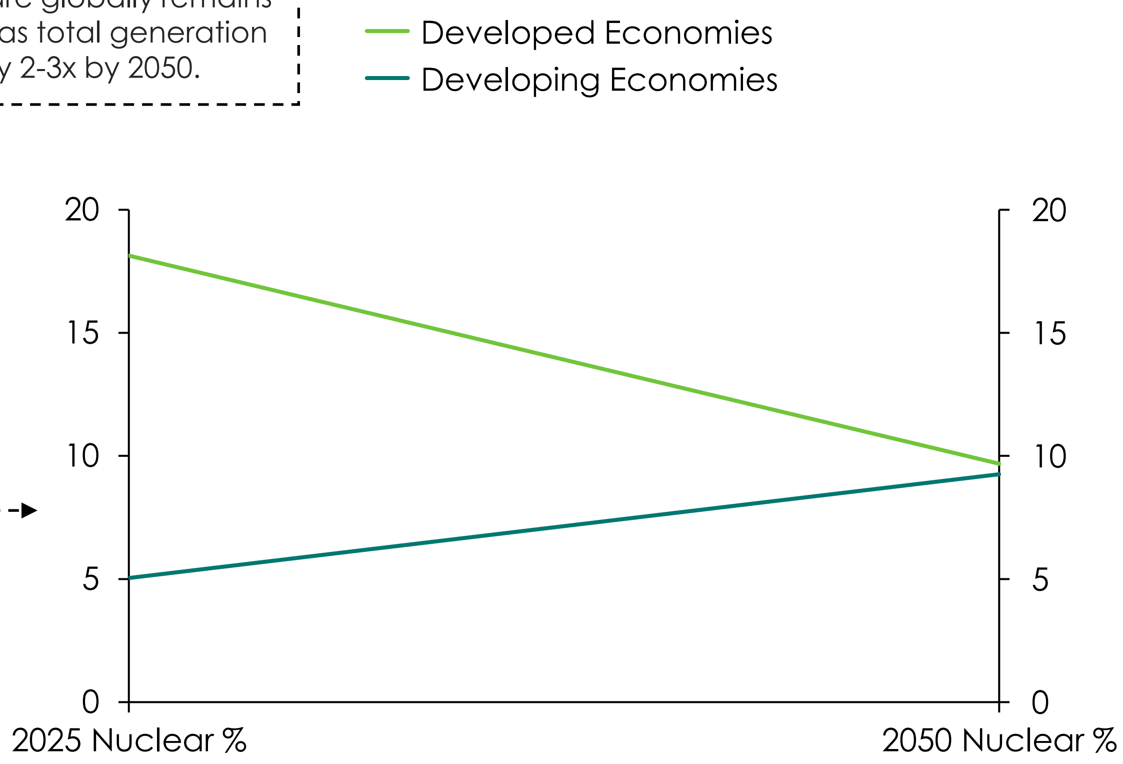
Source: adapted from Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; World Nuclear Association (2025), *Reactor Database*

Future power system scenarios suggest nuclear as ~10% of total generation, requiring a significant increase in generation compared to today

Global nuclear vs non-nuclear generation by scenario (2023 and 2050)
'000 TWh



Average nuclear share of generation by region in BNEF NZS
% of Generation

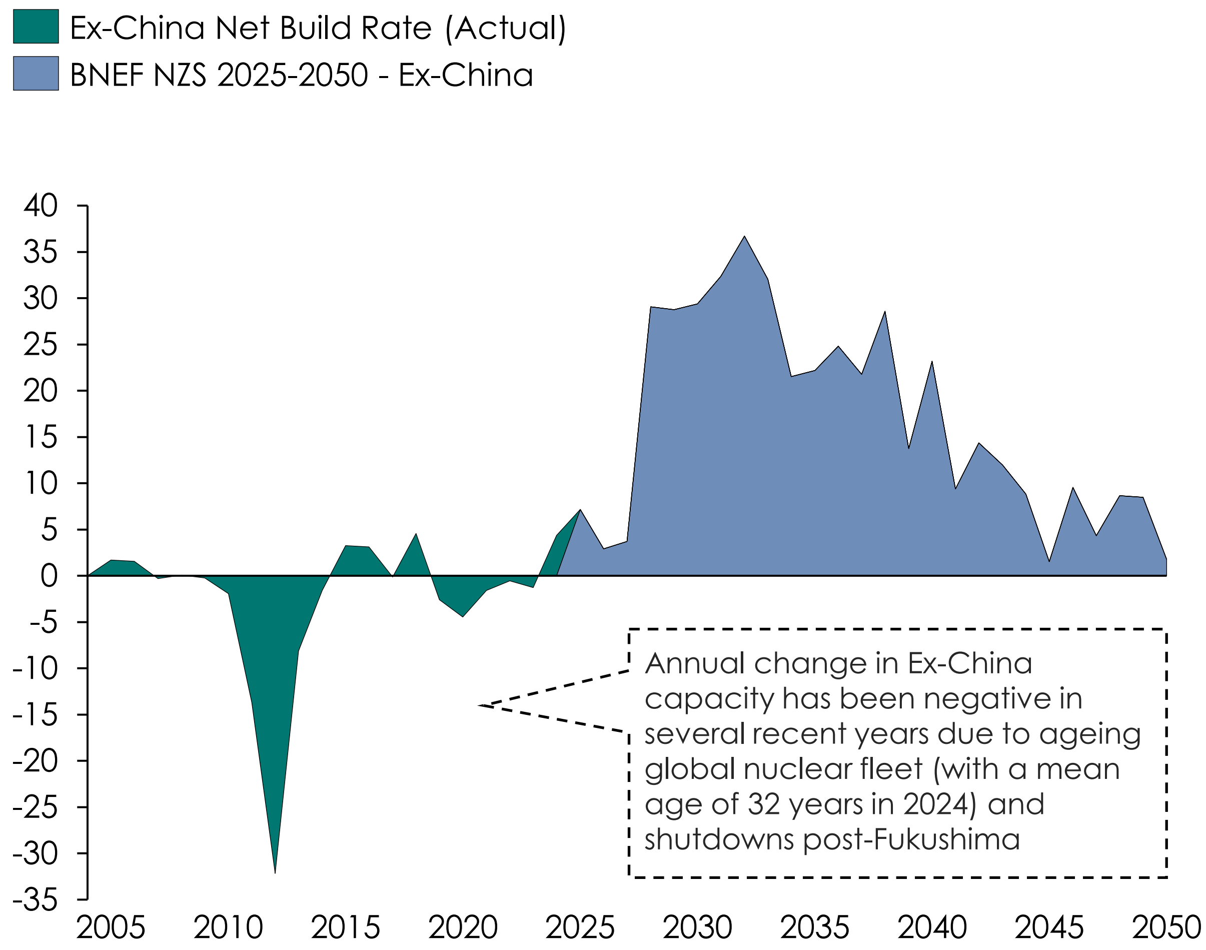


In many cases, nuclear plant lifetimes can and should be extended safely. Nuclear plant lifetime extensions are frequent but do present some risks (e.g. structure/component ageing, technical limitations and physical ageing of system design).

