



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

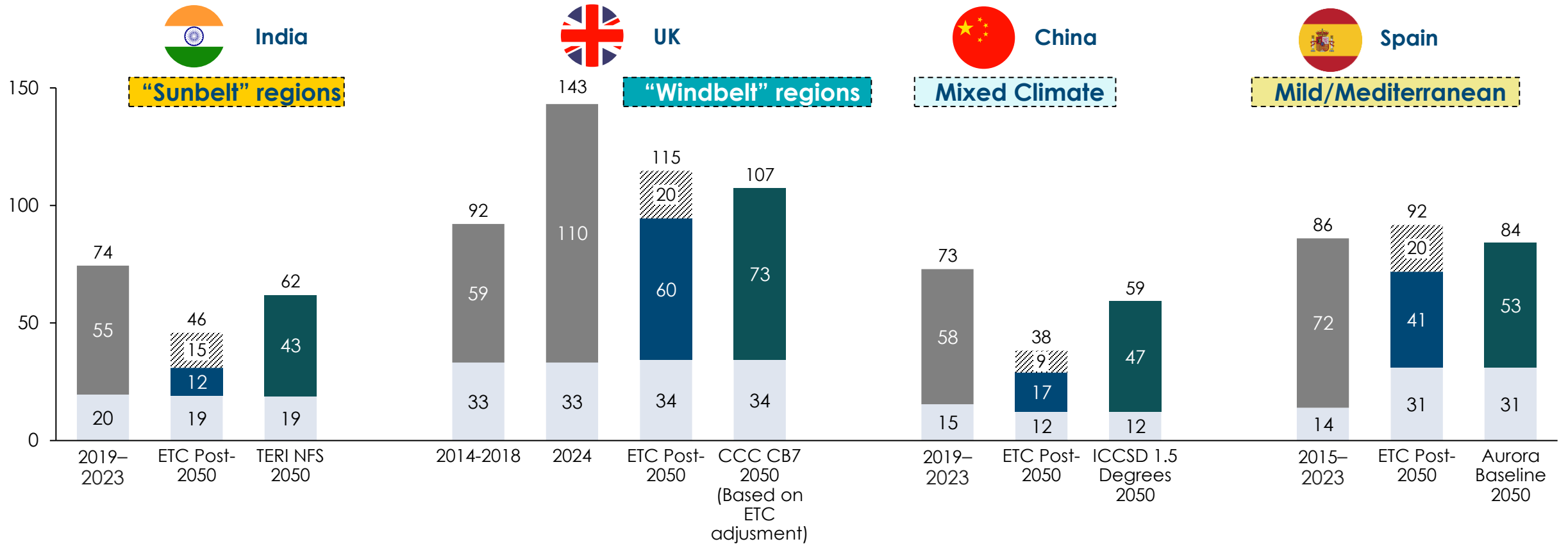
- 1** It is technically and economically possible to operate and balance power systems with high shares of wind and solar (e.g. 70-80%+) through technologies existing today. **The cost of each system varies significantly based on whether it is wind (“wind belt”) or solar (“sun belt”) dominated**
- 2** 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
 Dispatch model generation and balancing
 Cost of meeting balancing needs
 T&D costs (ETC est.)
 Wind/solar

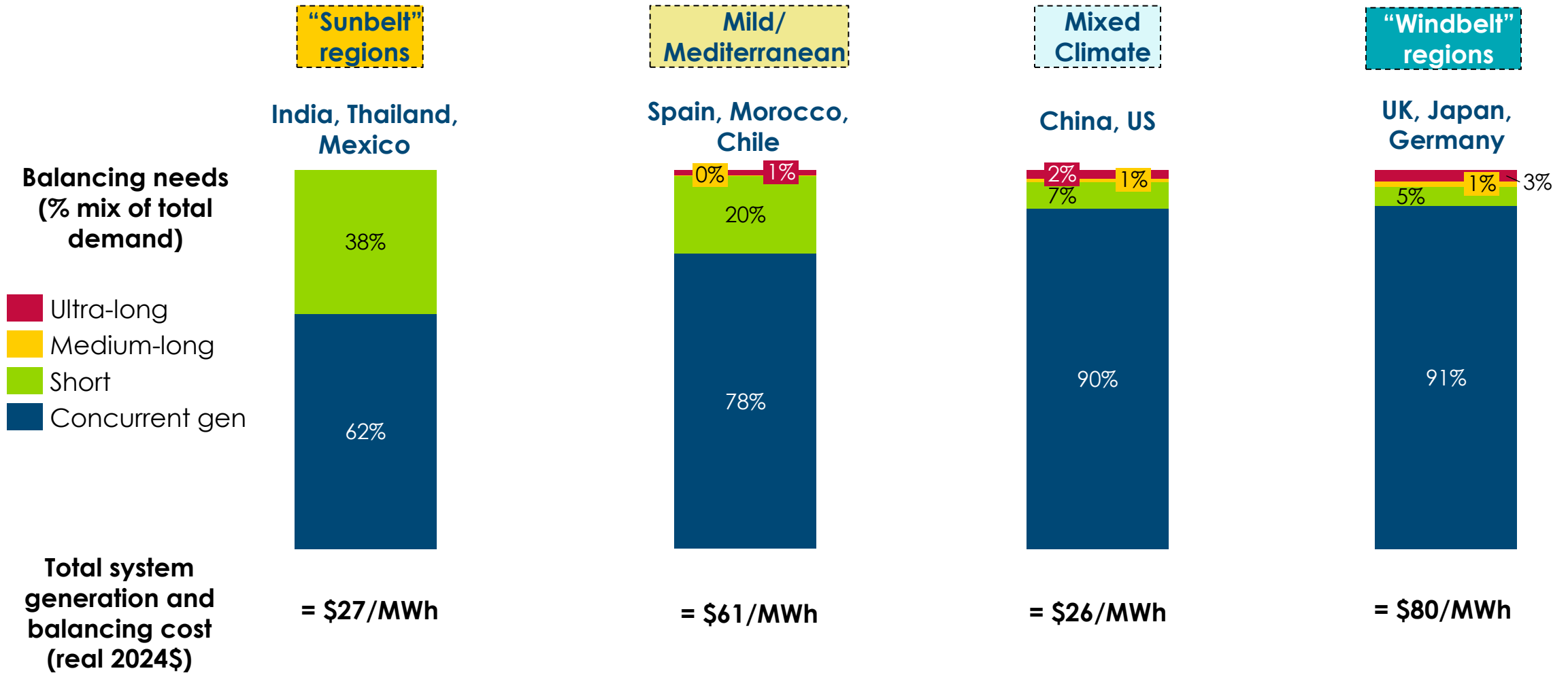


Note: Generation costs are derived based on the generation mix using BNEF 2050 mid CAPEX and OPEX estimates, alongside capacity factors from the average weather year supply scenario (representing the long-term average), 30-year project lifetimes, and real WACC of 4%, 5%, and 6% for solar, onshore wind, 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:


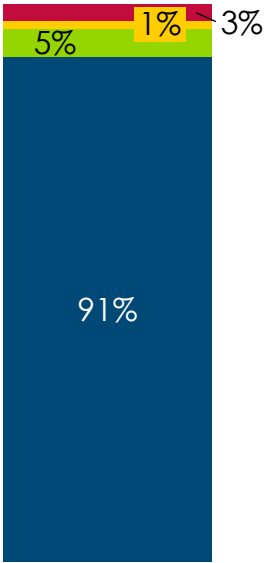



Source: Systemiq analysis for the ETC (2025)

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	 <p> Ultra-long (3%) Short (5%) Medium-long (1%) Wind and solar (91%) </p>	<p>Generation: 778 TWh at \$45/MWh</p> <p>Short storage: 26 TWh at \$80/MWh</p> <p>Medium-long: 7 TWh at \$170/MWh</p> <p>Ultra-long: 16 TWh at \$460/MWh</p>	 <p> Ultra-long (14) Short (4) Medium-long (2) Generation (60) Total: 80 </p>

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**

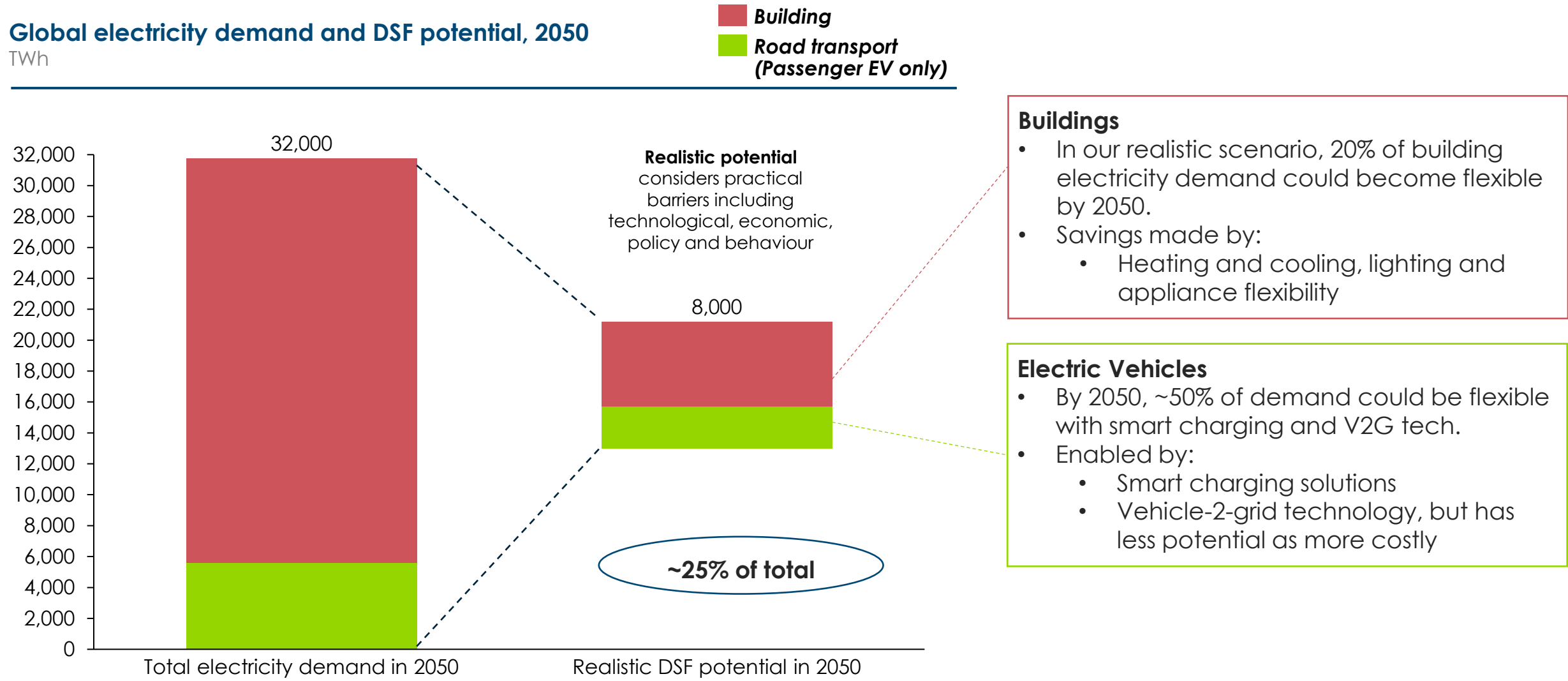
Note: Generation costs are derived based on the generation mix using BNEF 2050 mid CAPEX and OPEX estimates, alongside capacity factors from the average weather year supply scenario (representing the long-term average), 30-year project lifetimes, and real WACC of 4%, 5%, and 6% for solar, onshore wind, 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.



