



Energy
Transitions
Commission

Unlocking Enablers for Power Systems Transformation

3rd February 2025

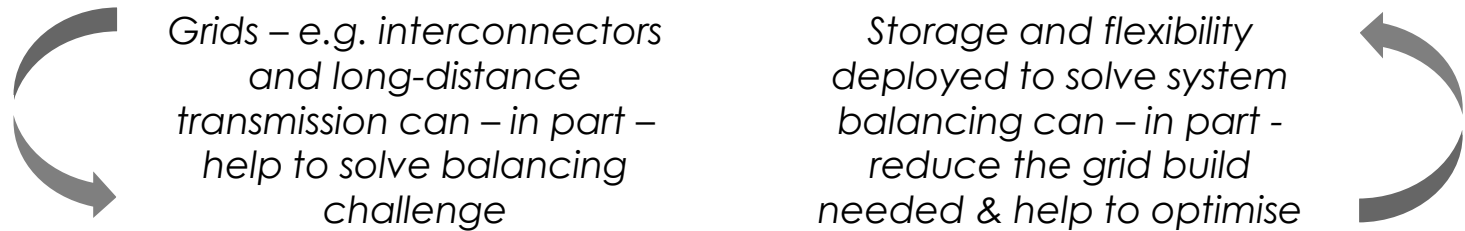
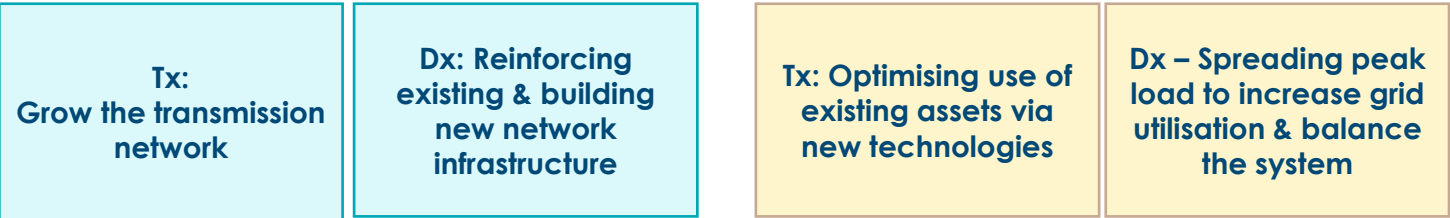
Workshop agenda

1. **Context: How the power system is changing and the role of emerging technologies**
2. **Key enablers required to deploy these technologies**
 1. Market design
 2. Grid regulation
 3. Data, infrastructure and workforce
 4. Financial and economic incentives
 5. Consumer engagement
3. **Conclusions**



This year, focus on two key challenges for power systems transformation

Building and optimising grids



Managing the system balancing challenge (in high variable renewable systems)



Running future power systems raises two major challenges, can be addressed via a set of emerging technologies

Build & optimise grids

Need to build vast amounts of new grids, as well as optimise new and existing grids for maximum efficiency.

Manage system balancing

Need to manage the system balancing challenge, which arises as the penetration of wind and solar grows



Innovative grid technologies



Flexible dispatchable generation



Energy storage



Heat storage



Demand side flexibility



Long distance interconnection

Context: How the power system is changing and the role of emerging technologies



Power generation will need to expand significantly to 2050

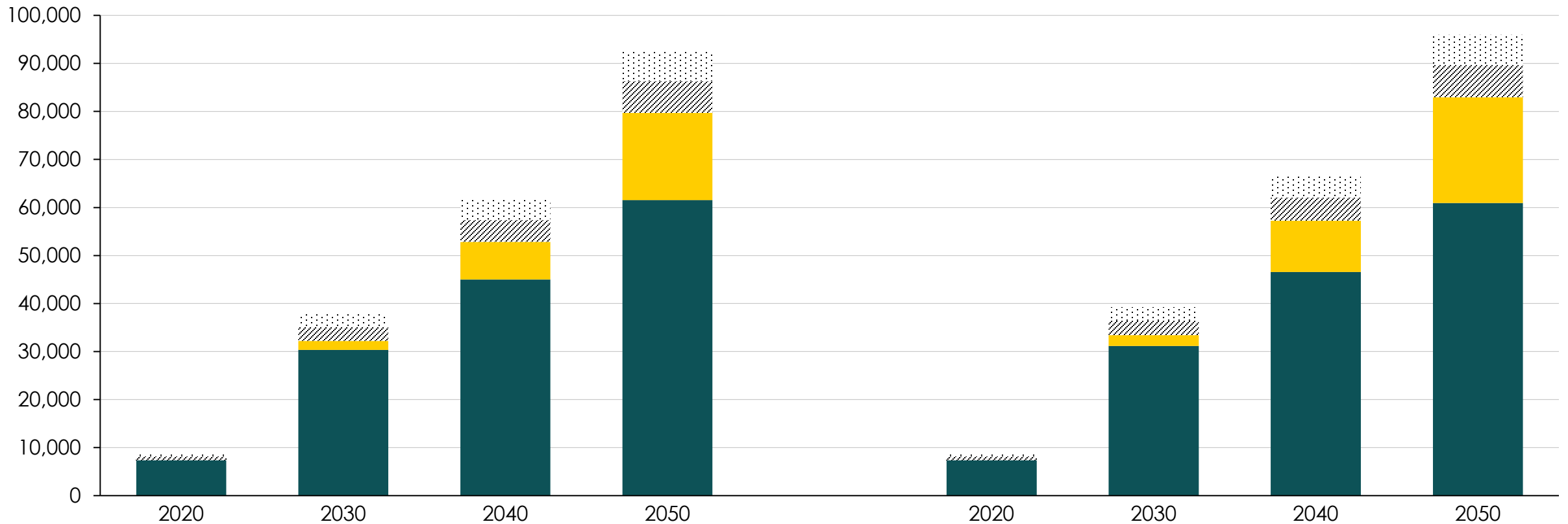
Annual electricity demand, 2024–2050

TWh

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

ACCELERATED BUT CLEARLY FEASIBLE (ACF)

POSSIBLE BUT STRETCHING (PBS)



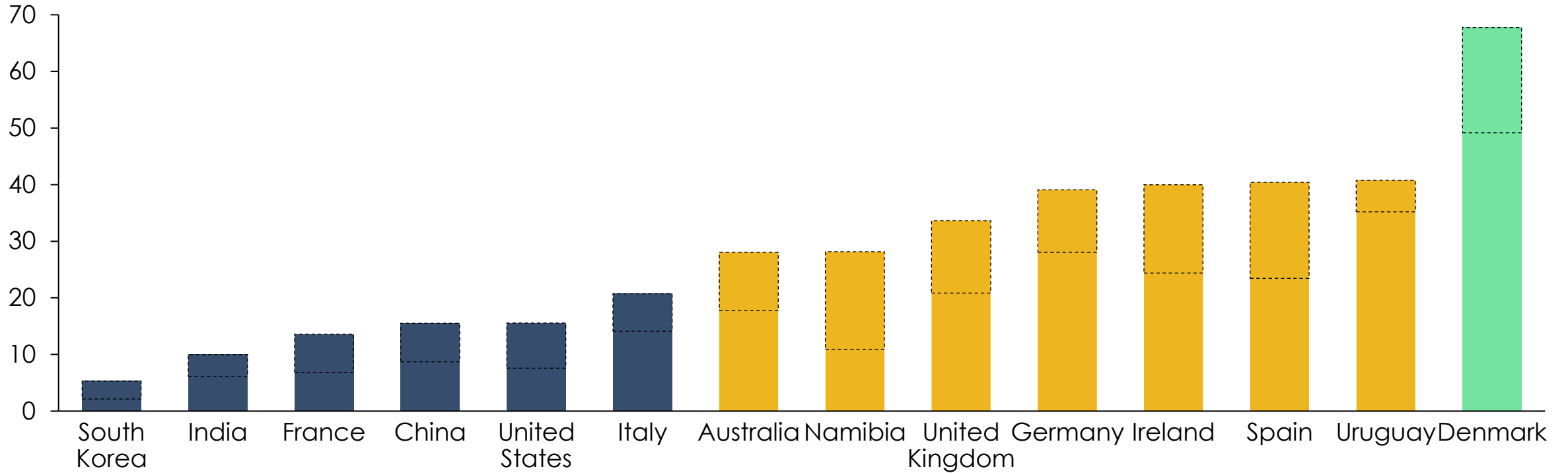
Note: ¹Mainly from green sources. ²Final energy demand from Modern biomass to be finalized. Excludes wood products, pulp and paper.
 Source: Systemiq analysis for the ETC (2023)