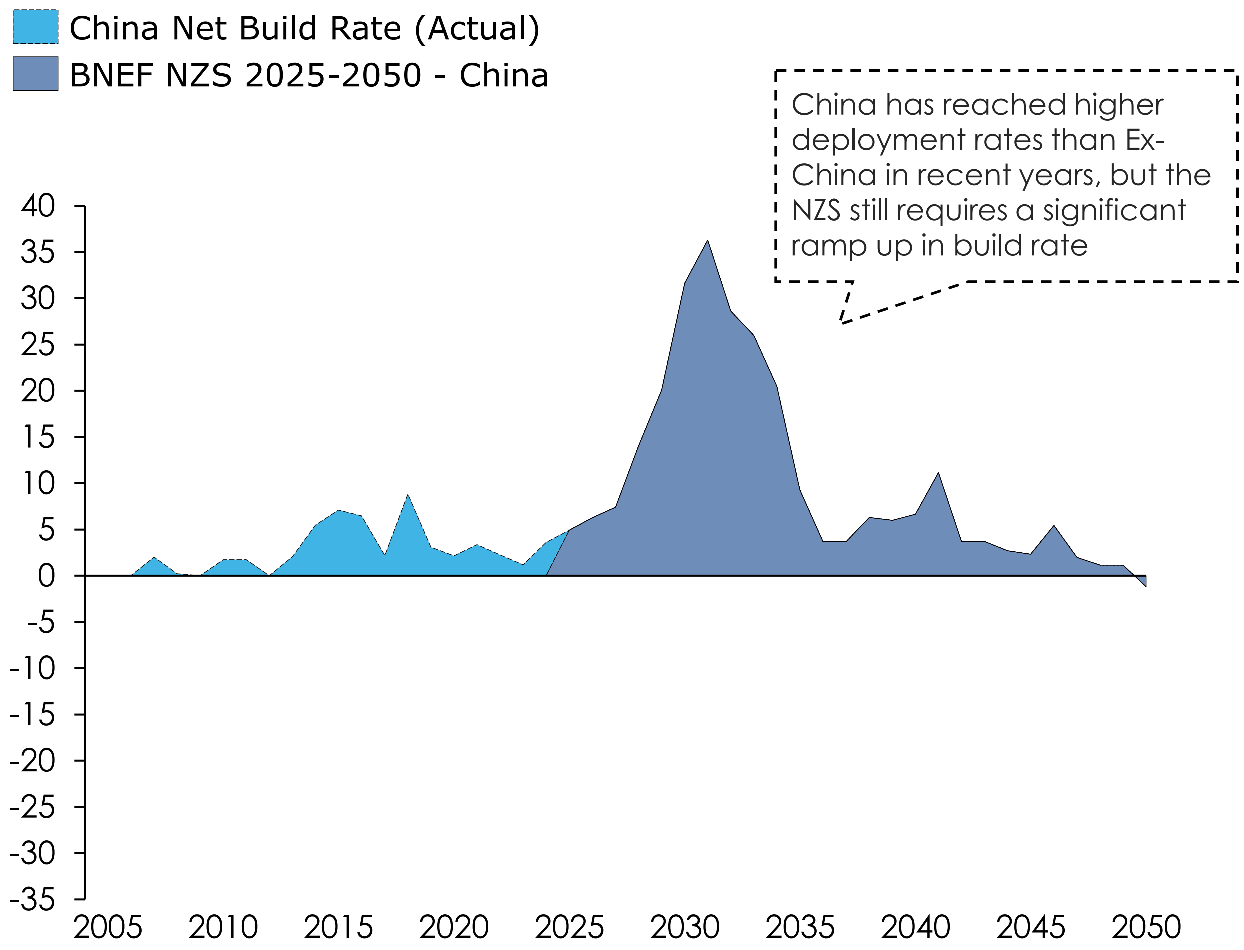
Notes: Nuclear generation includes conventional and SMR. SP = Stated Policies, AP = Announced Pledges, NZE = Net Zero Emissions, ETS = Economic Transition Scenario, NZS = Net Zero Scenario.
Sources: BNEF (2025), *New Energy Outlook 2025*, IEA (2024), *World Energy Outlook 2024*

Nuclear build rates lag far behind what is indicated in most Net Zero scenarios

Ex-China nuclear annual change in nuclear installed capacity, 2005 - 2050
GW/y



China nuclear annual change in nuclear installed capacity, 2005 - 2050
GW/y



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

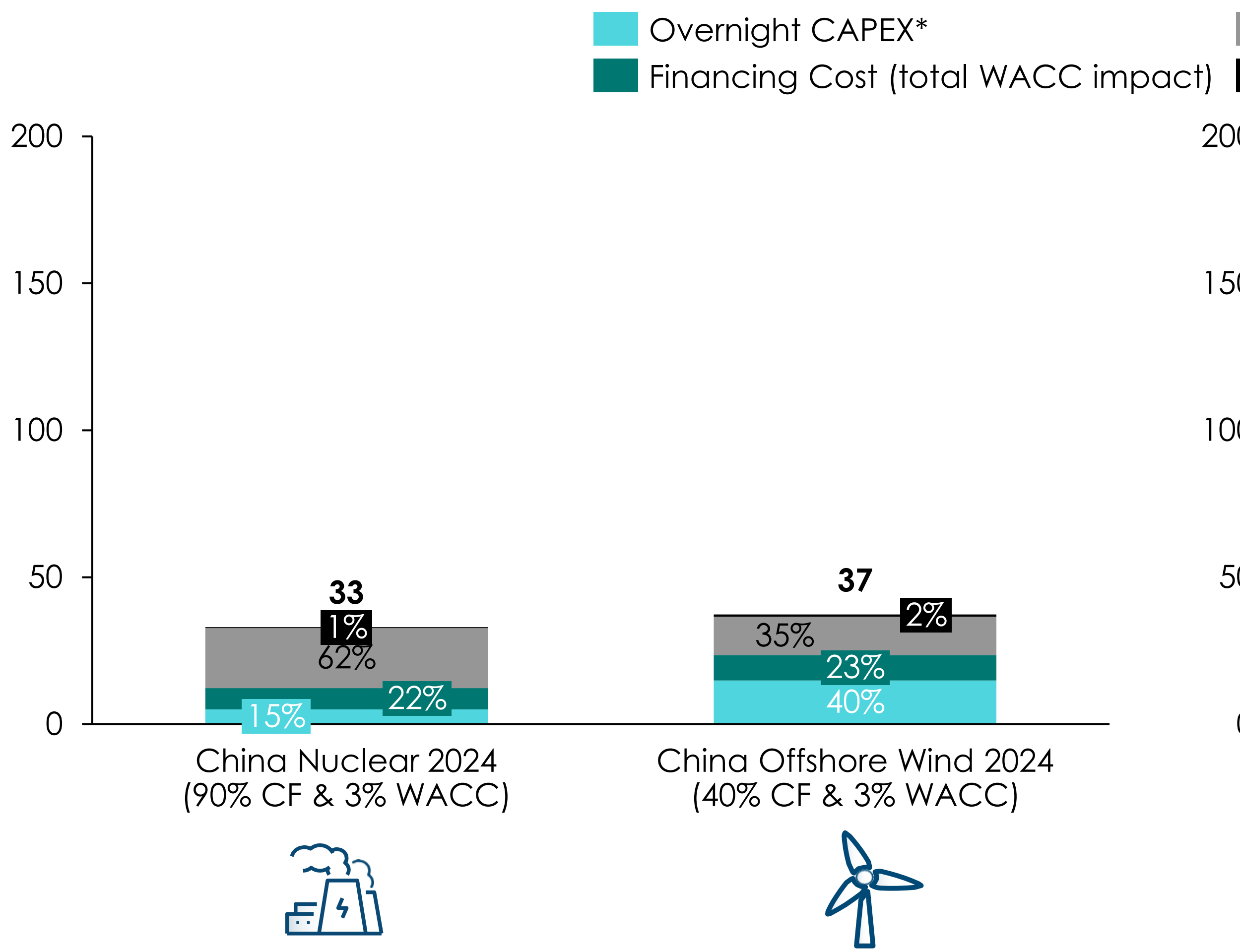
Estimates of levelised cost of energy (LCOE) is diverging across regions and alternative technologies