3 ~25% of building + passenger EV electricity demand in 2050 could be flexible

Global electricity demand and DSF potential, 2050

TWh



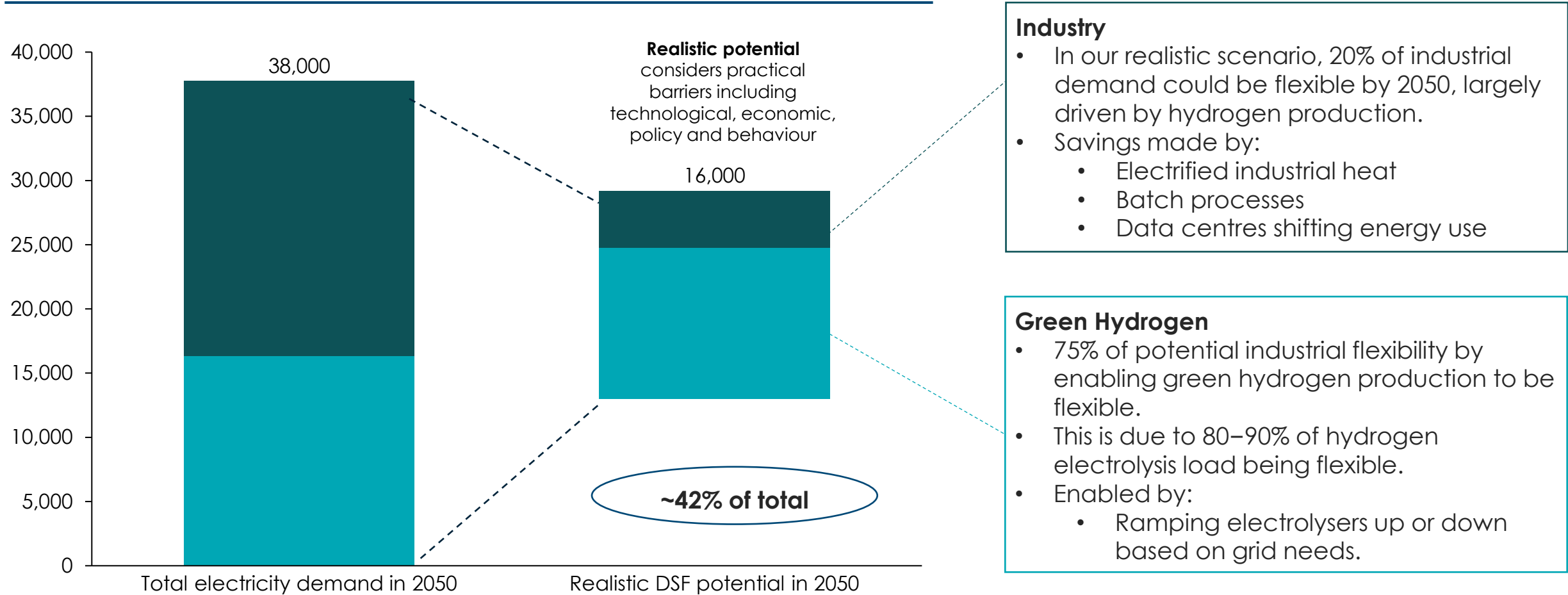
Note: In our DSF Briefing Note, we look at two scenarios "realistic" and "theoretical" to consider the ideal possibilities and what can be realistically achievable. In this analysis, we focus on the realistic potential of DSF, as it provides a more grounded and actionable view of what can be delivered 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
■ Green Hydrogen

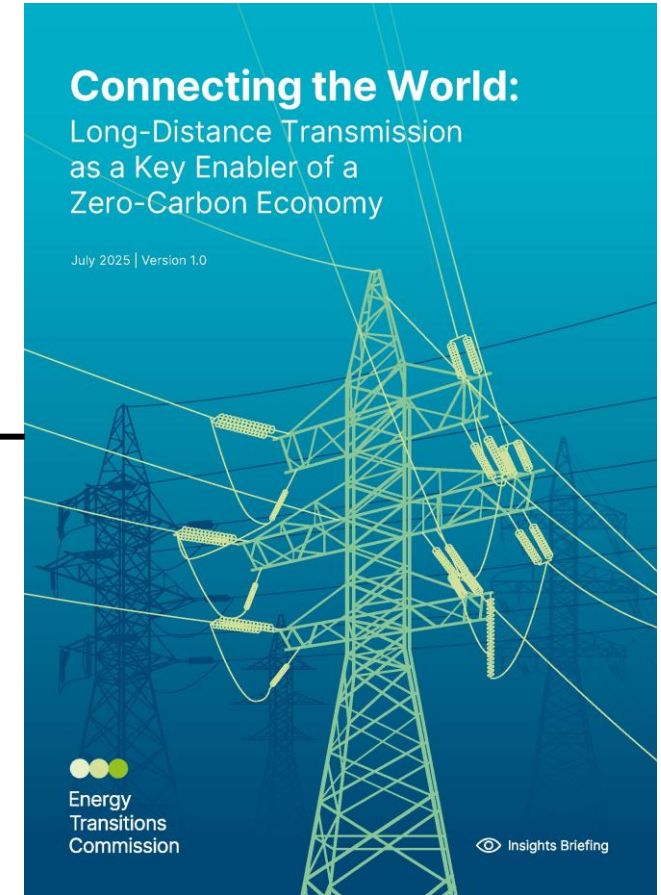
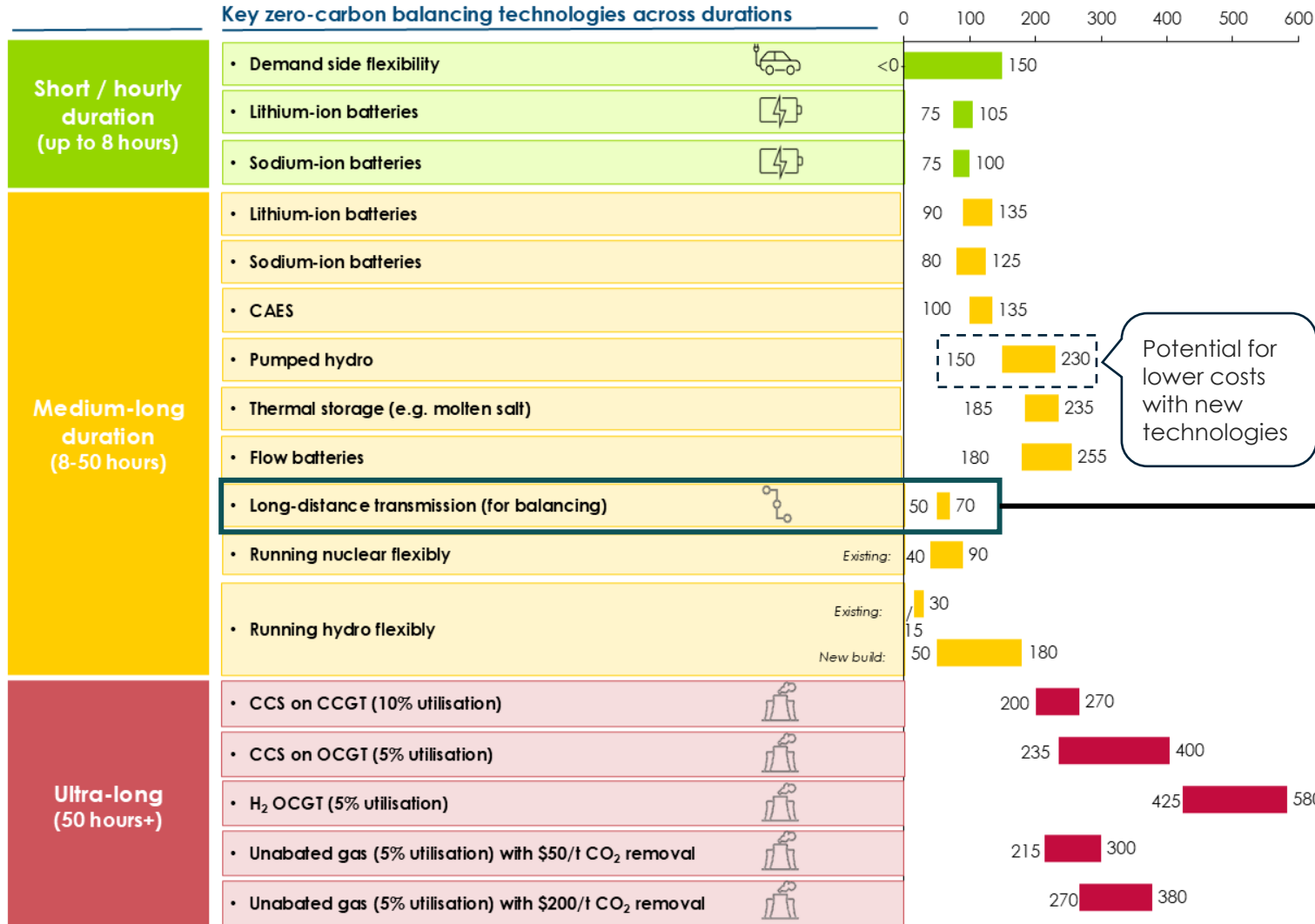


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4 Long-distance interconnection, batteries and pumped hydro are a very cost-effective flexibility source at longer durations, if feasible