Wind and solar are growing as share of global power generation

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

% Wind and solar annual electricity generation, 2018, 2023



This points to three phases of system operation:

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

2023
 2018



Source: Ember (2024), *Electricity Data Explorer*, featuring latest available data (2023)

Building and optimising grids

Build & optimise grids

Need to build vast amounts of new grids, as well as optimise new and existing grids for maximum efficiency.



Innovative grid technologies



Energy storage



Heat storage



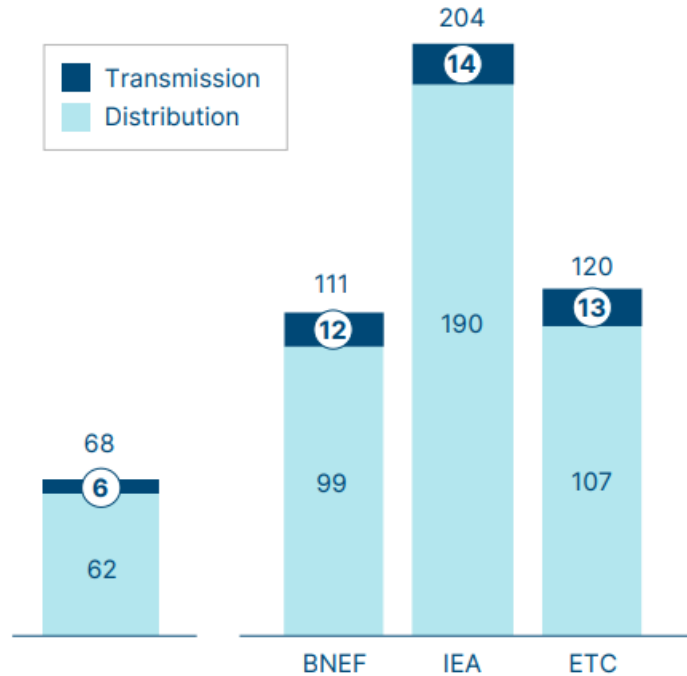
Demand side flexibility



Long distance interconnection

Network build will have to increase drastically across regions

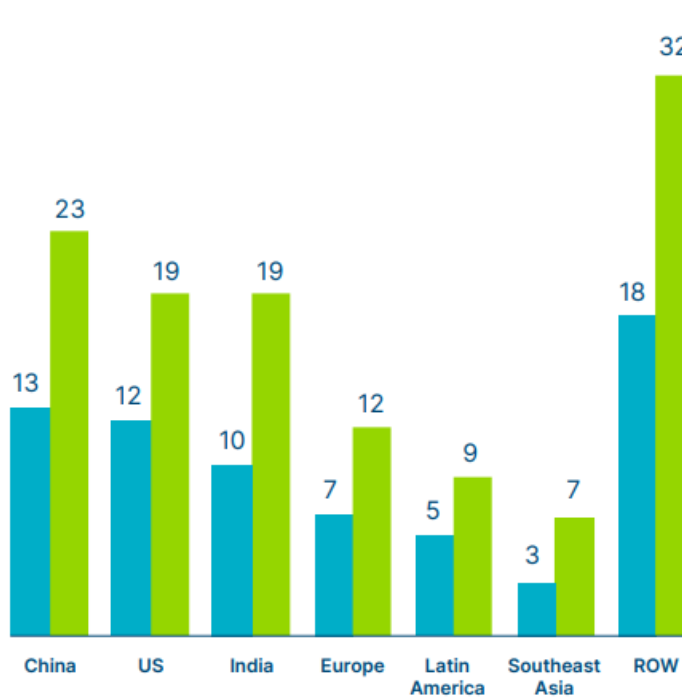
Estimated wires required under various assumptions
Million km



2023 **2050**

Significantly more transmission and distribution wires are needed

Estimated wires required from 2023 to 2050
Million km



2023 vs 2050

All regions will have to increase their estimated wire build substantially under a net-zero scenario



- **Grid growth should aim to optimise the system**, reducing total build required by deploying innovative grid technologies that increase the efficiency of power flows, increasing storage and flexibility and the use of long-distance interconnectors.
- **However, even full deployment of all optimisation routes will not eliminate the need to build new grids**



Innovative Grid Technologies can help power flow more efficiently

Existing rights of way *Changes to pylons and wires*

Existing wires and networks *No changes to pylons and wires*

Main methods to increase grid capacity:

Capacity increase for a given line

- Direct capacity improvement compared to conventional technologies

Better understanding of actual line limits

- A static limit must be very conservative, to not overload lines in adverse (hot) conditions;
- Dynamic ratings exploit natural line cooling

Dynamically controlling power flows on the grid

- Power flows through a network are often limited by its weakest line
- By dynamically controlling power flows (e.g. like road traffic management) more capacity is unlocked on the existing grid

Better understanding of actual inertia limits/stability limits

- Inertia on the grid decreases with more RES in the system, which may cause stability issues and RES curtailment
- Precise measurement of inertia allows curtailment to only happen when necessary

Technology options:

- **Advanced conductors**
- **Superconductors**
- **Voltage upgrade** (via larger pylons)
- **Double circuiting**
- **SATA** (Storage as transmission asset)

- **Dynamic Line Rating**

- **FACTS** (Flexible AC Transmission systems)