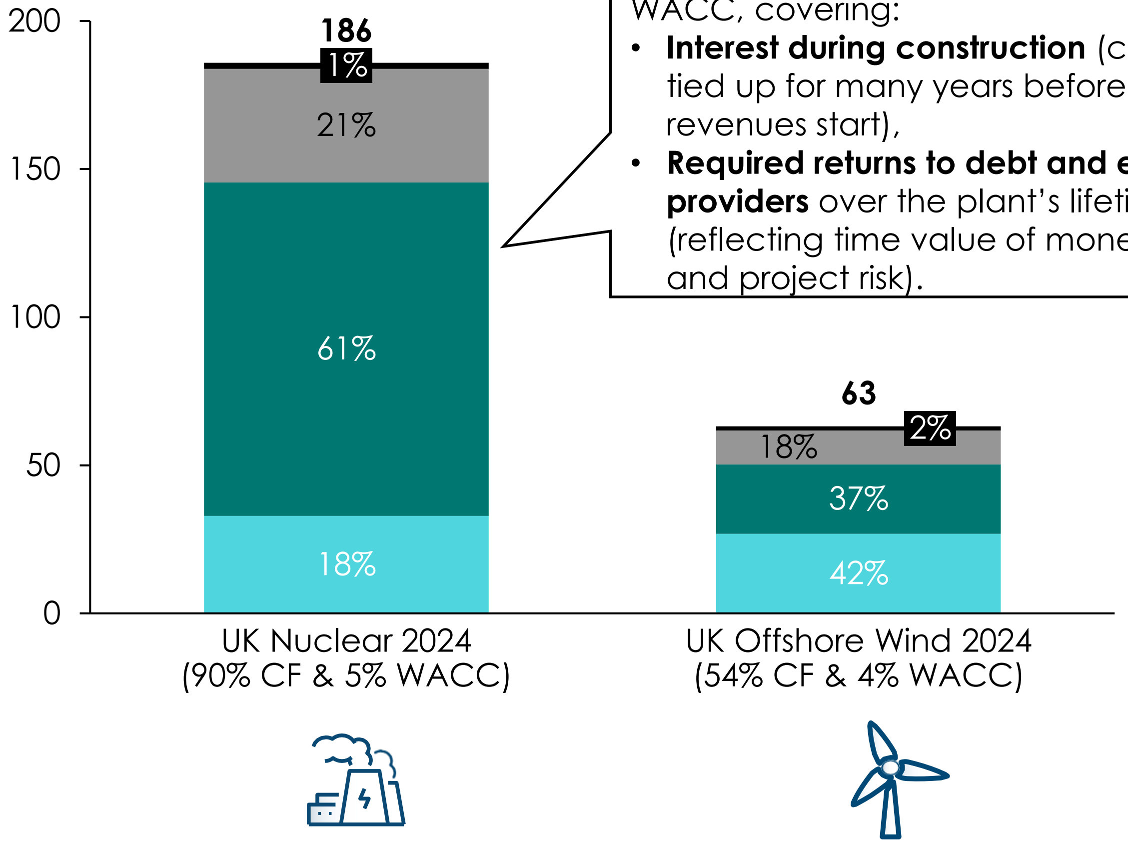
China: Nuclear and offshore wind indicative LCOE breakdown

$/MWh, real 2024

UK: Nuclear and offshore wind indicative LCOE breakdown

$/MWh, real 2024





Financing cost = the additional cost per MWh from applying the project's WACC, covering:

- **Interest during construction** (capital tied up for many years before revenues start),
- **Required returns to debt and equity providers** over the plant's lifetime (reflecting time value of money and project risk).

Notes: CAPEX, OPEX, & DECEX shown with 0% WACC applied to separate WACC impact into Financing Cost. CF = Capacity Factor, WACC = weighted average cost of capital (real), CAPEX = Capital Expenditure, OPEX = Operating Expenditure (incl. fueling), DECEX = Decommissioning Expenditure. Overnight CAPEX is the total CAPEX excluding financing costs. Source: BNEF LCOE Data Viewer, Nuclear Energy Cost Estimates for Net Zero World Initiative, ORE Catapult (2021), *End-of-life planning in offshore wind*

The nuclear cost divergence is driven by three key assumptions: weighted average cost of capital (WACC), overnight CAPEX, and construction duration

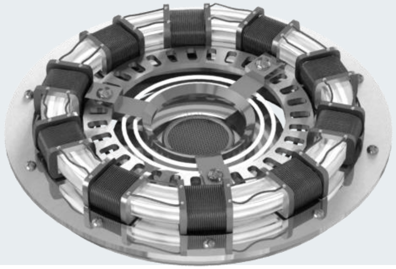
Key nuclear levelised cost of energy (LCOE) drivers: China and the UK

LCOE input	China	UK
WACC (%, real)	3%	5%
Overnight CAPEX (2024 $/kW)	2,400	15,500
Construction duration (years)	6	10

Source: BNEF LCOE Data Viewer, Nuclear Energy Cost Estimates for Net Zero World Initiative

Nuclear's near-term contribution will rely on proven Gen III+ fission reactors; Gen IV fission and fusion are still low-maturity