Electricity cost of \$40/MWh (applies only to selected technologies)
\$/MWh

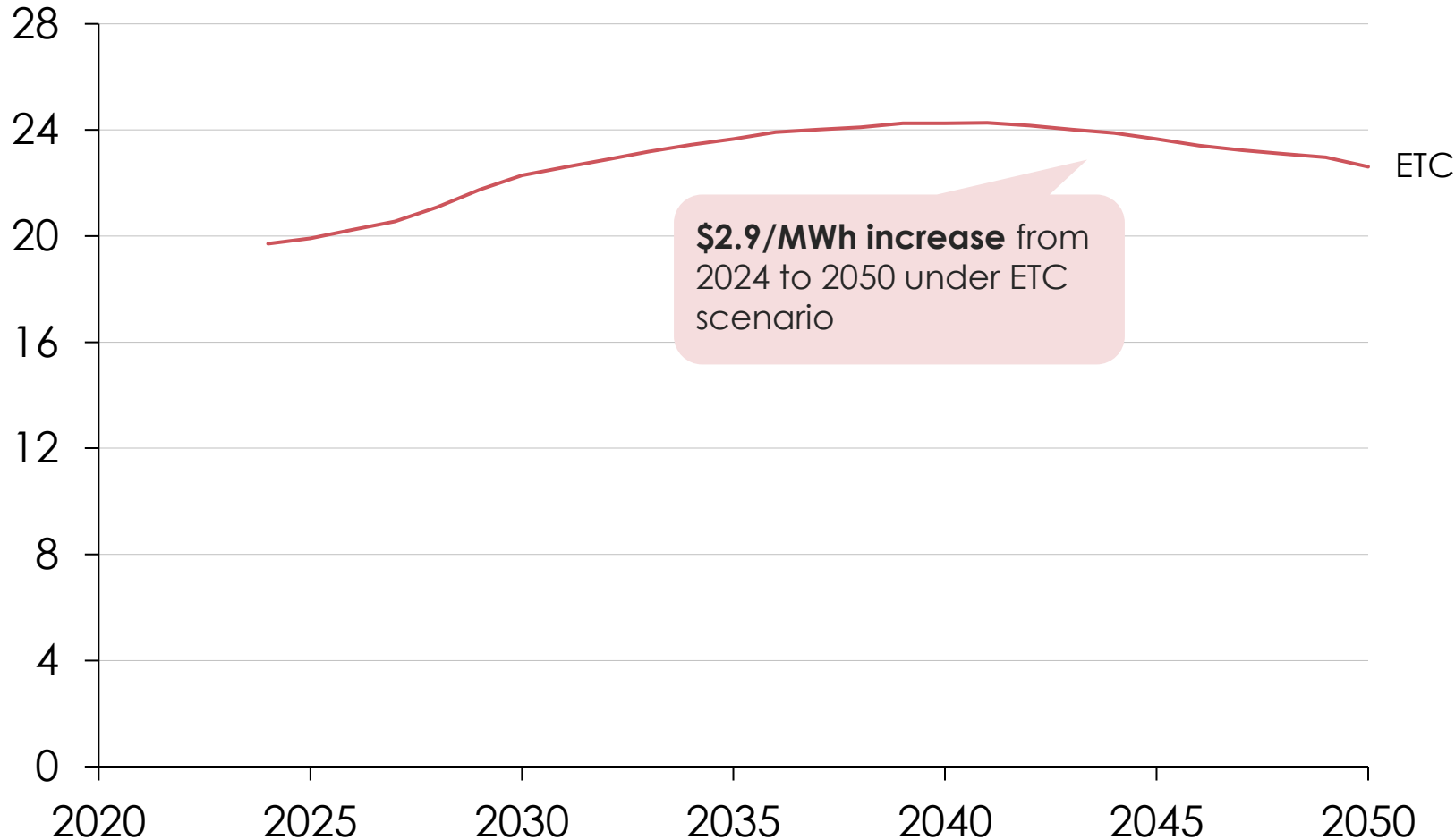
Cost of delivered electricity in 2035



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.

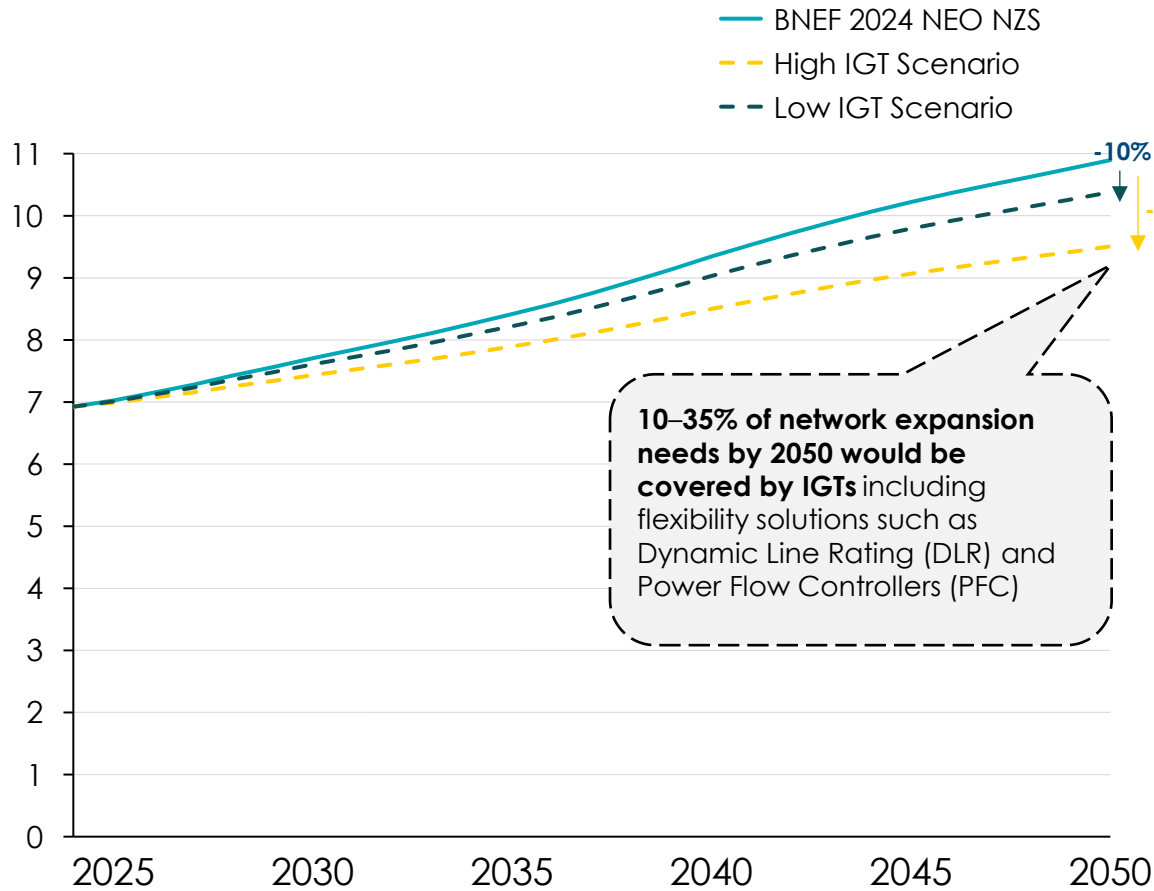


5

Innovative Grid Technologies could significantly reduce grid build & CAPEX

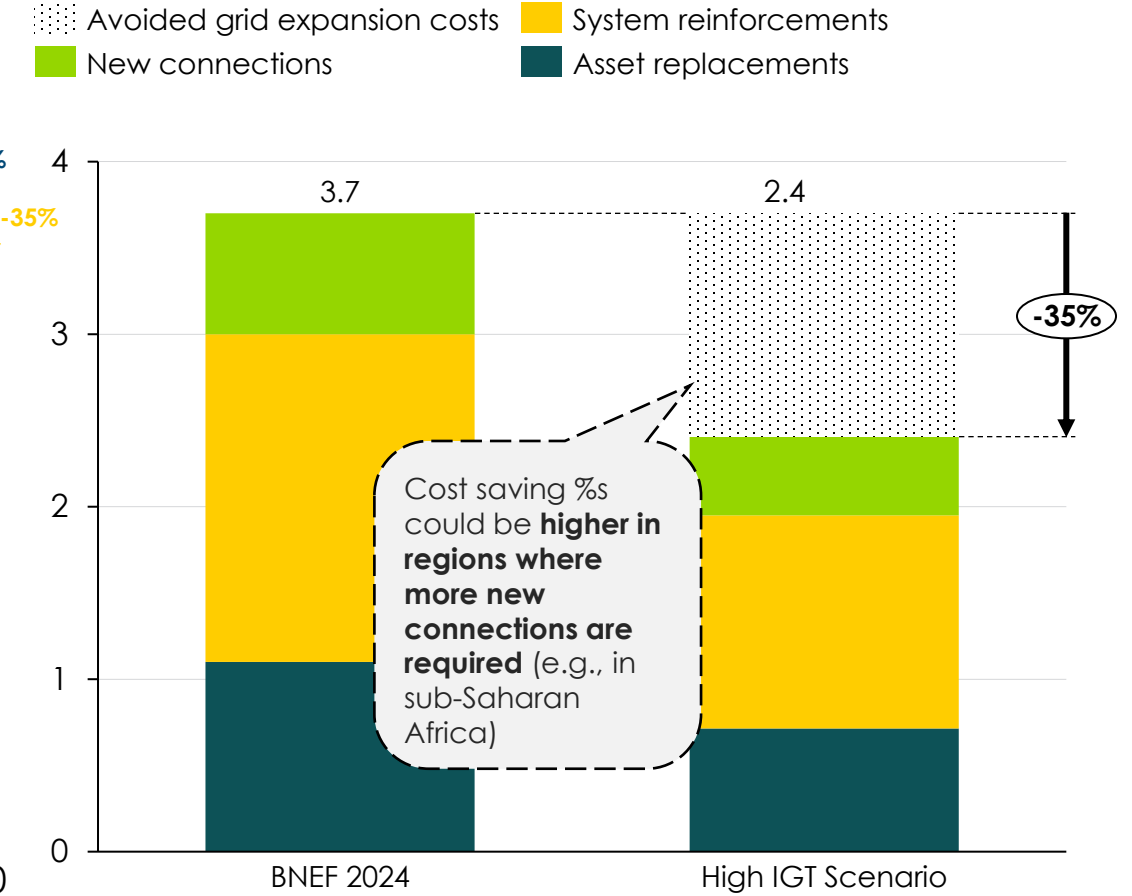
Benefits of IGTs compared to network expansion needs