- **Grid inertia measurements**

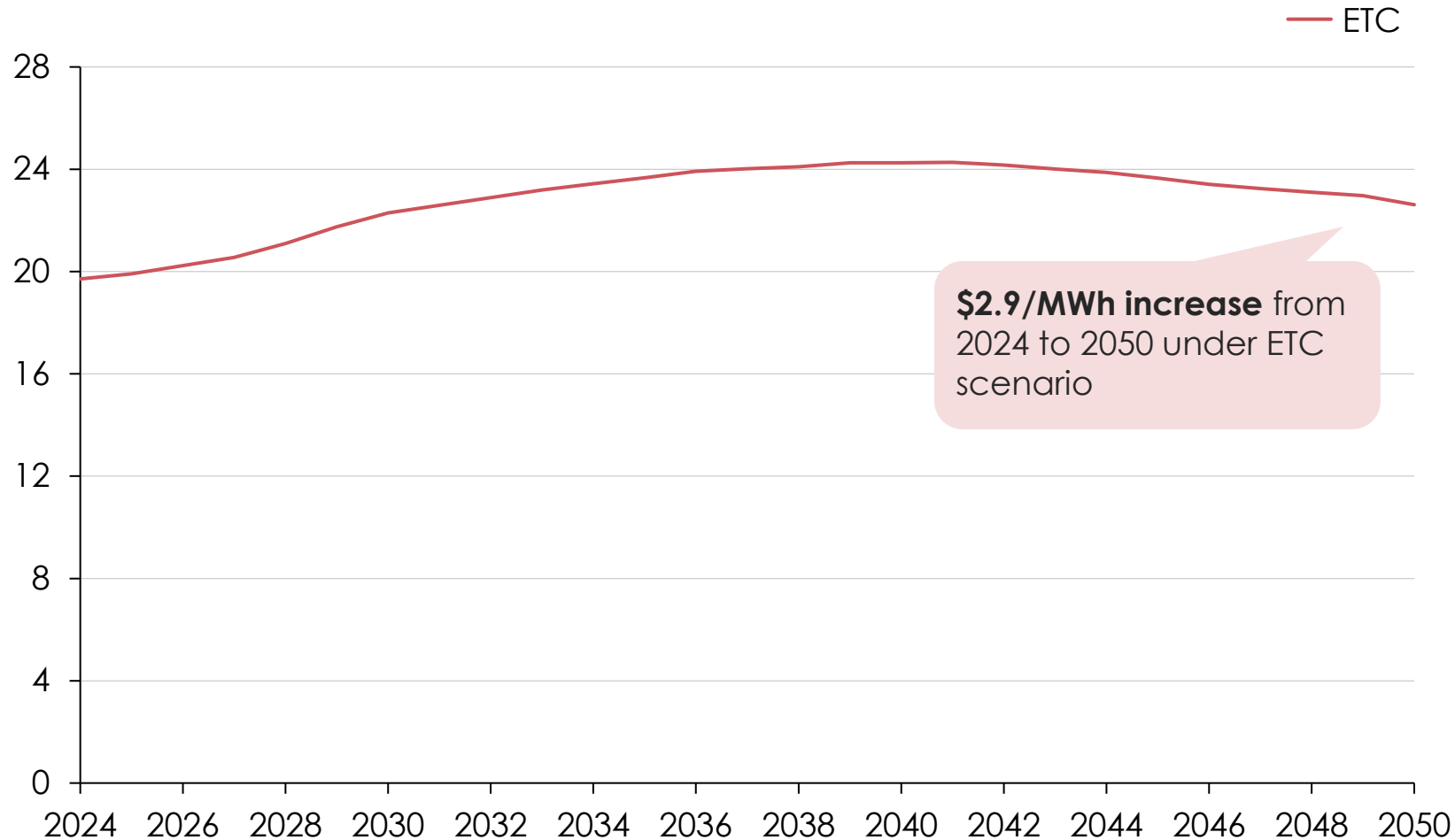
- **Digital twins, Flexibility software management solutions**



Grid Capex costs per MWh could be in line with today

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

\$/MWh; interest rate = 5%



\$2.9/MWh increase from 2024 to 2050 under ETC scenario

- **Initial increase in cost per unit of demand** is due to the upfront investments needed to build and reinforce the grid infrastructure for the anticipated rise in electricity demand
- As electrification progresses and demand increases, **the cost per unit of demand decreases** because the fixed costs are spread over a larger volume of electricity consumption. Additionally, grid optimization measures can further reduce the need for additional grid build, lowering overall costs.



Managing the system balancing challenge

Build & optimise grids

Need to build vast amounts of new grids, as well as optimise new and existing grids for maximum efficiency.

Manage system balancing

Need to manage the system balancing challenge, which arises as the penetration of wind and solar grows

Innovative grid technologies



Flexible dispatchable generation



Energy storage



Heat storage



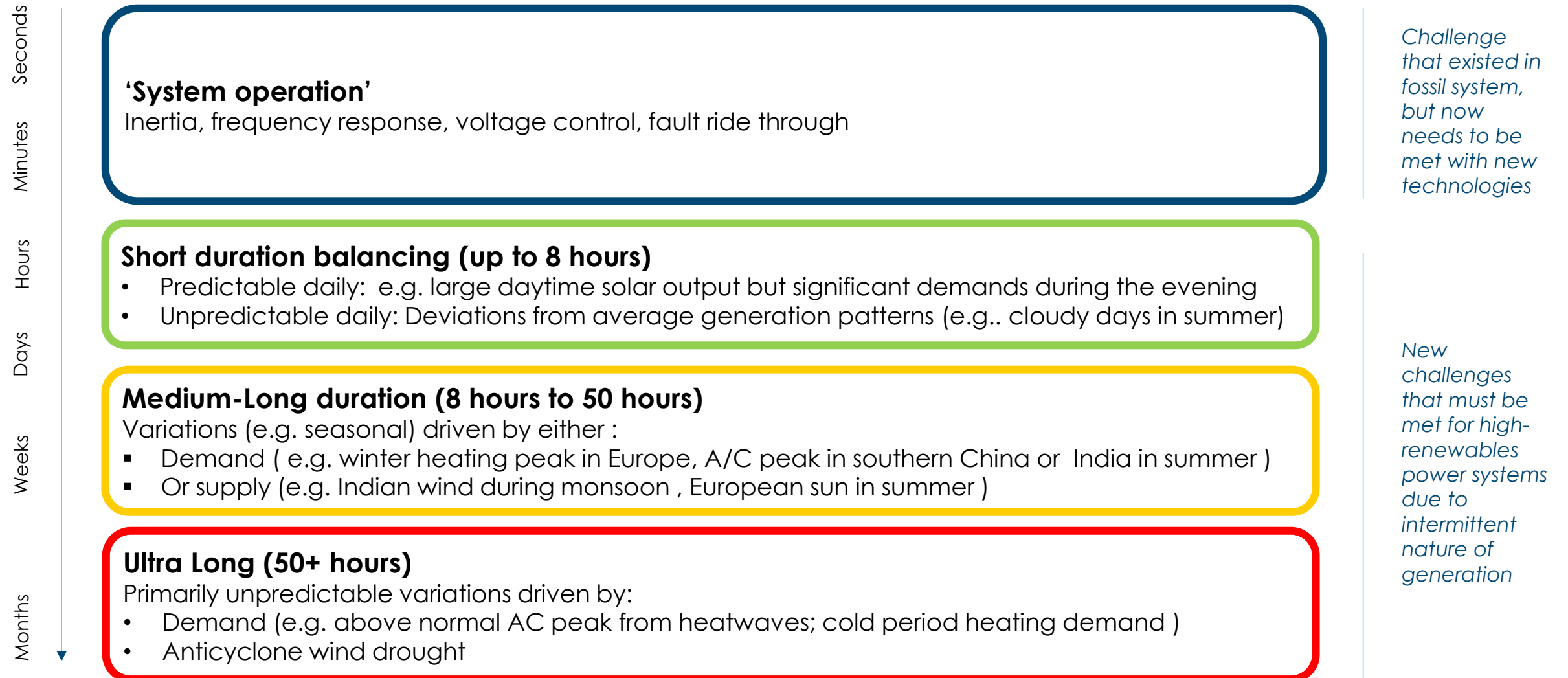
Demand side management







Long distance transmission

System balancing is across different durations

A high-renewable power system must be able to meet several challenges...