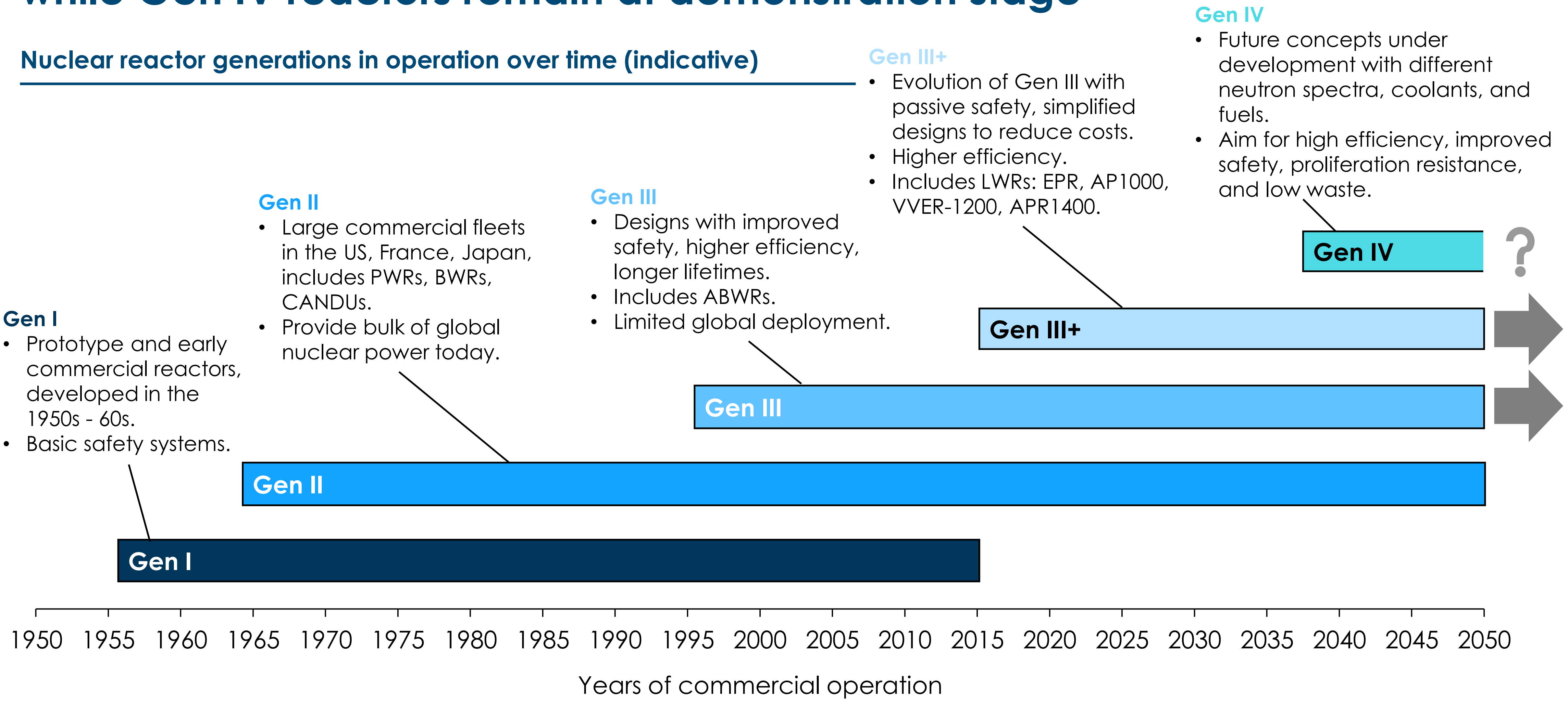
Decreasing Maturity

Generation	Reactor type	Image	Description	TRL (Technology readiness level)	FOAK (1^{st} commercial deployment)	NOAK (Large-scale deployment)
Gen I- III	**Conventional large-scale reactors**		• Global standard for commercial nuclear energy since the 1960s. • The main types are Pressurised Water Reactors (PWRs) and Boiling Water Reactors (BWRs).	TRL 9	1956	1956
Gen III+	**Small Modular Reactors (SMR)**		• SMRs are compact (generally advanced) reactors (10 – 500 MW) built in factories and shipped for assembly • Growing commercial interest due to scalability and flexibility	TRL 2-8	2029 +	2035 +
Gen IV	**Advanced reactors**		Next generation of nuclear fission technologies which use novel coolants including: • High-temperature gas reactors • Liquid metal reactors • Molten salt reactors • Fast breeder reactors	TRL 2-8	2030 +	2035 +
	Fusion		• Fusion joins light atomic nuclei like hydrogen into heavier ones to release energy • Massive clean energy potential with minimal long-lived radioactive waste • Remains in early-stage R&D	TRL 2-5	2040 +	2050 +

Notes: FOAK first of a kind TRL 9+ deployment; NOAK = n^{th} of a kind deployment. Assumed TRL scale: TRL 1-3 = Research to Proof of Concept; TRL 4-6 = Lab to Pilot Demonstration; TRL 7-9 = Prototype Demonstration to FOAK / Full Commercial Deployment. Sources: US DoE (2024), *Pathways to Commercial Liftoff: Advanced Nuclear*; Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; Third Way (2024), *The Global Race for Advanced Nuclear Is On*; Ben James (2024), *The Big Guide to Fusion*; Nuclear Innovation Alliance (2025), *Advanced Reactor Deployment Map*

Generation III+ reactors have been deployed at scale in the last decade, while Gen IV reactors remain at demonstration stage

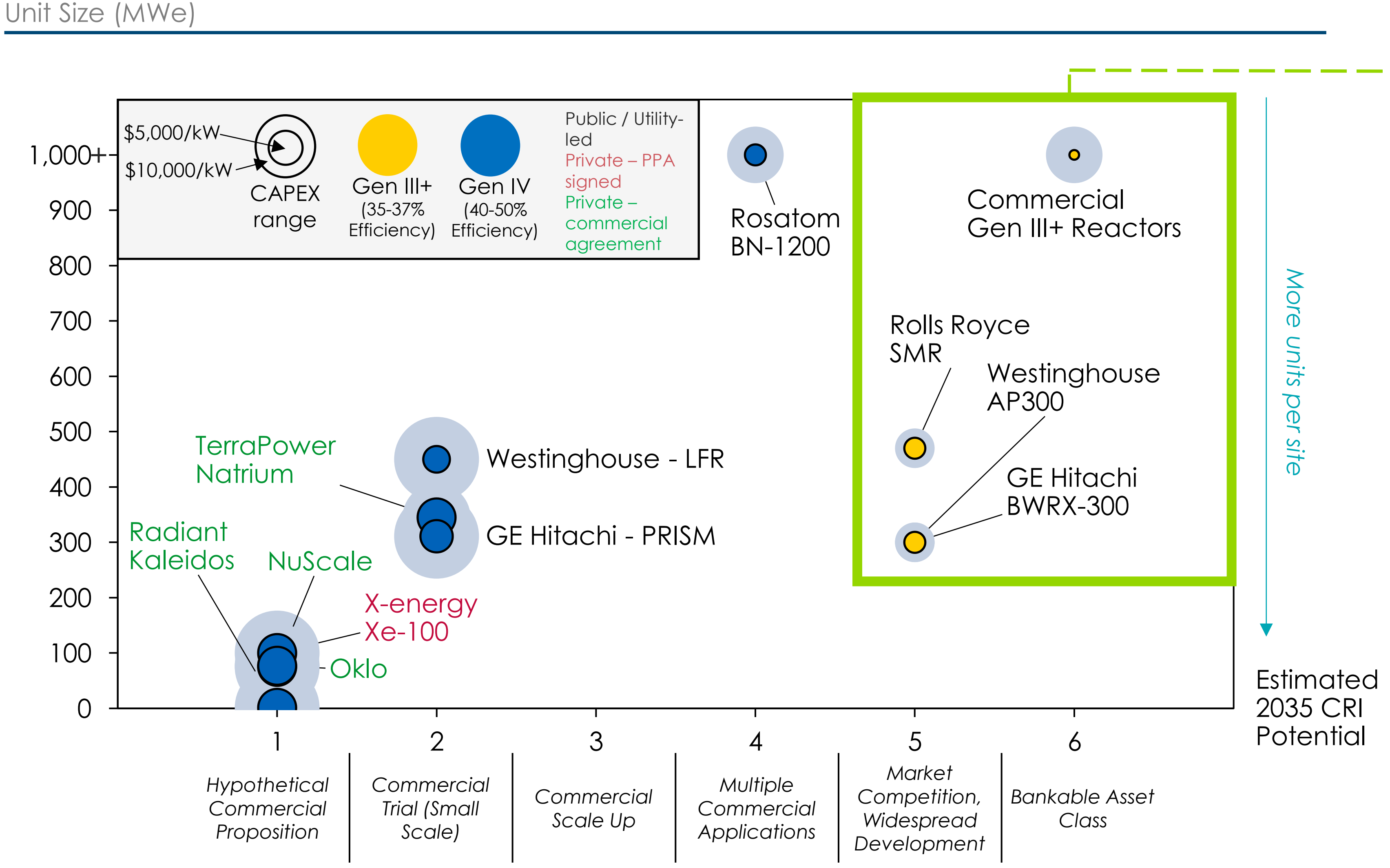
Nuclear reactor generations in operation over time (indicative)