Million km, Europe, 2024–2050



Cumulative investment in new power grid system, Europe

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



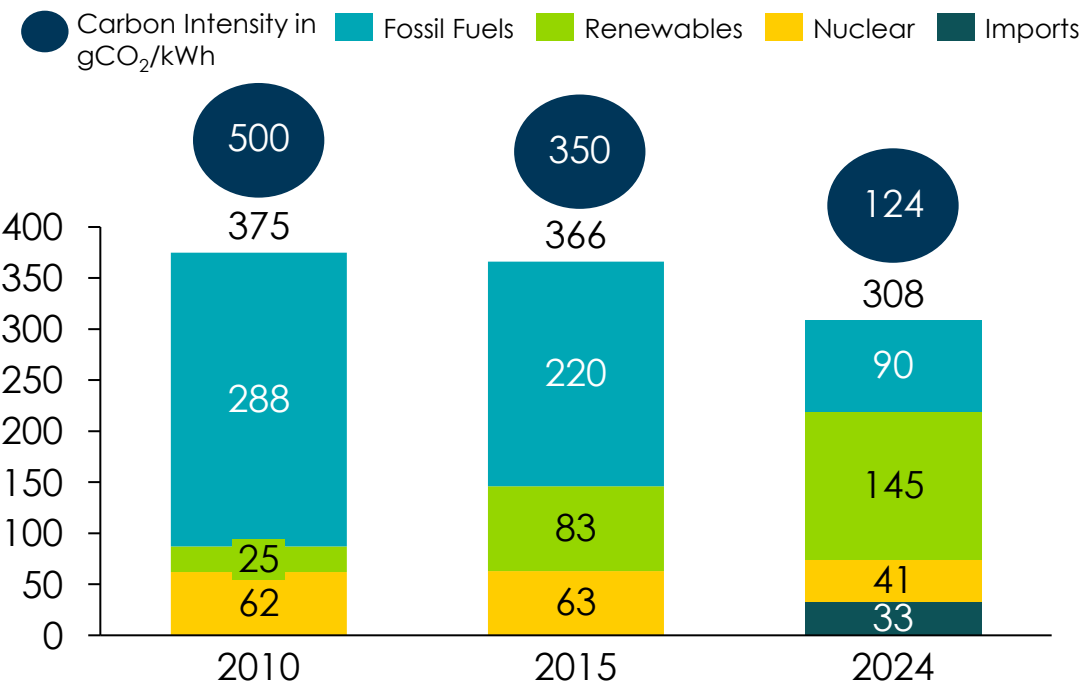
5 Balancing electrification and decarbonisation: the risks of a mismatch



Developed Countries e.g. UK

UK electricity generation and average emissions intensity, 2010–2024

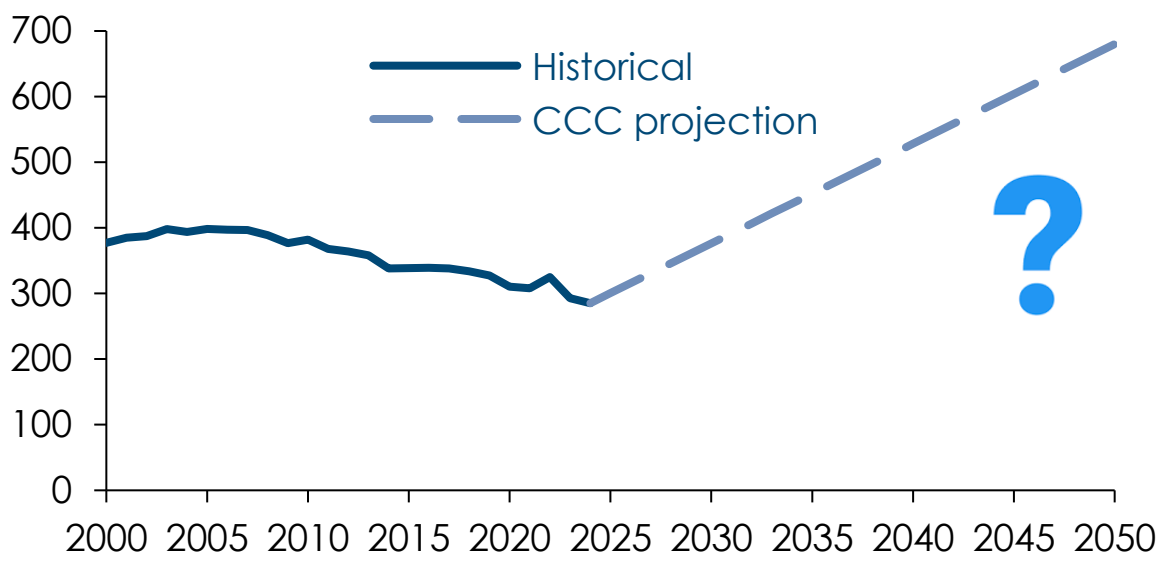
TWh



- **Decarbonisation occurring rapidly** in countries like the UK from 500g CO₂ 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

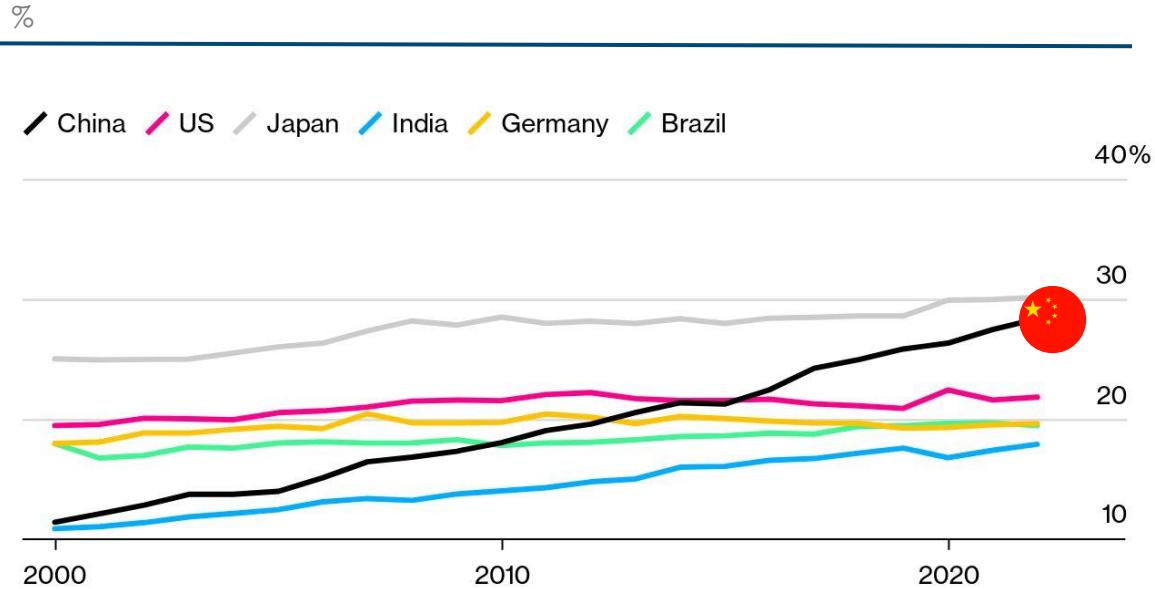
Notes: CCC balanced pathway forecast only includes direct electrification, line extrapolated from 2050 value. Source: Carbon Brief (2024), Analysis: UK emissions in 2023 fell to lowest level since 1879; Ember (2025) Electricity data explorer; CCC (2025) Seventh Carbon Budget



5 Balancing electrification and decarbonisation: the risks of a mismatch

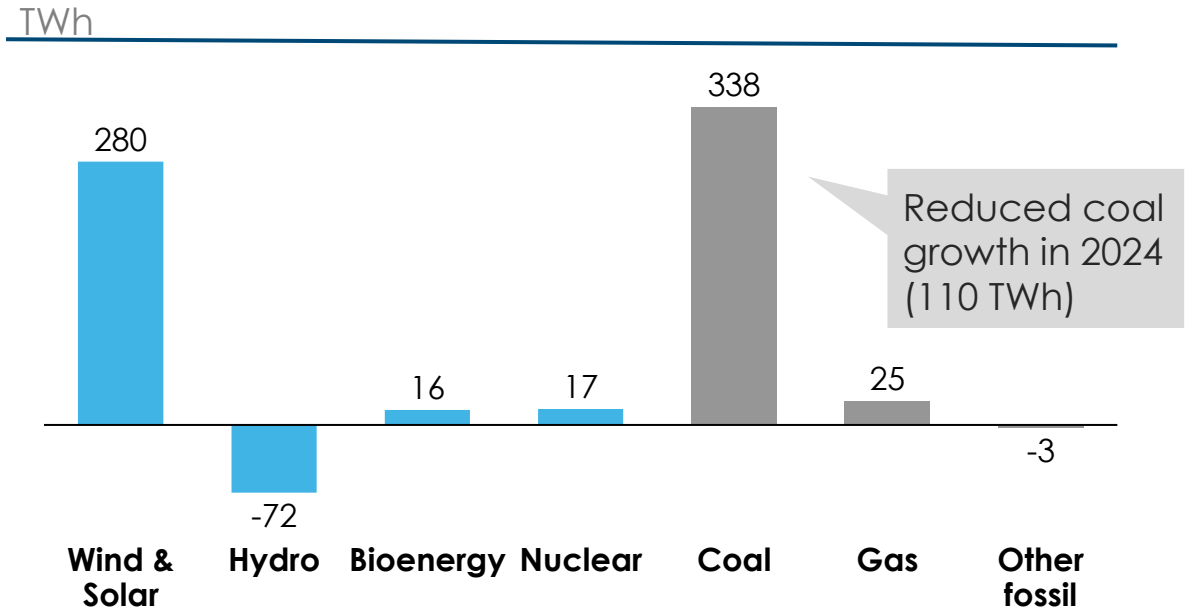
Developing Countries e.g. China

Electricity's share of final energy consumption



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

China changes in electricity generation, 2023



- But **supply is not yet decarbonised**, with China's power intensity remaining over 500g CO₂/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



Demand side flexibility – unleashing untapped potential for clean power

In February 2023, countries must submit new “nationally determined contributions” or NDCs, setting new, more ambitious emissions reduction targets for 2035. In our recent publication, *Cleaner Contributions: Better Plans for Europe’s Climate Ambition*, the Board of the ETC highlights that current NDCs for 2030 are 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 decarbonise electricity. At COP28, a Global Energy Storage and Grids Pledge was signed by 58 countries, including Brazil, the United States and United Kingdom. The Pledge builds on COP26’s pledge to triple renewables by 2030, signalling 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 GWh by 2030 and to add or refurbish 25 million km of grids as set out by the International Energy Agency (IEA).¹

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-users – demand is now positioned to play a much larger role in actively responding to system needs.

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

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.

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

Short-duration Flexibility Ladder

Demand side flexibility is the ability to shift the consumption of electricity at peak times. As renewables rapidly scale up, integrating more demand-side flexibility will be crucial to balancing the grid and maximising the use of clean electricity. It can help households and businesses lower energy bills and reduce strain on the grid - unlocking a more resilient energy system for all.