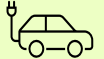
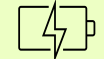






There are a set of balancing options across durations

			System operation	Short duration	Medium duration	Security of supply
Dispatchable generation 	Other zero carbon	Hydro, nuclear ¹	✓	✓	✓	✓
	Fossil	Fossil (or bioenergy) + CCS	✓	✓	✓	✓
		Fossil – low/very low utilisation	✓	✓	✓	✓
Long distance transmission 		Accessing complementary weather patterns and time shifting generation	✓	✓	✓	✓
Energy storage 	Pumped hydro		✓	✓	✓	✓
	Lithium ion battery ²		✓	✓	✓	✓
	Other technology (i.e. CAES, liquid air, etc.) ³		✓	✓	✓	✓
	Power-to-X (i.e. H ₂) ⁴		✓	✓	✓	✓
Heat storage		Heat battery		✓		
Demand side flexibility 	EV (smart charging, V2G)			✓		
	Heating load ⁵			✓		
	Industrial load ⁶			✓		✓

Notes: 1. Limited nuclear capacity for flexible ramping. 2. Li-ion storage is utility-scale and behind-the-meter. 3. Emerging tech might include gravitational storage and molten sands storage. 4. Examples of Power-to-X include the production of H₂ from electrolysis and re-conversion of hydrogen in power via gas turbines or fuel cells. 5. Residential and commercial standard heating needs. 6. Including hydrogen electrolysis, where production can be shifted to optimal times. Source: Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017), *Low-cost, low-carbon power systems*



Options & costs to meet balancing durations vary

Balancing needs	Key zero-carbon balancing technologies across durations	Full delivered electricity cost 2035 \$/MWh (estimated range) ^[1]
Short / hourly duration (up to 8 hours)	• Demand-side flexibility 	\$<0-50/MWh
	• Lithium-ion and sodium-ion batteries 	\$160-200/MWh
	• Heat storage 	\$75-150/MWh
Medium-Long duration (up to 50 hours)	• Energy storage (pumped hydro, compressed air, batteries) 	\$40-380/MWh
	• Long-distance transmission (for balancing) 	\$49-68/MWh
	• Running nuclear flexibly 	Existing: \$40-90 /MWh New build: \$58-480/MWh
	• Running hydro flexibly 	Existing: \$15-33/MWh New build: \$49-180/MWh
Ultra-long (50 hours+)	• H2 in CCGT, CCS on CCGT (low utilisation) 	\$177-435 MWh
	• Unabated gas (low utilisation)	\$90-197/MWh



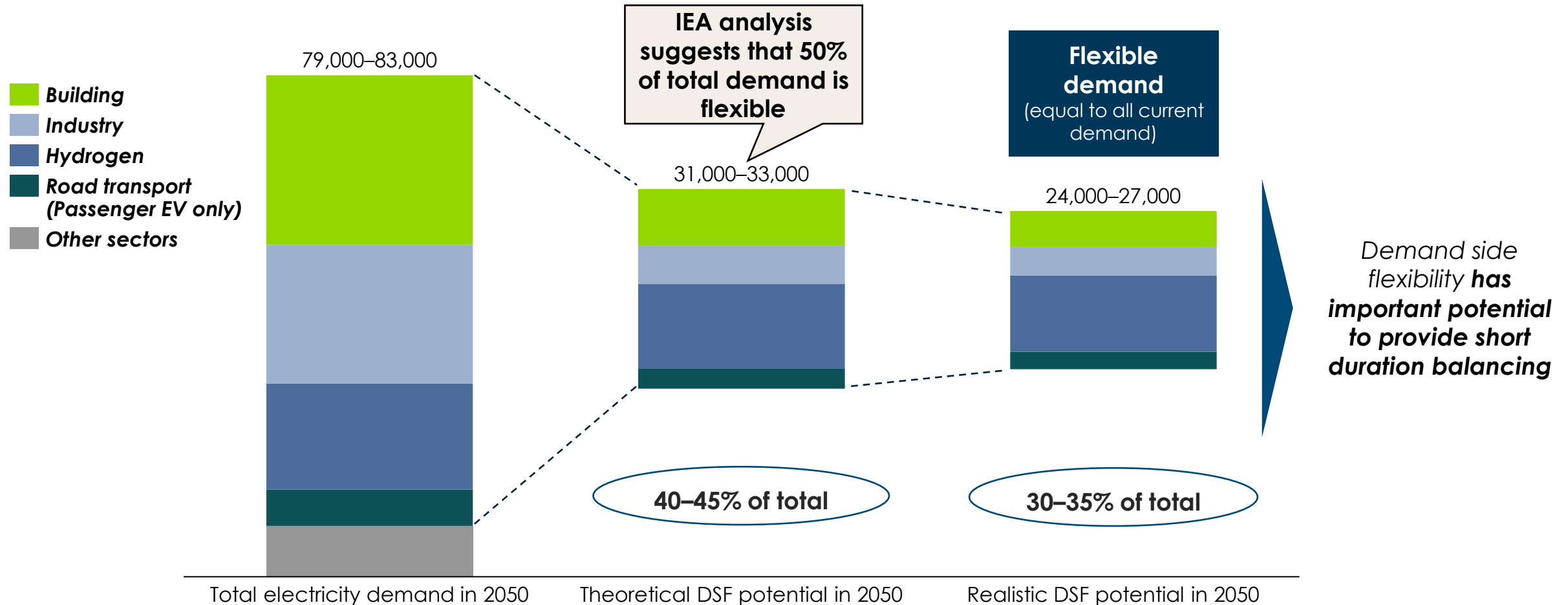
[1] The DSF range assumes that DSF can reduce total system costs at the lower end (through reducing overall demand) and that upgrades to smart, DSF-capable systems incurs a net cost at the upper end. LCOS calculations assume electricity input cost of \$0.06/kWh. All batteries are full LCOS calculations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