Notes: PWR = Pressurised Water Reactor, BWR = Boiling Water Reactor, CANDU = Canada Deuterium Uranium, ABWR = Advanced Boiling Water Reactors, LWR = Light Water Reactor (moderated and cooled by water), EPR = European Pressurised Reactor.
Source: World Nuclear Association (2021), *Advanced Nuclear Power Reactors*

Nuclear deployment in the next decade will be dominated by large Gen III+ reactors, while Gen IV designs remain lower TRL and higher risk

Illustrative diagram of the unit size and Commercial Readiness Index (CRI) of selected designs



Deployment in the next decade will be dominated by designs using:

1. **Conventional technology** (e.g., Gen III+) with a more certain pathway to cost reduction / regulatory approval
2. **Large unit sizes** (e.g., 300+ MW) to capture plant-level economies of scale
3. **Standardisation and modularisation** to offer a route to low-cost via:
   - Manufacturing efficiencies
   - FOAK to NOAK learning

The impact / scalability of innovations to improve efficiency (e.g. via new fuels and designs) and modularisation both **remain largely unproved in practice**

Notes: Circle diameter represents CAPEX scale. CRI 1 = TRL 2-8; CRI 2 = TRL 9. Commercial Gen III+ Reactors include reactors such as AP1000, EPR, APR-1400, HPR-1000. FOAK = first of a kind, NOAK = n^{th} of a kind. Source: ARENA (2014), *Commercial Readiness Index for Renewable Energy Sectors*

Geothermal

Geothermal potential spans shallow heating to deep power generation

What is geothermal energy?

- **Thermal energy stored in rock, soil and fluids beneath the earth's surface**, used for electricity, district heating and cooling, and ground-source (shallow) heat pumps
- The technology applied depends on temperature, depth and reservoir characteristics

What are the different types of geothermal?

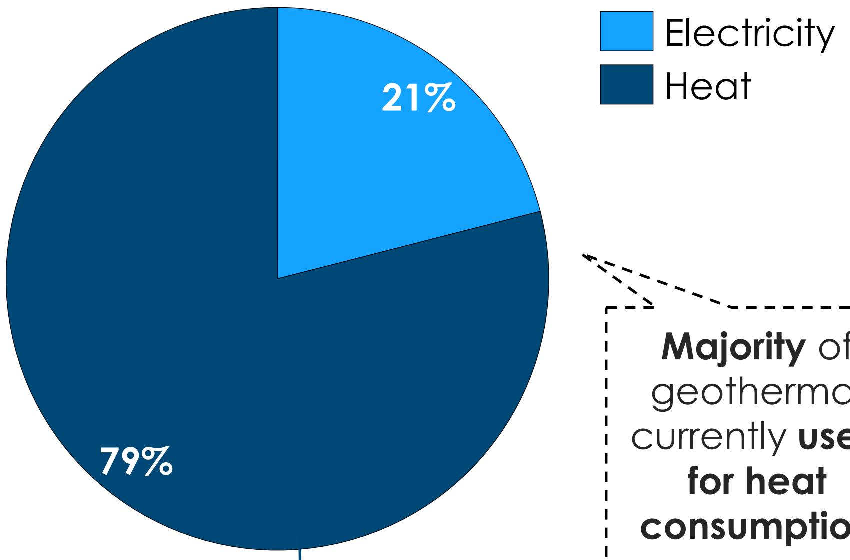
- **Shallow or direct-use** – ground-source heat pumps and small-scale heating, using low-temperature heat at <500 m depth
- **Conventional hydrothermal** – naturally occurring hot water or steam in permeable rock, typically 1–3 km deep, used for electricity and large district heating; mature and widely deployed
- **Non-conventional (enhanced or engineered)** – creates or exploits deeper, hotter reservoirs (3–5 km+) by fracturing hot dry rock or using closed-loop systems to generate power where natural hydrothermal resources are absent

How does depth impact geothermal's capacity?

- **Shallow (<500 m):** supports ground-source heat pumps and small-scale heating, site-specific
- **Conventional hydrothermal (**1–3 km): enables baseload electricity and large district heating where naturally permeable, water-filled reservoirs exist
- **Deep engineered systems** (3–5 km+): tap wider high-temperature resources but need advanced drilling and stimulation

The majority of geothermal energy consumption is currently used for heat

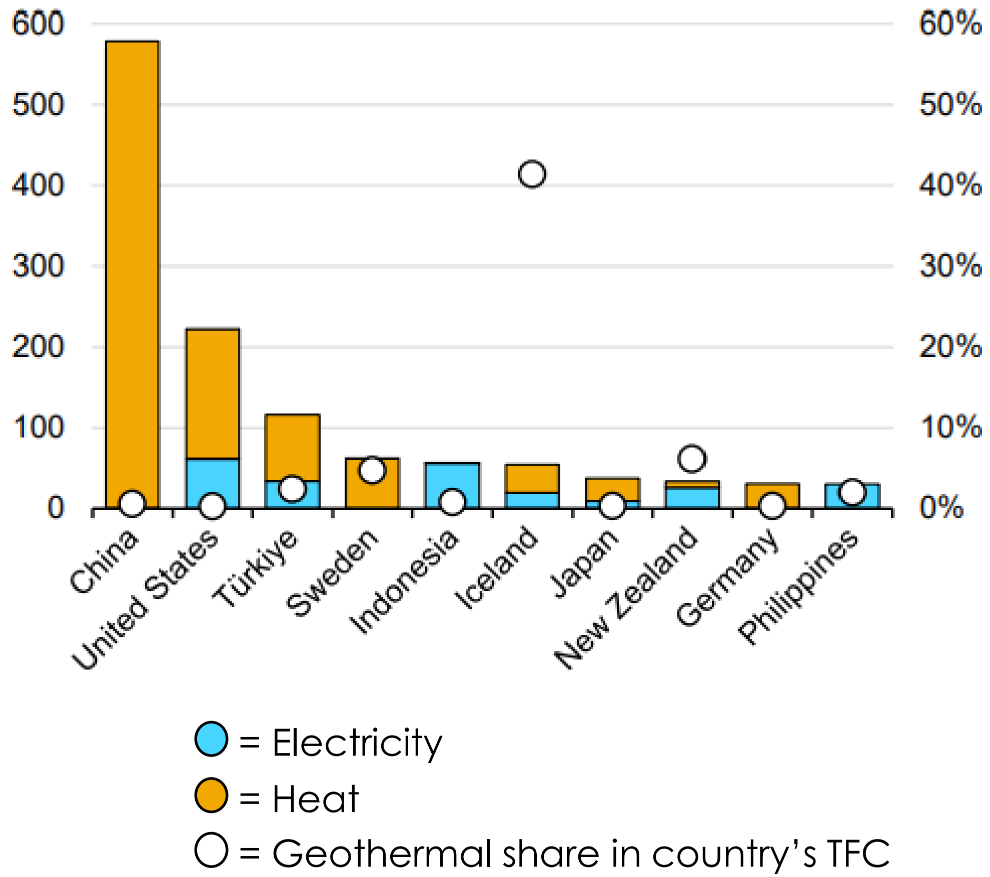
Total final geothermal energy consumption by application, world
%