High Priority	Shedding	Shifting	Distributed Storage	Other solutions
Low cost, low barriers, high efficiency, potential for automation	the ability to reduce electricity use for a short time period and typically on short notice	the ability to change the timing of electricity use	the ability to store excess energy (e.g., electricity, heat) during low-demand periods and release it during peak demand	
A Virtually free solutions	Home smart systems (actions either combined or separate) Dynamic temperature adjustment (heat pump/AC) Lighting sensors	Pre-heating/cooling in well-insulated homes Smart EV smart charging (residential) Commercial building management systems Centralised, dynamic HVAC systems	EV battery swapping Hot water storage	Existing interconnectors
B Low-cost, easy-to-implement solutions		Crypto mining Shifting data centre demand ¹	Industrial heat battery-boilers (e.g. heat storage) Distributed energy storage (e.g. batteries)	Existing flexible hydro Grid scale lithium-ion batteries
C Moderate-cost solutions		Timing “batch” production processes (e.g., paper, food); flexible aluminium electrolysis Flexible industrial maintenance Running H2 electrolyzers flexibly		
D High-potential but capital-intensive solutions			Residential Vehicle to Grid (V2G)	Other storage ² New interconnectors
E High-cost, high-barrier solutions				
F Expensive, low-priority solutions				
G Undesirable				
Low Priority/Undesirable High cost, high barriers				

Note: This DSF ladder infographic is published under CC-BY 4.0 and the ladder concept has been adapted from Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 5.0, 2023. Original Concept credit: Ashraf Hani, Energy Cities.
¹Non-critical data processes, such as AI training, can be postponed or shifted to low-demand periods without real-time constraints. Flexibility also exists when companies run computing centres across different countries / regions to allow load shifts over geographies.
²Medium-duration storage (including pumped hydro) is less competitive for short-duration balancing than batteries, driven by the higher round-trip efficiency of batteries.

Elena Pravettoni • 1st
Head of Analysis at Energy Transitions Commi...
4d • 600 reactions

As renewables rapidly scale up, how can we balance and optimise power systems and maximise the use of clean electricity?

Demand side flexibility - the ability to shift consumption of electricity at peak times - is essential, helping to lower energy bills and deliver benefits for the grid.

Excited to share a new infographic the Energy Transitions Commission team and I have been developing over the past weeks as part of our ongoing power systems transformation work.

Our Demand Side Flexibility Ladder, adapted from Michael Liebreich's Clean Hydrogen ...more

267 reactions • 32 comments • 17 reposts

Love Comment Retost Send

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)

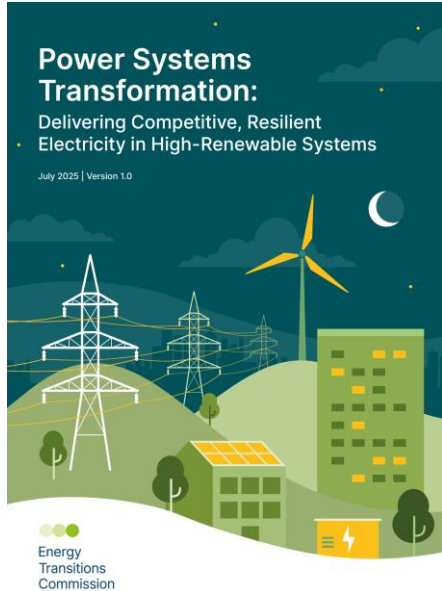
Michael Liebreich “This is great... to understand that there are smarter and dumber solutions, and to get the discussion focused.”

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



Europe's first grid crisis may not be its last



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



The great Iberian power cut need not spell disaster for renewables



We briefed:

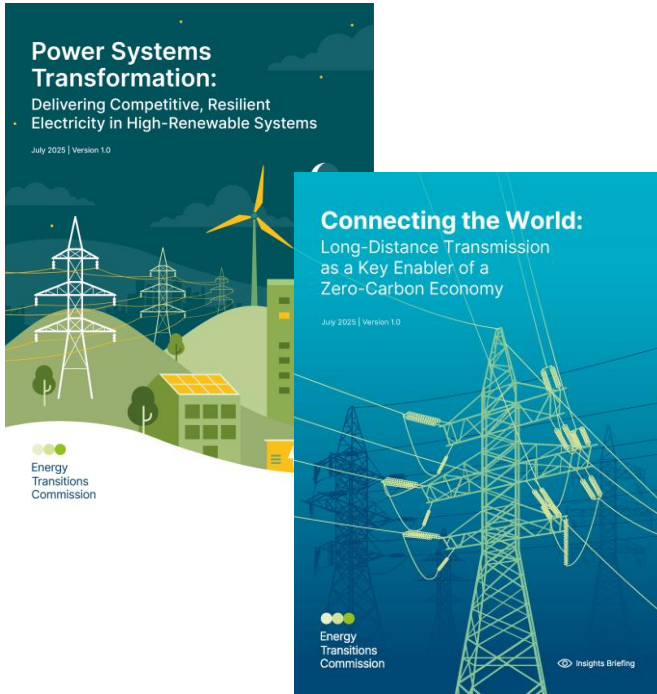
- **Journalists**, including The Economist, Financial Times & Reuters
- **Media panel with GSCC - 30 Tier 1/European media**

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 

TROPICAL COUNTRIES CAN HALVE POWER COSTS BY 2050 BY RELYING ON SOLAR:

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

 **CARBONCOPY**
MAKING CLIMATE SENSE



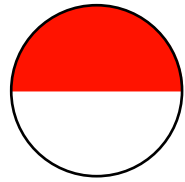
Engagement & Partnerships

- **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



Next steps in the power systems campaign

Region-specific engagement



Indonesia
New Energy
Systems



Africa Sunbelt
opportunity



India AgriPV



UK balance
sheet

Second wave of media and engagement (Sep-Nov)



Global
Renewables
Alliance



CLIMATE
WEEK
NYC
CLIMATE GROUP



FT FINANCIAL
TIMES



COP30
BRASIL
AMAZONIA
BELEM 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

Short-form content development, topic focus



Innovative Grid Technologies:
1-2 page briefing & op-ed



Baseload optimisation tool



Key messages video

“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

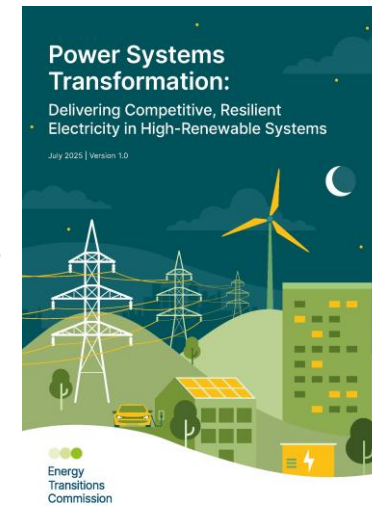
Ongoing debates that we've addressed

- 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?

Other debates addressed by new work

- What is the role of nuclear and geothermal in clean power systems?
- How can we enable low costs to pass through to consumers?

2025



2024/5



2024/5



To be addressed in a new ETC workstream in 2025 with a report published in 2026

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

- **Renewed political momentum:** >20 countries pledged at COP28 to triple capacity by 2050
- **Corporate buyers** (Microsoft, Google) exploring nuclear
- **Large influx of new entrants to the nuclear technology space**
- **Challenges to be addressed:** High upfront cost, long permitting, safety and waste concerns

Geothermal

- **Expanding as a dispatchable renewable** with “always-on” potential
- **New technologies, such as Enhanced Geothermal Systems** broadening geographic reach
- **US DOE “Earthshot” programme** aiming for a 90% cost reduction target by 2035
- **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**



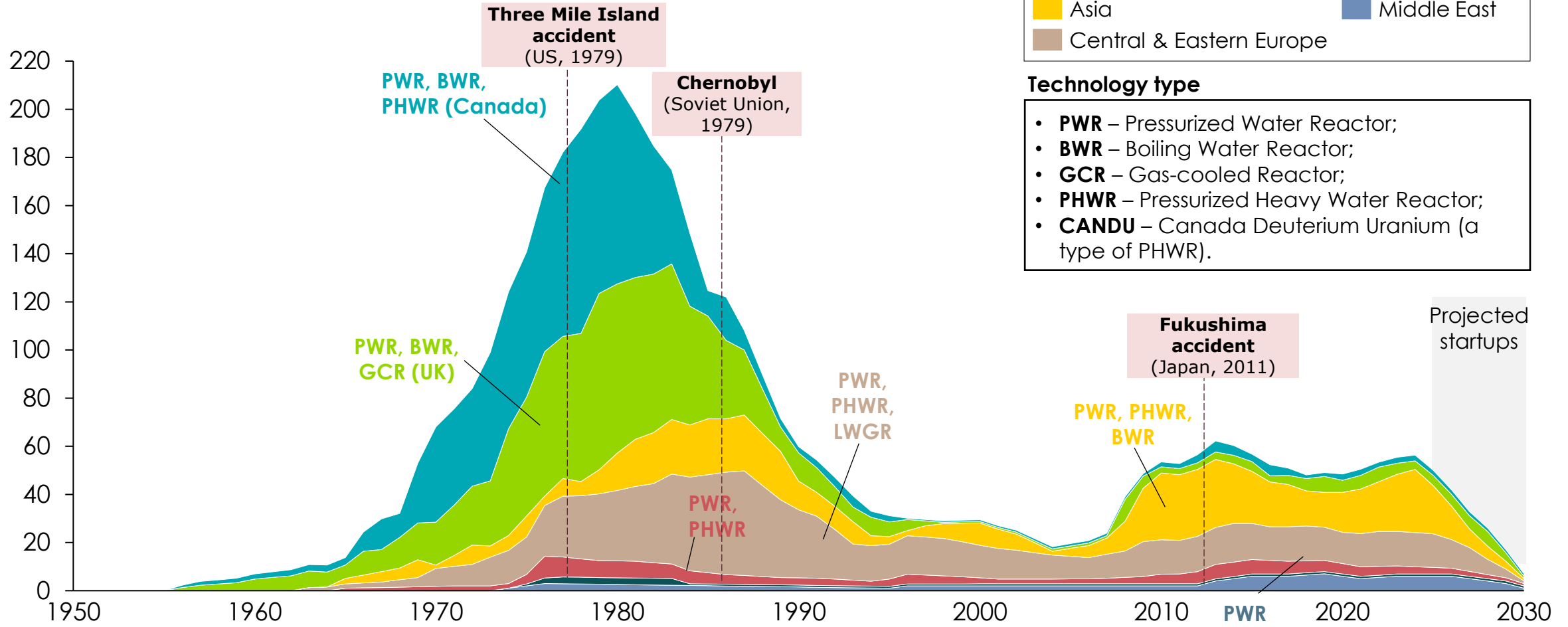
Nuclear



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)



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)