~ 30% of overall electricity demand in 2050 could be flexible

Global electricity demand and DSF potential, 2050

Ranges based on ETC scenarios ACF and PBS

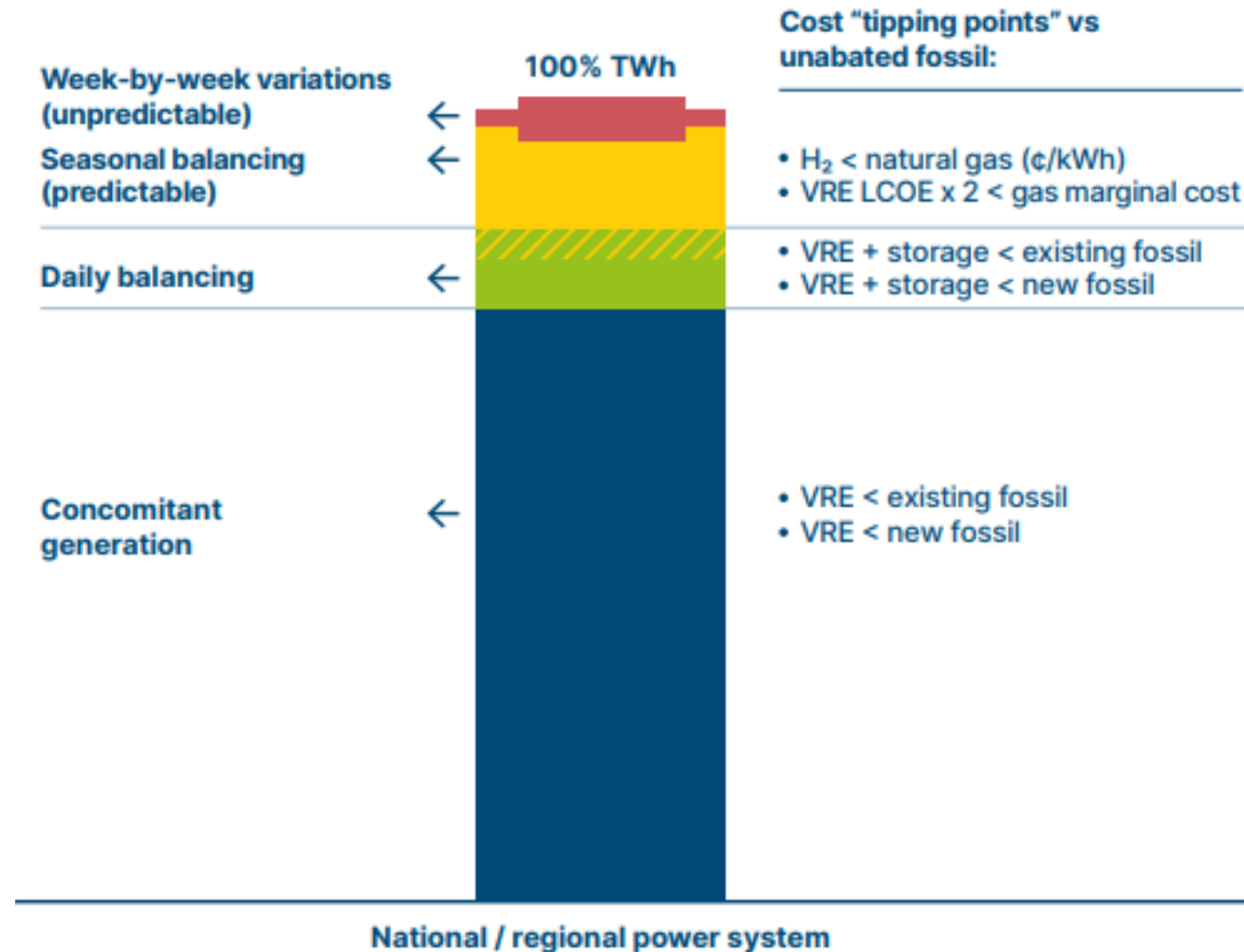
TWh



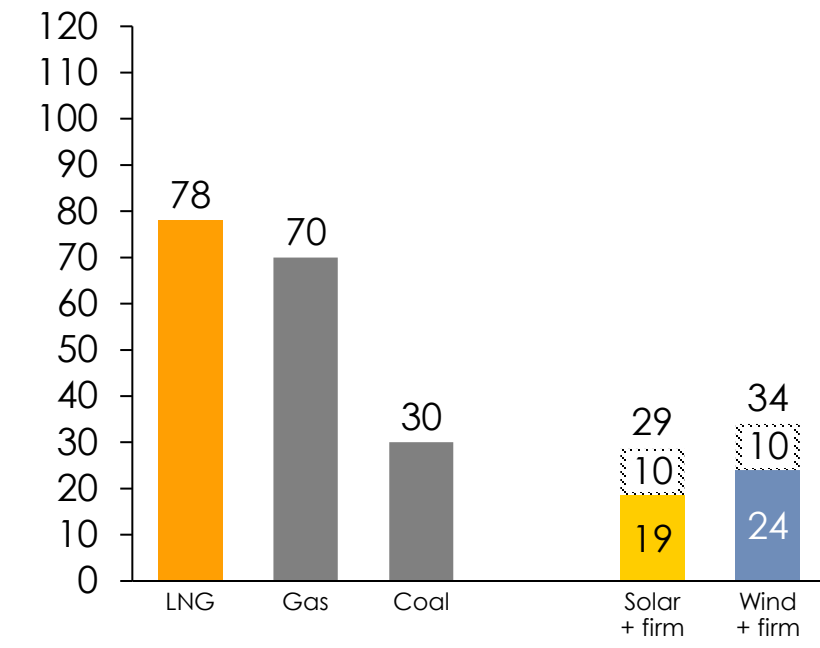
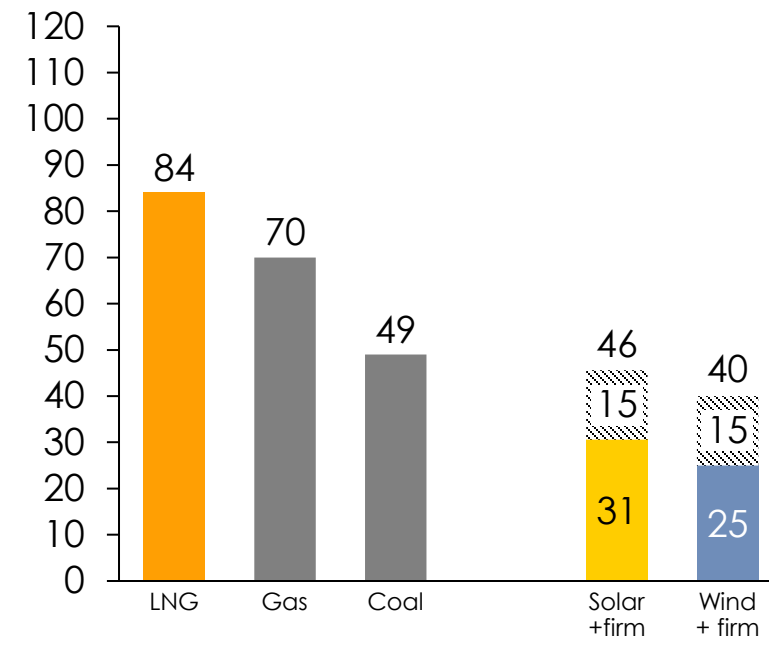
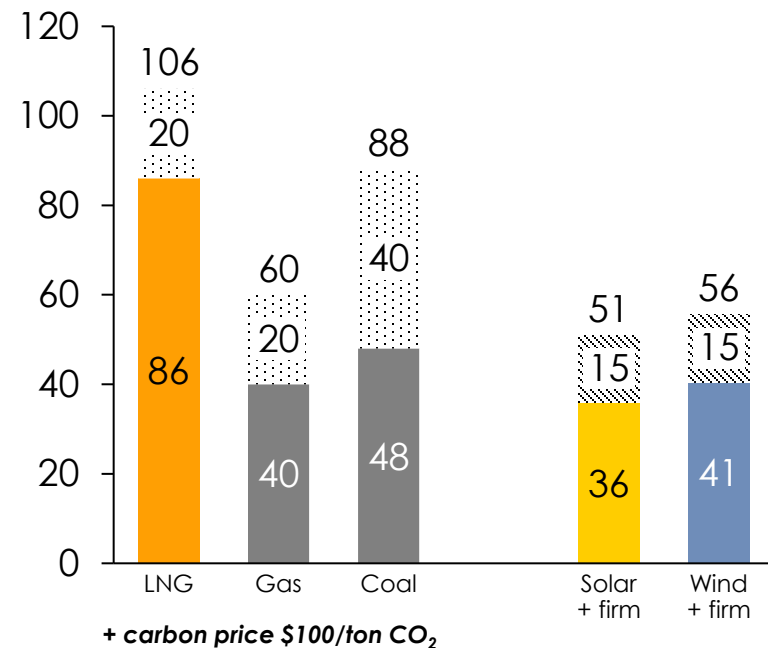
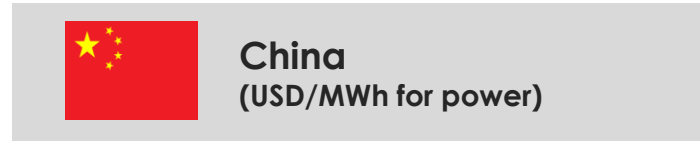
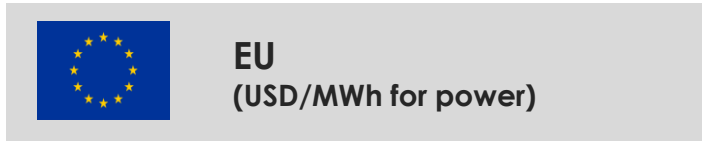
To assess demand-side flexibility (DSF) potential, we start by looking at theoretical potential—the maximum flexibility we could achieve if all technology and behaviour changes were fully adopted. Then, we evaluate realistic potential, which considers practical barriers including technological, economic, policy and behaviour. This approach helps us understand both the ideal possibilities and what can be realistically achieved in the near term.