Majority of geothermal currently **used for heat consumption**

Geothermal heat provides useful energy in the form of space and district heating, industrial process heat, and agricultural heat

Top 10 consuming countries of geothermal energy
PJ (LHS), % (RHS)

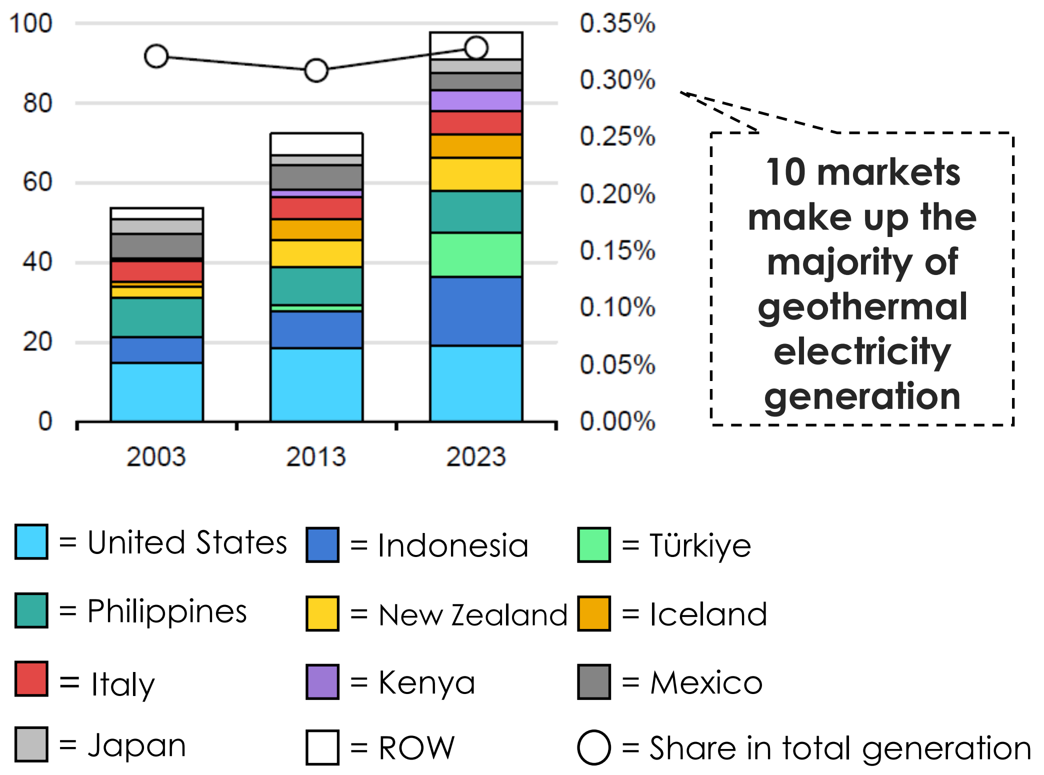


Source: IEA (2024) The Future of Geothermal Energy

Currently, geothermal plays a small role in global electricity generation, and is primarily concentrated in a few countries

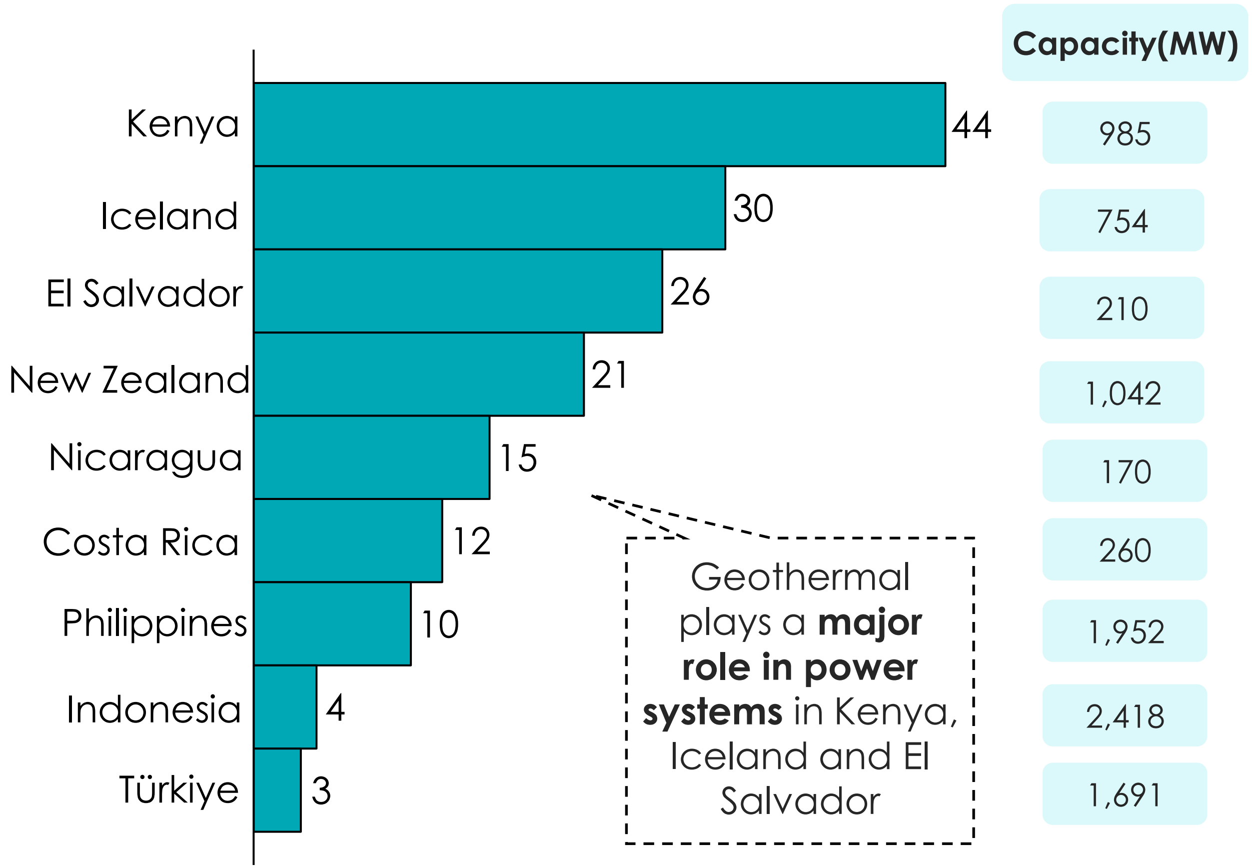
Global electricity generation from geothermal, % of global total