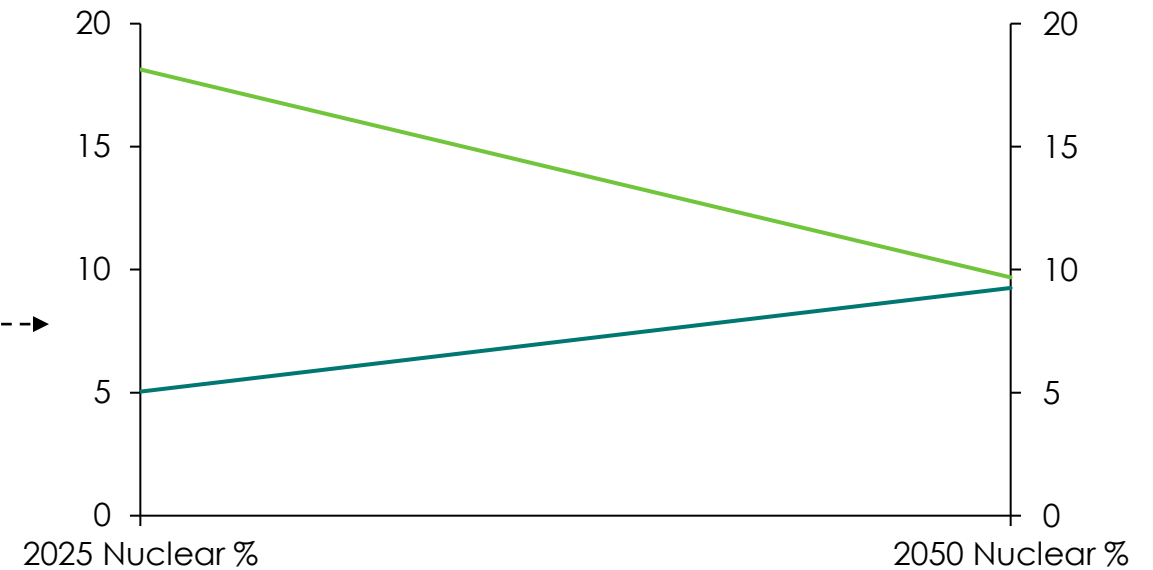
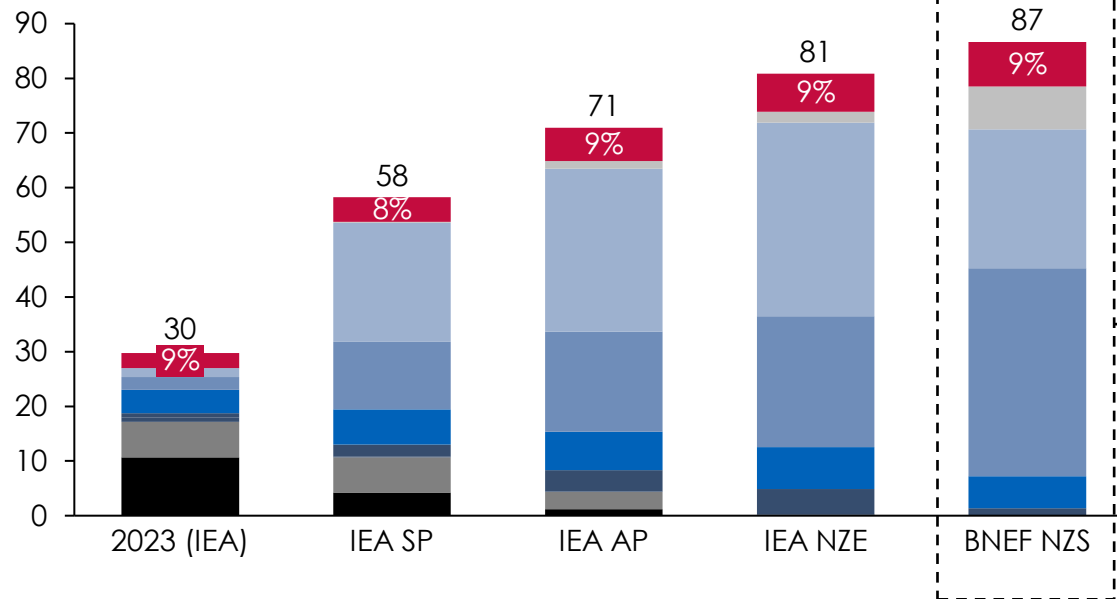
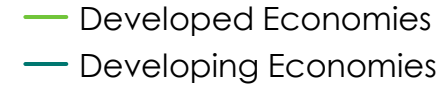
'000 TWh



Nuclear share globally remains ~10% even as total generation increases by 2-3x by 2050.

Average nuclear share of generation by region in BNEF NZS

% of Generation

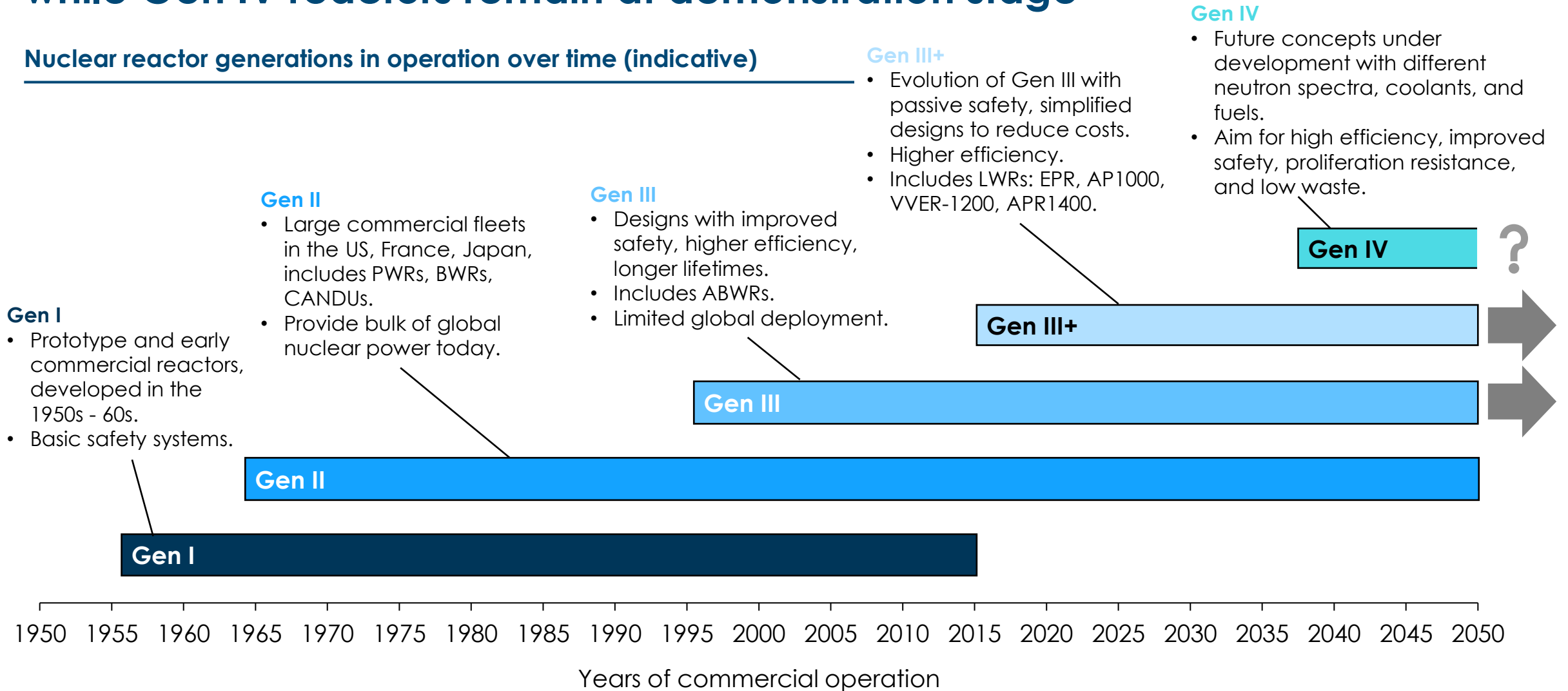


In many cases, nuclear plant lifetimes can and should be extended safely. Nuclear plant lifetime extensions are frequent but do present some risks (e.g. structure/component ageing, technical limitations and physical ageing of system design).

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

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

		Decreasing Maturity			
		TRL (Technology readiness level)	FOAK (1 st commercial deployment)	NOAK (Large-scale deployment)	
Gen I - III	Conventional large-scale reactors		TRL 9	1956	1956
Gen III+	Small Modular Reactors (SMR)		TRL 2-8	2029 +	2035 +
Gen IV	Next-generation reactors		TRL 2-8	2030 +	2035 +
	Fusion		TRL 2-5	2040 +	2050 +

- Global standard for commercial nuclear energy since the 1960s.
- The main types are Pressurised Water Reactors (PWRs) and Boiling Water Reactors (BWRs).
- SMRs are compact reactors (10 – 500 MW) built in factories and shipped for assembly
- Growing commercial interest due to scalability and flexibility
- Next generation of nuclear fission technologies which use novel coolants including:
 - High-temperature gas reactors
 - Liquid metal reactors
 - Molten salt reactors
 - Fast breeder reactors
- 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

Notes: FOAK first of a kind TRL 9+ deployment; NOAK = nth 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*



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

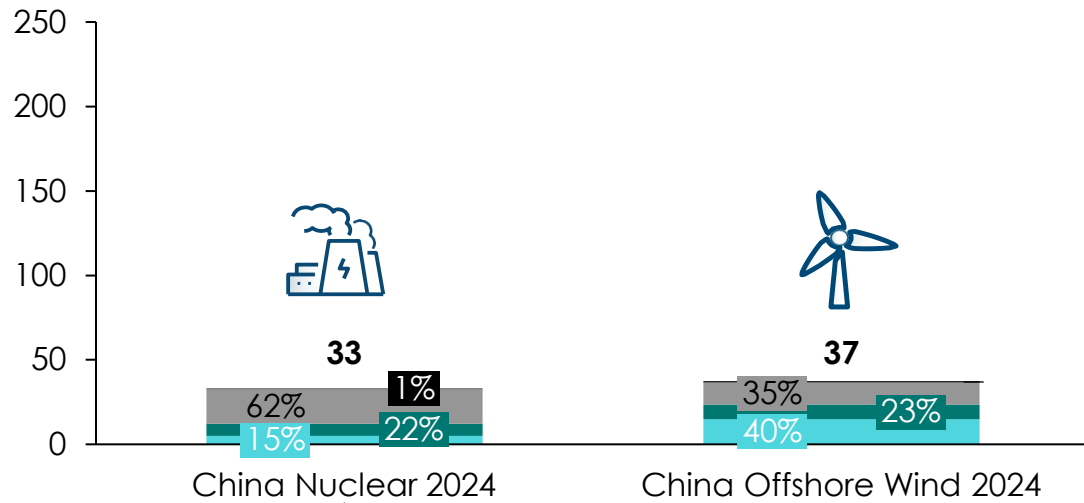
China: Nuclear and offshore wind indicative LCOE breakdown