Source: Systemiq analysis for ETC.

The cost impact of VRE + optimal mix of balancing solutions will be influenced by cost “tipping-points”



Solar and wind with clean balancing can beat cost of fossil



Ensuring these technologies can scale requires action to keep costs low & remove barriers to entry)



Note: Mix of solar/wind + firm depends on preliminary ETC analysis on balancing requirements in high-VRE systems.
 Sources: ETC (2022) *Bioresources technical annex*. Data from S&P Global (2024), *Commodity Insights – LNG Analytics*; IEA (2024), *Price of US LNG*; Other fossil fuel data from World Bank (2024); Monthly Prices; BNEF (2023), *2H 2023 LCOE: Data Viewer v.1.0*; European Commission (2024), *Liquefied natural gas*

Emerging technologies must scale at pace - what are the enablers required?

Build & optimise grids

Need to build vast amounts of new grids, as well as optimise new and existing grids for maximum efficiency.

Manage system balancing

Need to manage the system balancing challenge, which arises as the penetration of wind and solar grows



Innovative grid technologies



Energy storage



Heat storage



Demand side management



Long distance interconnection



Flexible dispatchable generation



What are the enablers to ensure we can scale these technologies?



Key enablers required to deploy these technologies



For emerging technologies, scaling requires addressing several areas

Strategic vision & planning

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



Market design

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



Grid regulations

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



Data, AI and smart grids

- Data and AI modernisation
- Advanced metering and digitalisation



Supply chain, workforce and financing regimes

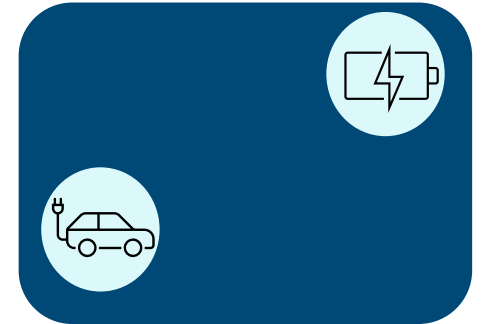
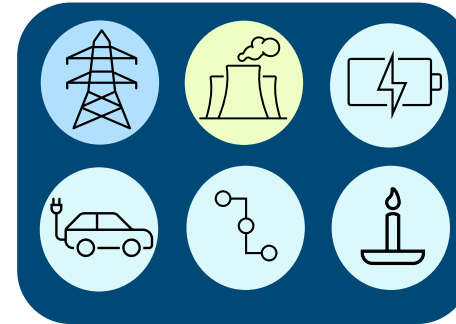
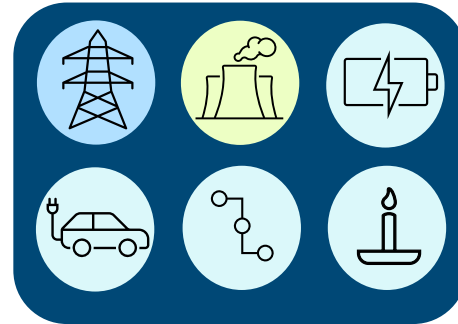
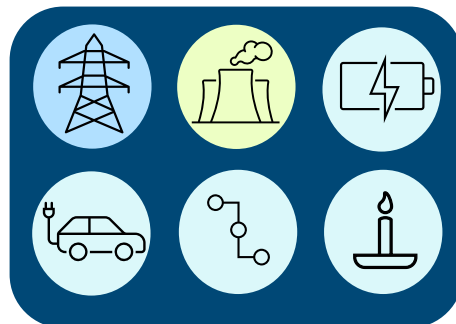
- Supply chain concerns
- Workforce education
- Anticipatory financing



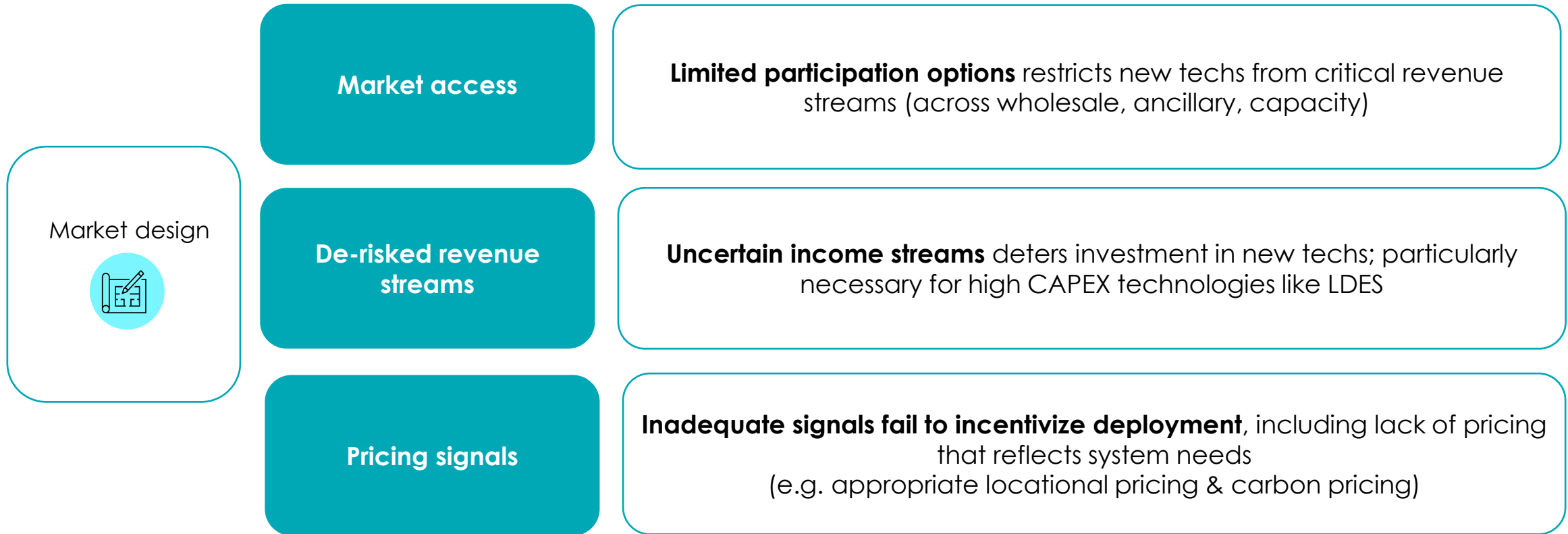
Consumers

- Consumer engagement and trust-building

Technology:



Current market design doesn't provide sufficient support



Reform is needed on grid regulation

Grid regulations



Reform of grid fees

Current grid fees are hampering deployment of new techs and grid decarbonization efforts, e.g. via double charging, lack of rewards for grid services, & inconsistent fee structures across regions

Evolution of connection rules

Outdated grid connection rules are leading to grid capacity limitations for new techs and long connection queues

Modernisation and harmonisation

Divergent grid codes, fee structures, and regulatory frameworks between countries or regions create inefficiencies and complicate cross-border energy trading