TWh



Share of total national electricity generation, 2023

%

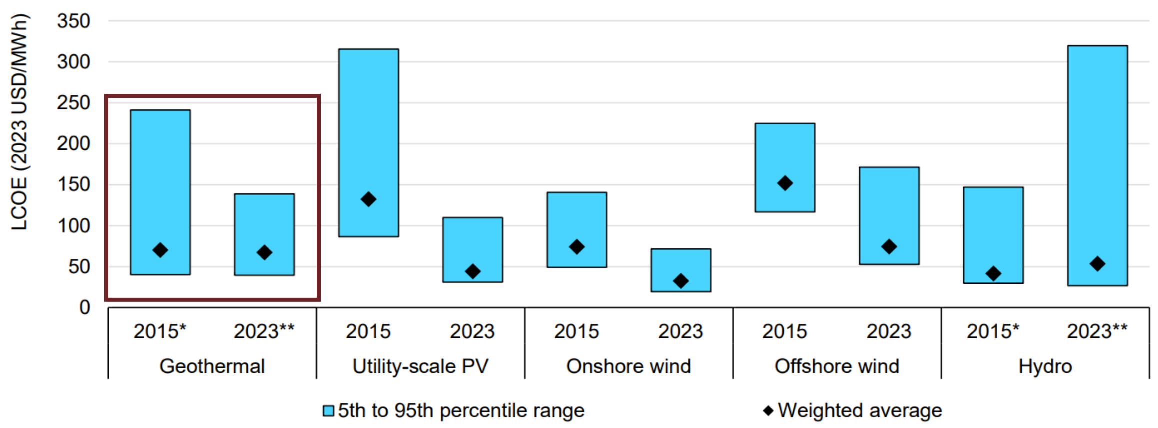


Source: IEA (2024) The Future of Geothermal Energy; ThinkGeoEnergy (2025), ThinkGeoEnergy's Top 10 Geothermal Countries 2023: Power Generation Capacity; SIGET (2024), Capacidad instalada de generacion eectrica 2023; TheGlobalEconomy.com (2024), Nicaragua: Geothermal electricity capacity (MW); International Renwable Energy Agency (2024), Renewable Capacity Statistics 2024

Conventional geothermal is already cost-competitive; using Enhanced Geothermal Systems could unlock global scalability if costs fall

Typical LCOE range for renewable power technologies, 2015-2023

USD/MWh, 2023 real



- Conventional geothermal (1-3km deep) sits within the cost range of other renewables (~50–140 USD/MWh)
- Costs have not fallen as dramatically as solar and onshore wind, limiting competitiveness based on cost

Key techno-economic parameters and scalability potential for electricity generation

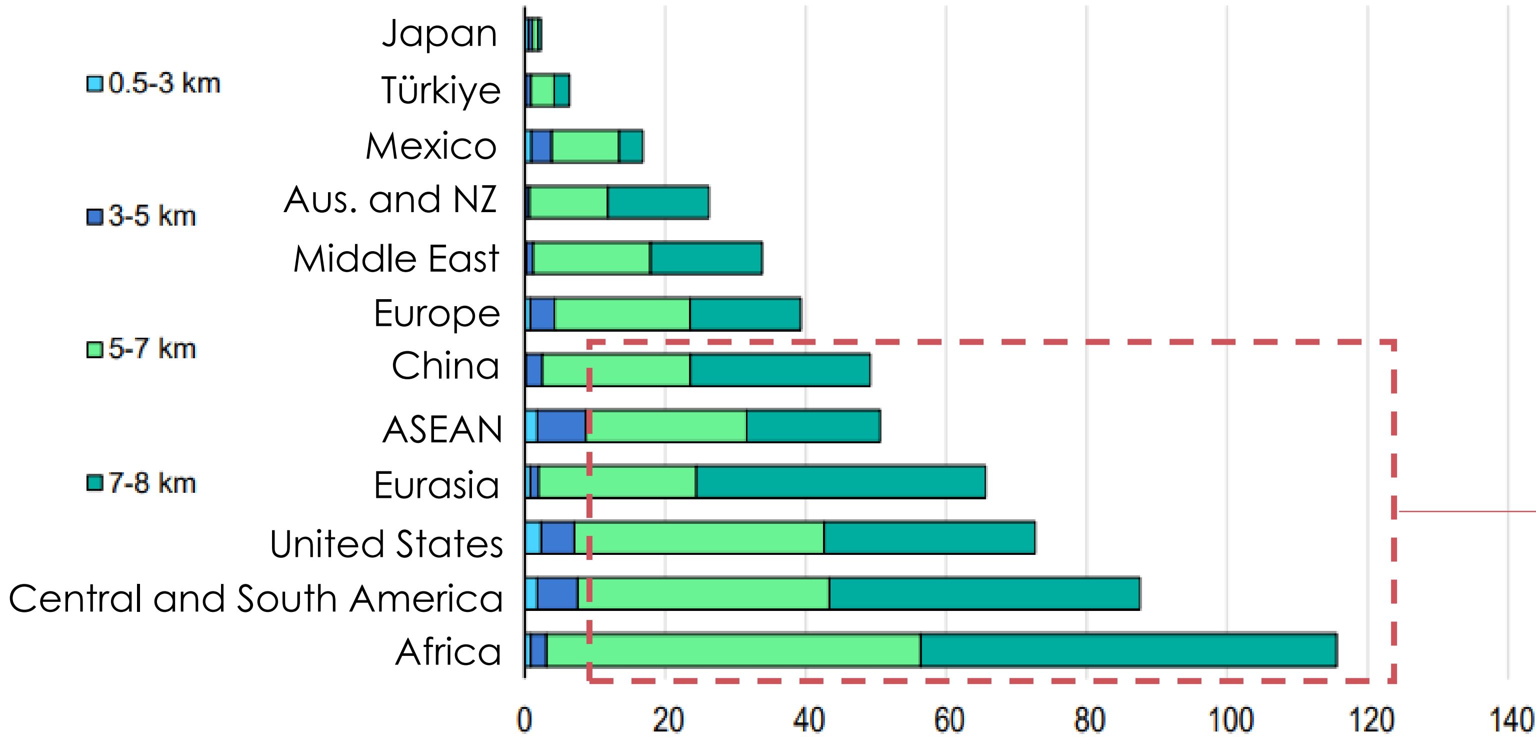
Parameter	Conventional Geothermal	Enhanced Geothermal Systems
LCOE (2023)	~50–140 USD/MWh (IEA data)	80–200+ USD/MWh (higher uncertainty)
Dispatchability	High (baseload power)	
Resource Dependency	Requires hydrothermal reservoirs	Engineered systems; no need for natural reservoirs
Geographic Limitation	High	Low
Global Scalability	Modest increase projected (up to ~1% of global gen.)	High – transformative potential (pending commercialisation)
Technology Maturity	Mature	Emerging

- Enhanced Geothermal Systems could overcome geographic limits by decoupling from natural reservoirs
- However, current costs remain uncertain (80–200+ USD/MWh), and the technology is still at demonstration stage

Source: IEA (2024) The Future of Geothermal Energy

EGS highlights that there is massive widespread global potential of geothermal electricity generation, but high costs pose a barrier

Technical potential for EGS electricity capacity by depth in selected countries, regions
TW