\$/MWh, real 2024

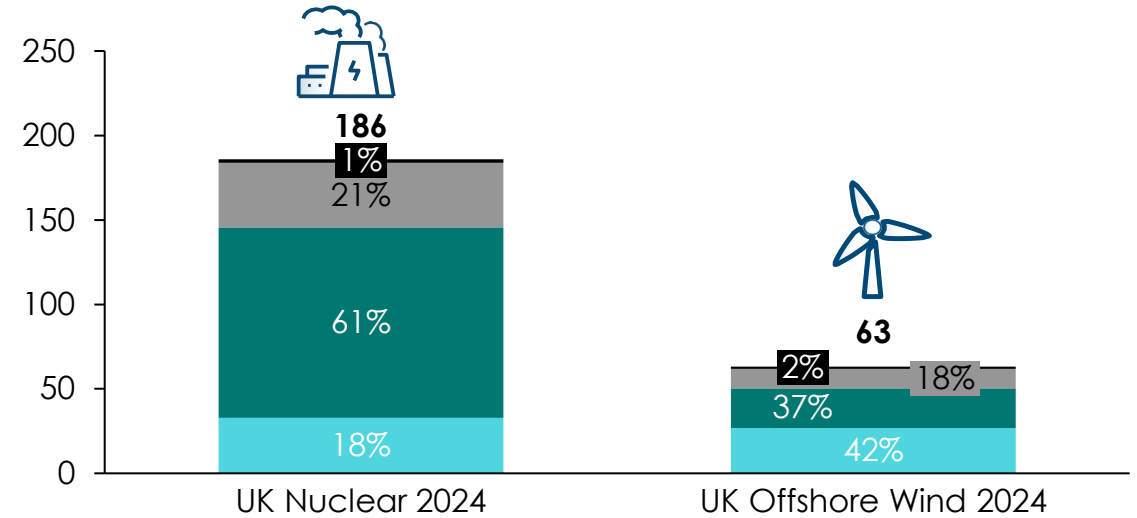


UK: Nuclear and offshore wind indicative LCOE breakdown

\$/MWh, real 2024



- **WACC:** 3%, real
- **Overnight CAPEX:** \$2,400/kW
- **Construction time:** 6 years
- **Capacity factor:** 90%



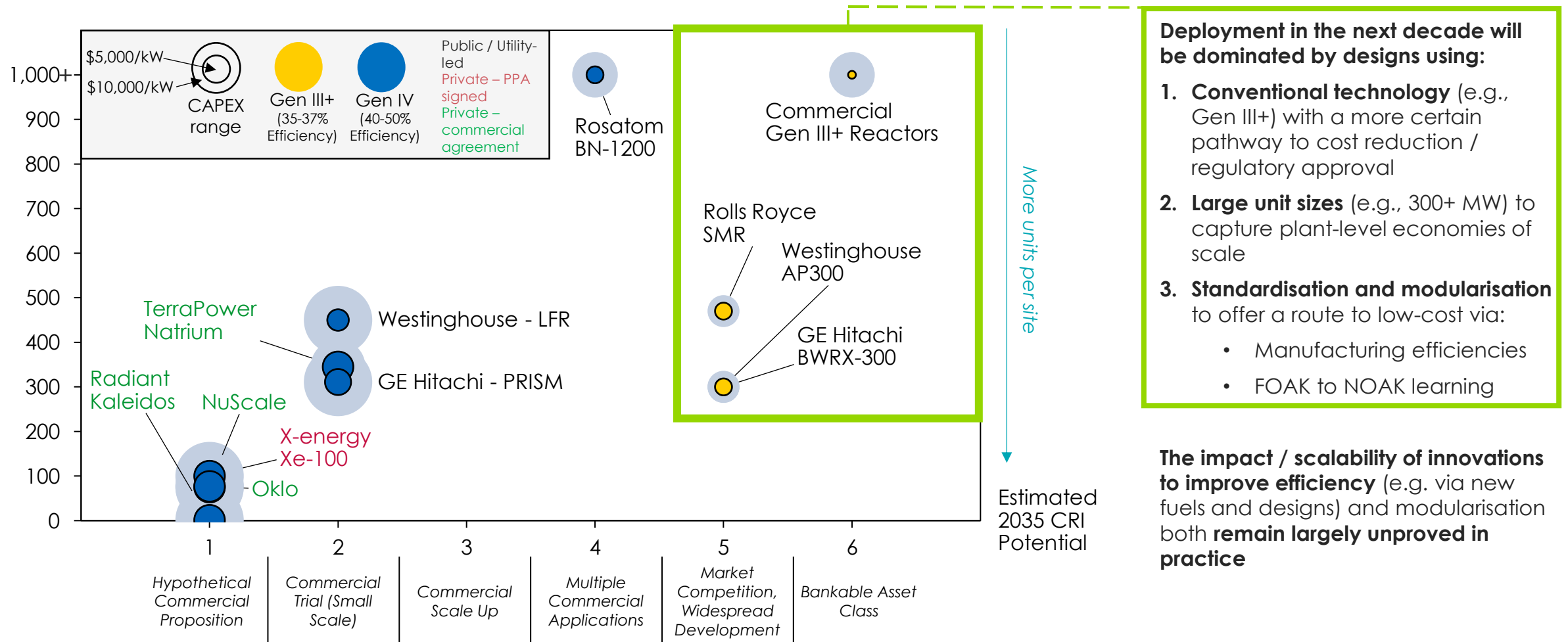
- **WACC:** 5%, real
- **Overnight CAPEX:** \$15,500/kW
- **Construction time:** 10 years
- **Capacity factor:** 90%

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

Next-decade nuclear deployment will be dominated by large Gen III+ reactors, while Gen IV remain lower-readiness and higher-risk

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

Unit Size (MWe)



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 = nth of a kind. Source: Systemiq analysis for the ETC (2025); ARENA (2014), *Commercial Readiness Index for Renewable Energy Sectors*

Geothermal



Geothermal potential spans shallow heating applications to deep power generation

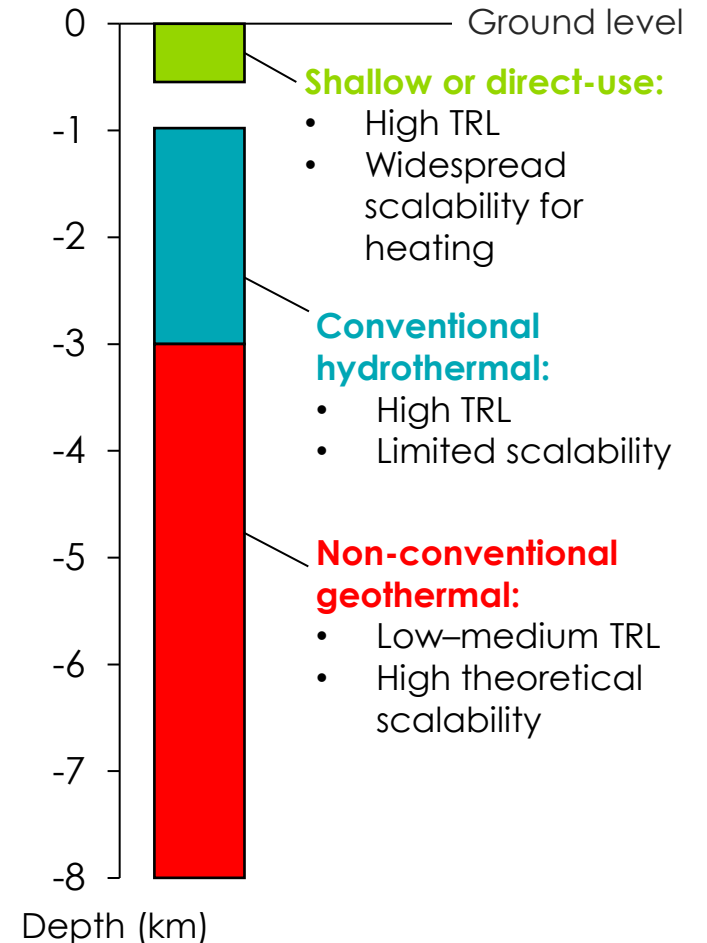
What is geothermal energy?

- **Thermal energy stored in rock, soil and fluids beneath the earth's surface**, used for:
 - Ground-source (shallow) heat pumps
 - District heating and cooling
 - Electricity
 - Industrial heat and hybrid applications
- Viability depends on:
 - **Subsurface conditions** (temperature gradient, depth, permeability)
 - **Surface conditions** (heat/electricity demand, infrastructure proximity)

What are the different types of geothermal?

- **Shallow or direct-use (<500 m)**: Ground-source heat pumps, aquifer thermal energy storage, and shallow district heating. Acts as an electricity consumer (via heat pumps) rather than producer.
- **Conventional hydrothermal (1-3 km)**: naturally occurring hot water or steam in permeable rock, used for baseload electricity and large district heating; mature but geographically constrained.
- **Non-conventional geothermal (3-8 km)**:
 1. **Enhanced geothermal systems (EGS)**: expand or create reservoirs by drilling deep wells and increasing rock permeability using hydraulic, thermal, or chemical stimulation methods.
 2. **Closed-loop geothermal systems (CLGS)**: use sealed underground wells as heat exchangers, circulating fluid through deep rock to absorb heat via conduction without interacting with the reservoir.

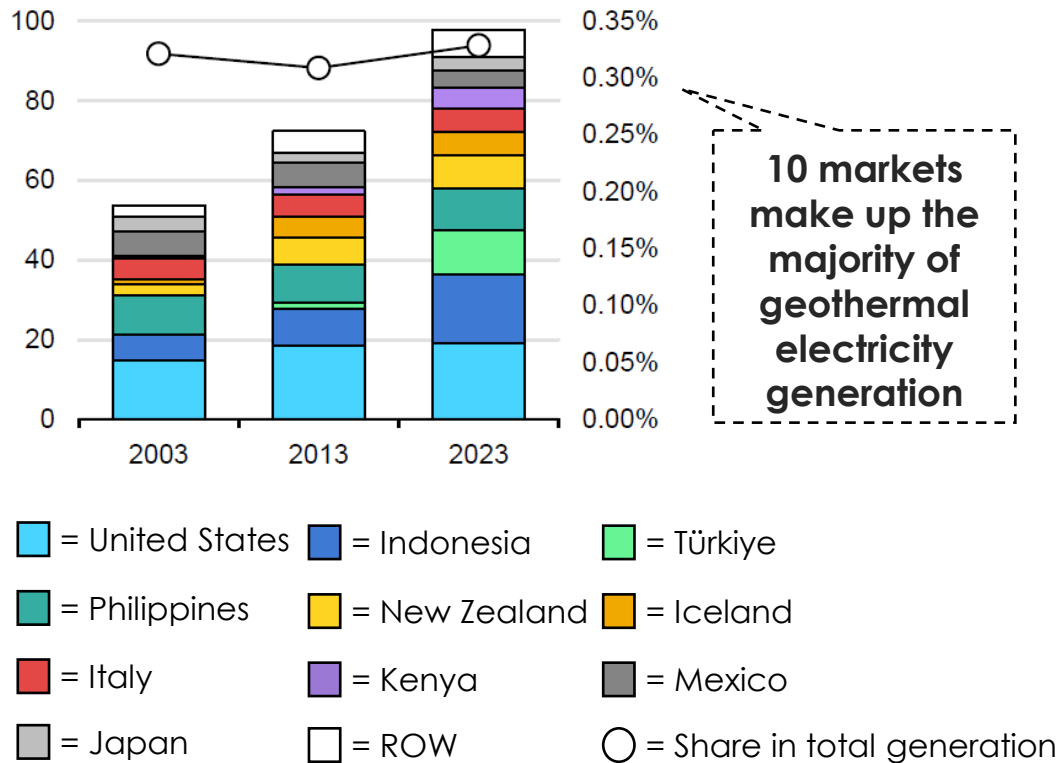
How does depth impact deployment?