Data, infrastructure and workforce reforms to address 3 key challenges

Data,
infrastructure and
workforce



Data and AI modernisation

Accelerate deployment of data and AI to ensure system resiliency, and improve grid optimization and efficiency (e.g. AI-driven grid forecasting)

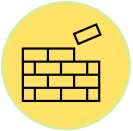
Advanced metering and digitalisation

Outdated grid technologies impede the effective deployment and operation of storage and flexibility solutions



Supply chain, workforce and infrastructure require anticipatory funding and tracking to prevent bottlenecks

Supply chain,
workforce and
infrastructure



Supply chain barriers

Supply chain bottlenecks delay storage deployment, increasing costs and limiting scalability

Workforce development

A skilled workforce is essential to integrate and operate grid storage and flexibility solutions effectively

Financing regimes

Anticipatory financing will enable grids to aptly support power growth



Consumer engagement to address one key challenge

Consumer and
end-user



**Consumer
engagement
and trust-
building**

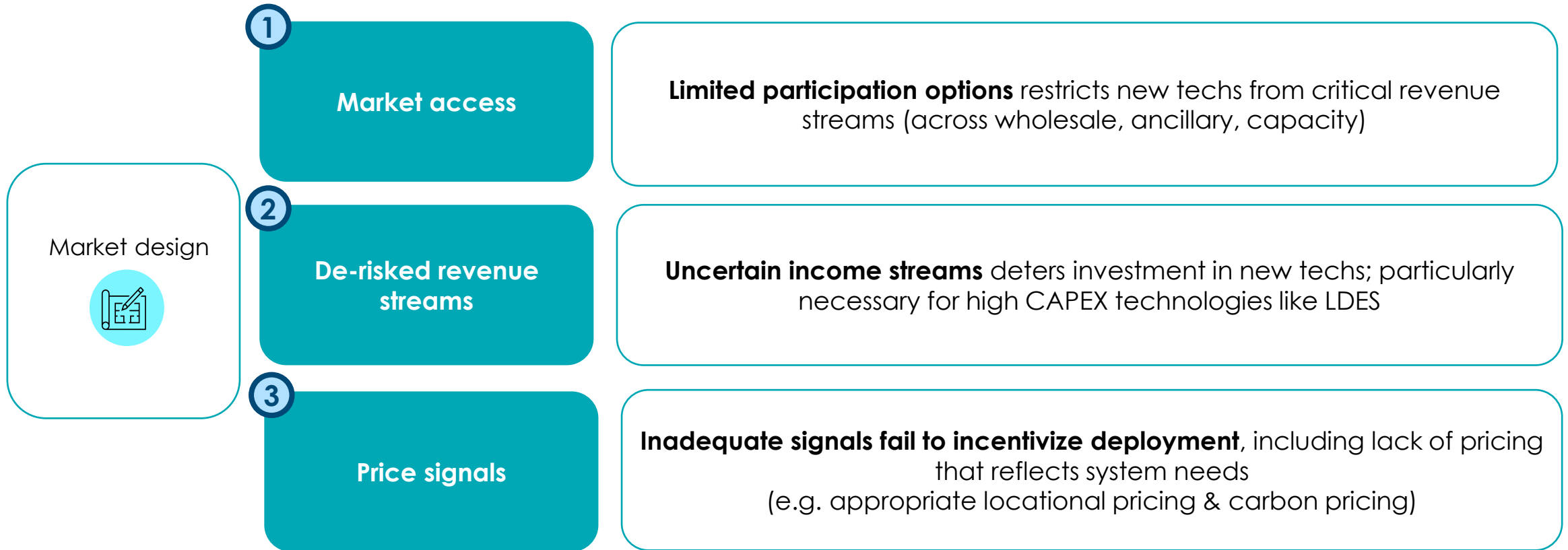
Lack of consumer awareness and participation limits the adoption of storage and flexibility technologies