The IEA finds almost 600 TW of technical capacity if deep resources below 8 km were developed

Technical potential is orders of magnitude larger than current consumption – **4,800,000 TWh/year compared to 30,500 TWh global electricity demand***

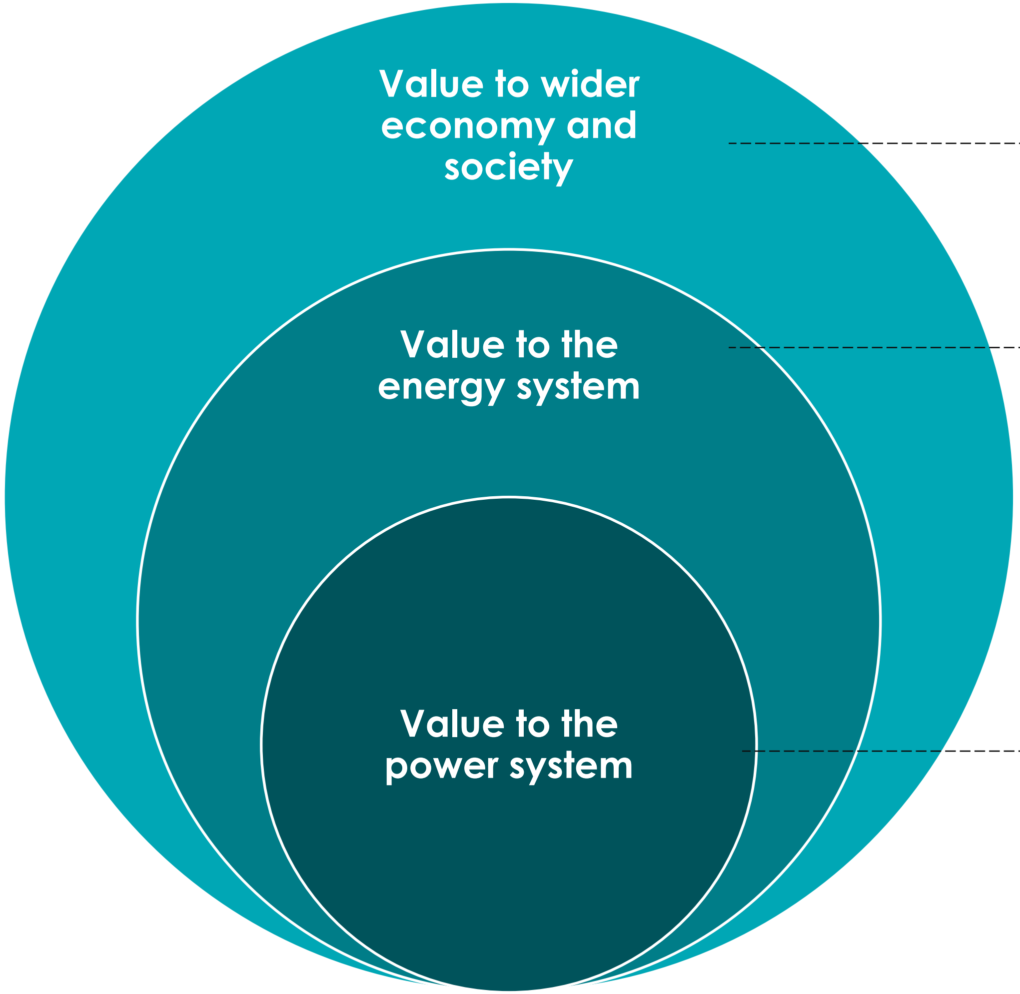
Global crustal heat gradients mean most regions reach >200 °C by 7 km, **giving near-universal technical potential at 5–8 km**

However, technical constraints rise steeply below ~5 km: drilling and stimulation costs escalate, hard rock and high pressure–temperature cause equipment

Note: * Assumes a 25 year operating life at continuous full-power operation. Source: IEA (2024) The Future of Geothermal Energy

System value

Value of firm power should be assessed holistically against alternatives



Considerations around relative domestic economic value-add and jobs; environmental risks; energy security ★

Hybrid applications (E.g. heat, hydrogen, desalination)

Total system costs (e.g. LCOE, balancing, grid expansion & grid stability costs) ★

Considerations on diversification and resilience

★ = in-depth focus

To understand how nuclear and geothermal can complement highly renewable systems

Firm power can offset some system costs of wind/solar-only systems; the higher cost of generation is a critical determinant

Preliminary

Illustrative view of components of total system cost and variation by system, UK Case Study in 2050

	100% Renewables	20% Nuclear + 80% Renewables*
Generation costs (LCOE) - *weighted*	$60 /MWh	$80/MWh
Balancing costs; Curtailment & congestion costs	$20/MWh	$15/MWh
Grid stability costs	$5/MWh	~$3/MWh
Transmission & distribution	$35/MWh	$24/MWh
Total system costs	$120/MWh	~$124/MWh

Note: *% share of annual generation. LCOE input to 2050 generation costs assumed to be Solar: $20/MWh, Onshore: $31/MWh, Offshore: $56/MWh, Nuclear: $130/MWh. Other system cost assumptions will be outlined in detail in the ETC's nuclear workshop on October 3rd.
Source: ETC (2025) Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems

Power system mix choices will depend on planning, operation, and public acceptance

System Planning

- **Grid build-out** is a major constraint for renewables; nuclear can help scale clean power with less reliance on transmission expansion.
- **Lead times:** Nuclear projects typically take >10 years to deliver, while renewables+storage can be built within 2–5 years.
- **Deployment speed** favors renewables, but nuclear may still play a role where grid expansion is slow.

System Operation

- **High renewables systems** are technically and economically feasible, though balancing needs grow with penetration
- **Firm output** reduces the scale of long-duration balancing required.
- **System stability** is supported by nuclear's inertia and voltage control.

Public Acceptance

- **Land and population density** constraints increase siting and permitting challenges for renewables.
- **Political dynamics**: Net zero faces pushback in some countries; nuclear often gains stronger centre-right support.
- **Security and safety** considerations restrict where new nuclear projects can be built

- **A diverse generation mix underpins energy security and system resilience**
- **Including some firm power may help in countries where grid, land, or system balancing constraints slow renewable deployment.**

Role of nuclear and geothermal will vary in different geographies

The role of nuclear and geothermal in clean power systems will depend on the following considerations:

Physical resources: Is there availability of other clean resources (wind, solar, hydro)?

- This may mean nuclear reaches higher shares (>20%) in systems with limited wind/solar potential

Costs and system value: is there an ability to complement wind and solar cost-effectively?

Wider energy system benefits: can hybrid applications be developed (heat + power, hydrogen, storage integration)?

Sufficient enabling capacity, eg. regulation, workforce and skills

Next steps for the nuclear and geothermal workstream

	Workshop	Date	Focus
1	**Workshop One: The role of Nuclear**	02 October 2025, 9:30am–12:30pm	The current state of play, the techno-economics of new projects, the system value nuclear can provide, and the wider risks and benefits of development.
2	**Workshop Two: Geothermal Workshop**	November/December	Geothermal techno-economics, system value, wider risks and benefits.
3	**Workshop Three: Key enablers to scale Nuclear and Geothermal**	Early 2026	Guidelines and enablers required to scale nuclear and geothermal.