Geothermal currently plays a small role in global electricity generation, and is primarily concentrated in a few countries

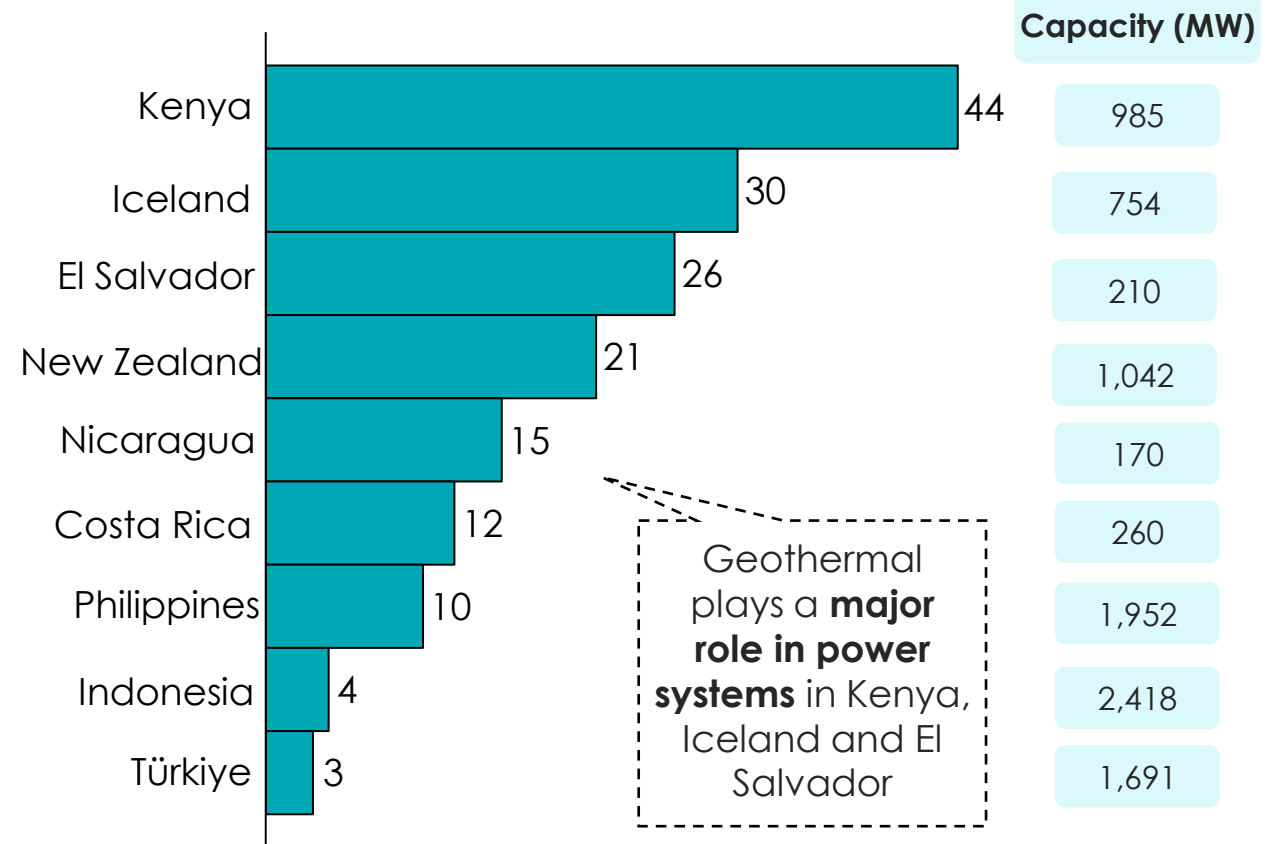
Global electricity generation from geothermal, % of global total

TWh



Share of total national electricity generation, 2023

%

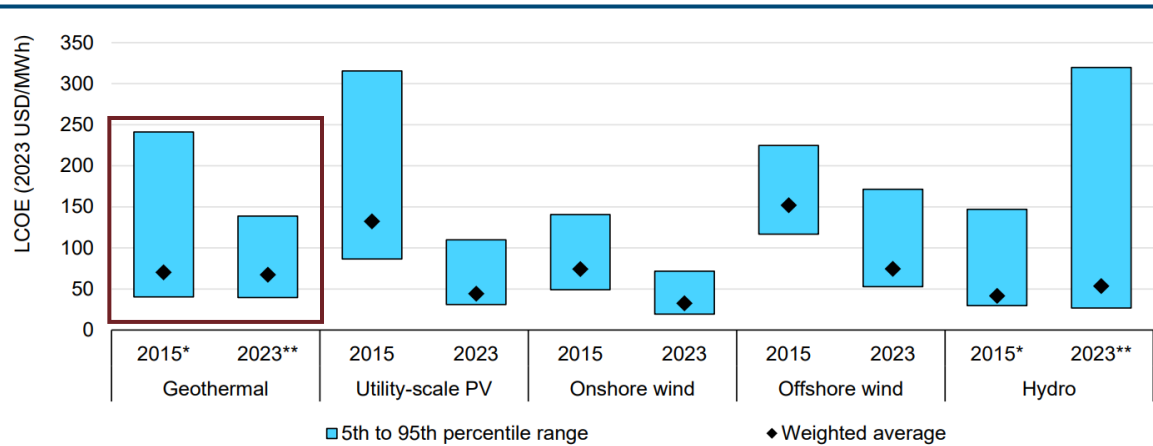


Source: IEA (2024) The Future of Geothermal Energy; ThinkGeoEnergy (2025), ThinkGeoEnergy's Top 10 Geothermal Countries 2023: Power Generation Capacity; SIGET (2024), Capacidad instalada de generacion eectrica 2023; TheGlobalEconomy.com (2024), Nicaragua: Geothermal electricity capacity (MW); International Renewable 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 (1-3 km 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

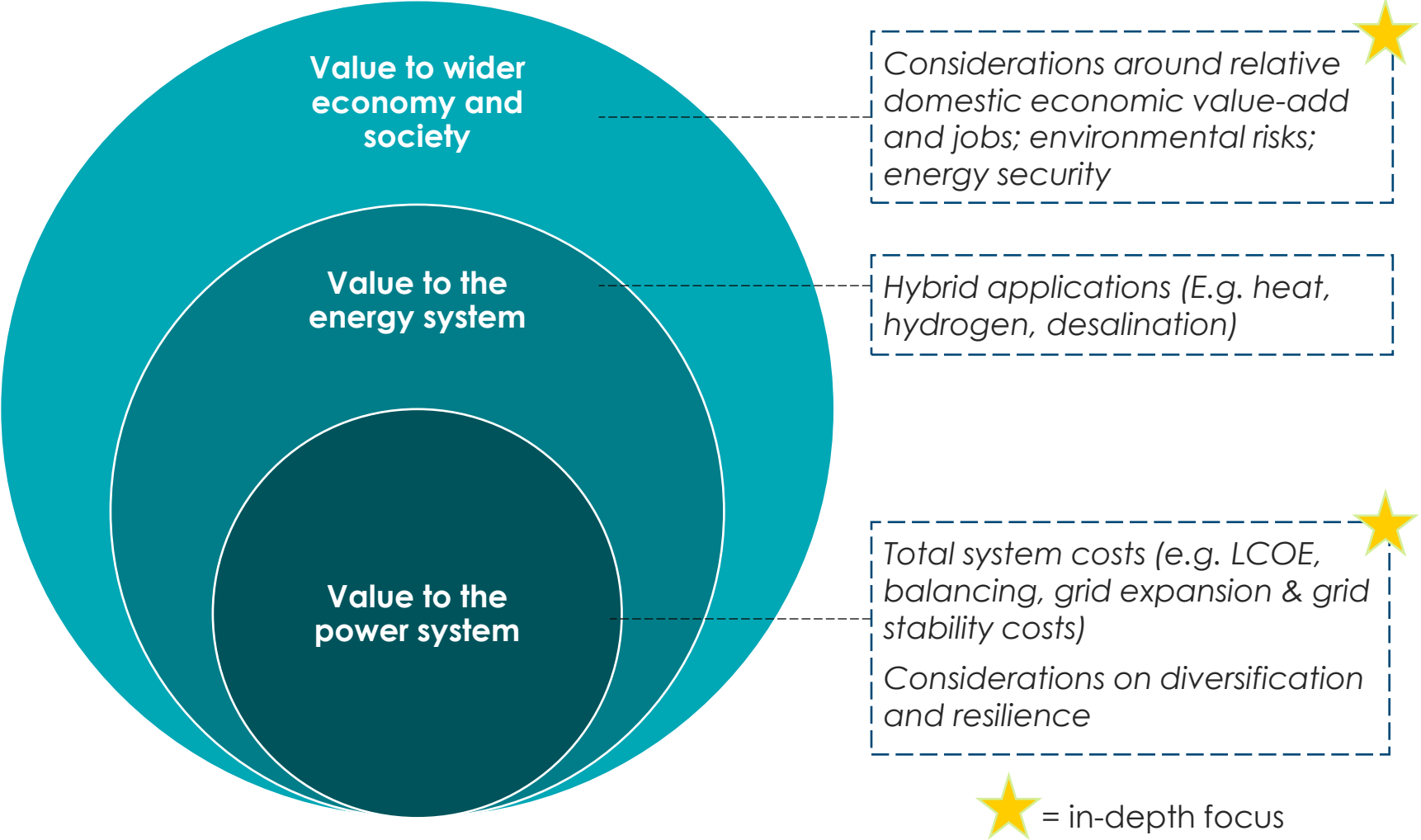
Parameter	Conventional Geothermal	Enhanced Geothermal Systems
LCOE (2023)	~50–140 USD/MWh (IEA data)	80–200+ USD/MWh (higher uncertainty)
Dispatchability	High (baseload power)	
Resource Dependency	Requires hydrothermal reservoirs	Engineered systems; no need for natural reservoirs
Geographic Limitation	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

System value



The system value of nuclear and geothermal energy should be assessed holistically against alternatives



To understand how nuclear and geothermal can complement high-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) - <i>weighted</i>	\$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:** major constraint for renewables; nuclear can reduce reliance on transmission expansion.
- **Lead times:** Nuclear projects typically take >10 years to deliver; renewables + storage can be built within 2–5 years.



System Operation

- **High renewables systems** are technically and economically feasible
- **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 for renewables.
- **Political dynamics:** 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)?

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, hydrogen, storage integration)?

Sufficient enabling capacity: Across regulation, funding, and workforce



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: The role of Geothermal	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.