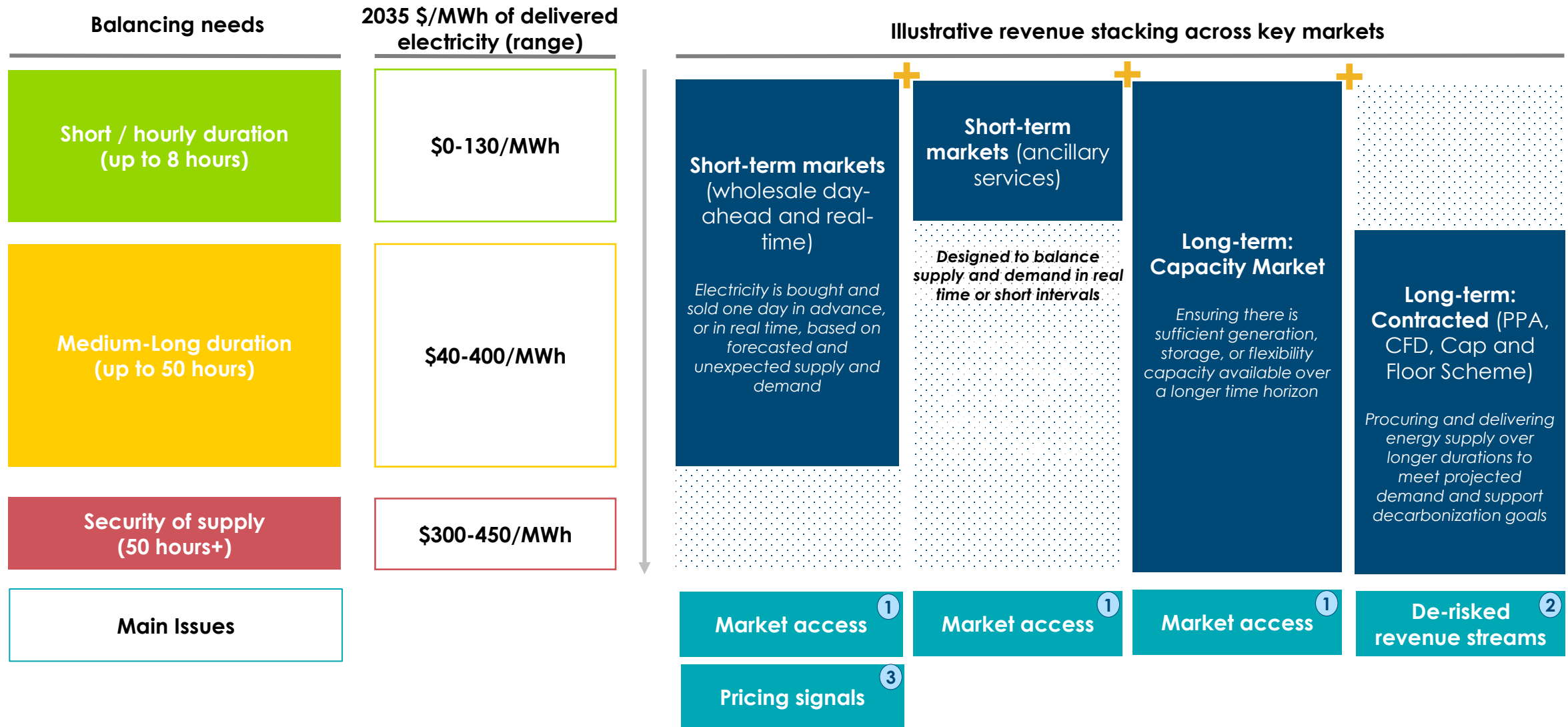
Market design



Current market design doesn't provide sufficient support



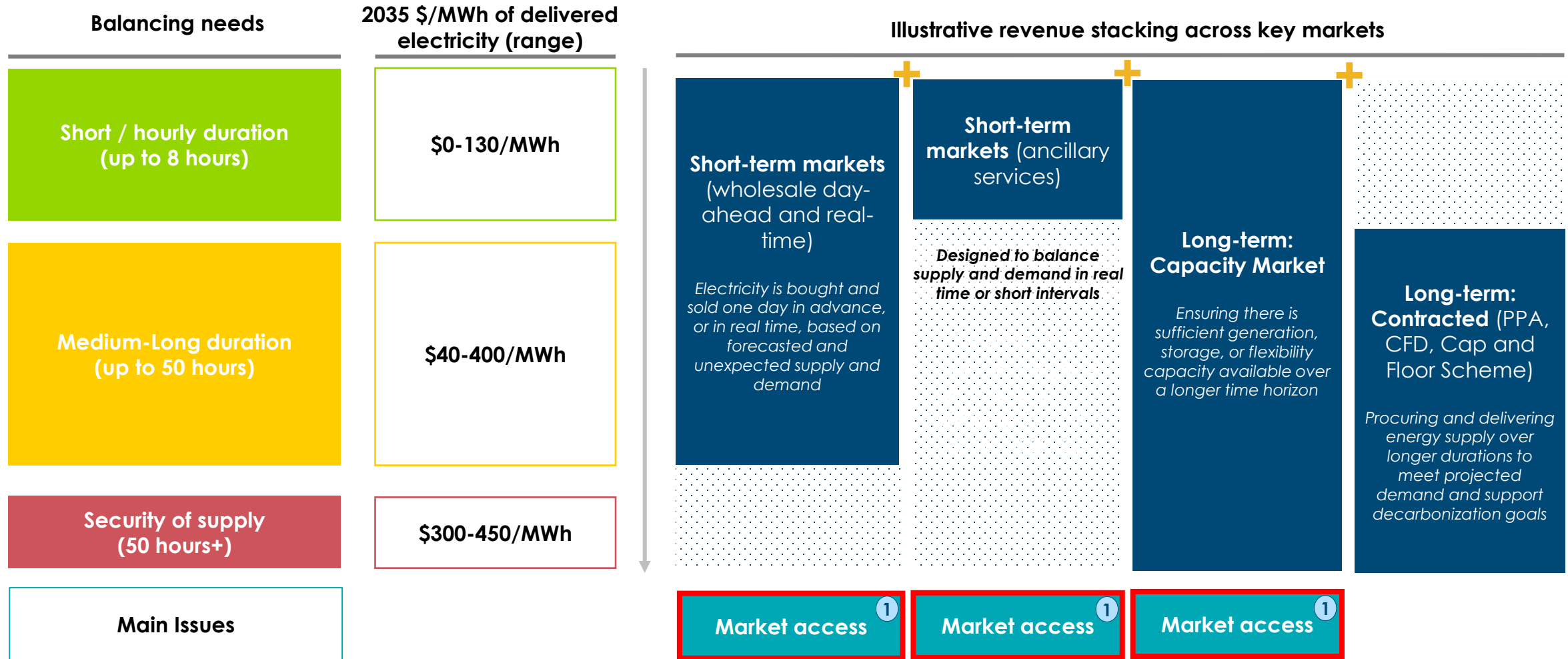
Storage and flexibility assets can play across multiple electricity markets



Note: Dotted areas indicates periods where technologies can play, but are less likely to due to the markets being less suited to the hourly duration being either too short or too long.



Business cases for flexibility will likely require revenue stacking across these multiple markets, making market access vital



Note: Dotted areas indicates periods where technologies can play, but are less likely to due to the markets being less suited to the hourly duration being either too short or too long.

Here are the 4 electricity markets available to storage and flexibility assets

Ancillary Services

Grid support functions that ensure stability, reliability, and security of the electricity system
Key services include: frequency regulation, voltage support, spinning reserves, ramping, and load balancing

Capacity Markets

Ensure long-term grid reliability by procuring sufficient generation, storage, or flexibility resources to meet peak demand
Key services include: capacity markets, decentralized capacity obligations

Wholesale Market

Facilitates the buying and selling of electricity between generators, suppliers, and traders before reaching end consumers
Key functions include: day-ahead, intraday, real-time market

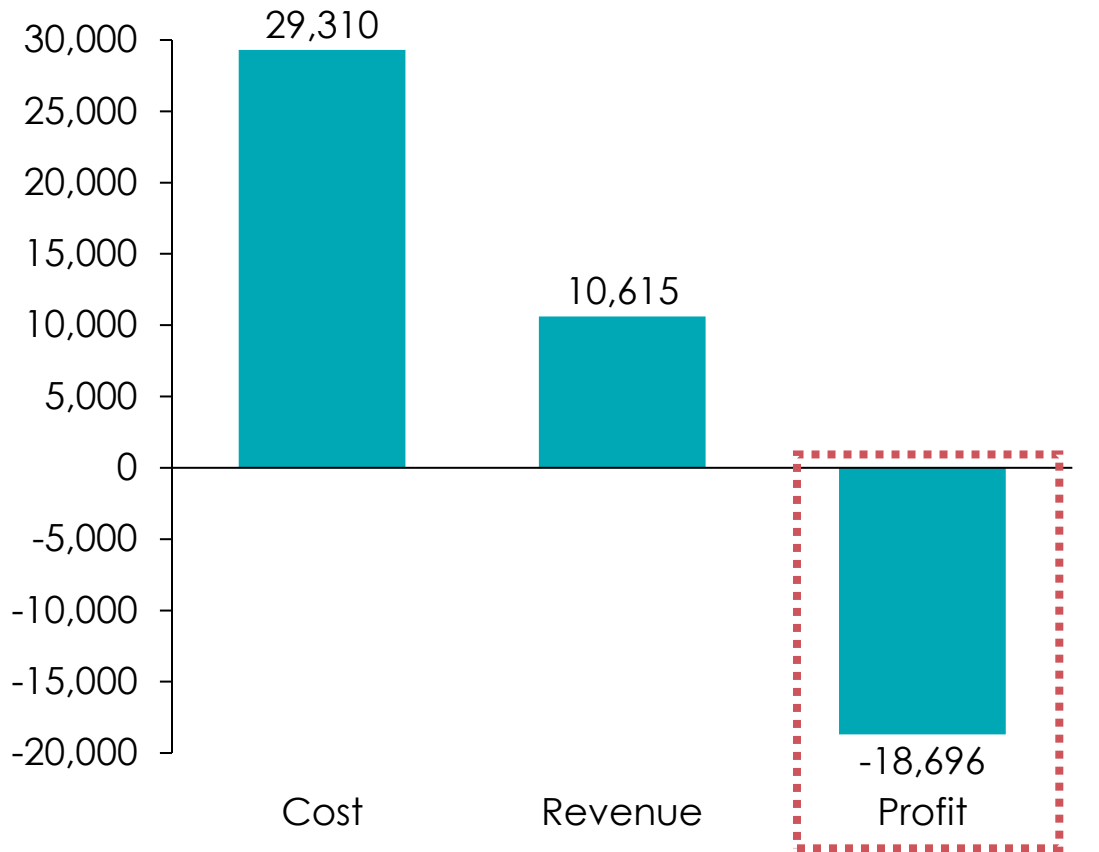
Balancing Mechanisms

Allow system operators to **manage real-time supply and demand** imbalances by dispatching flexible resources
Key functions include: e.g. UK Balancing Mechanism

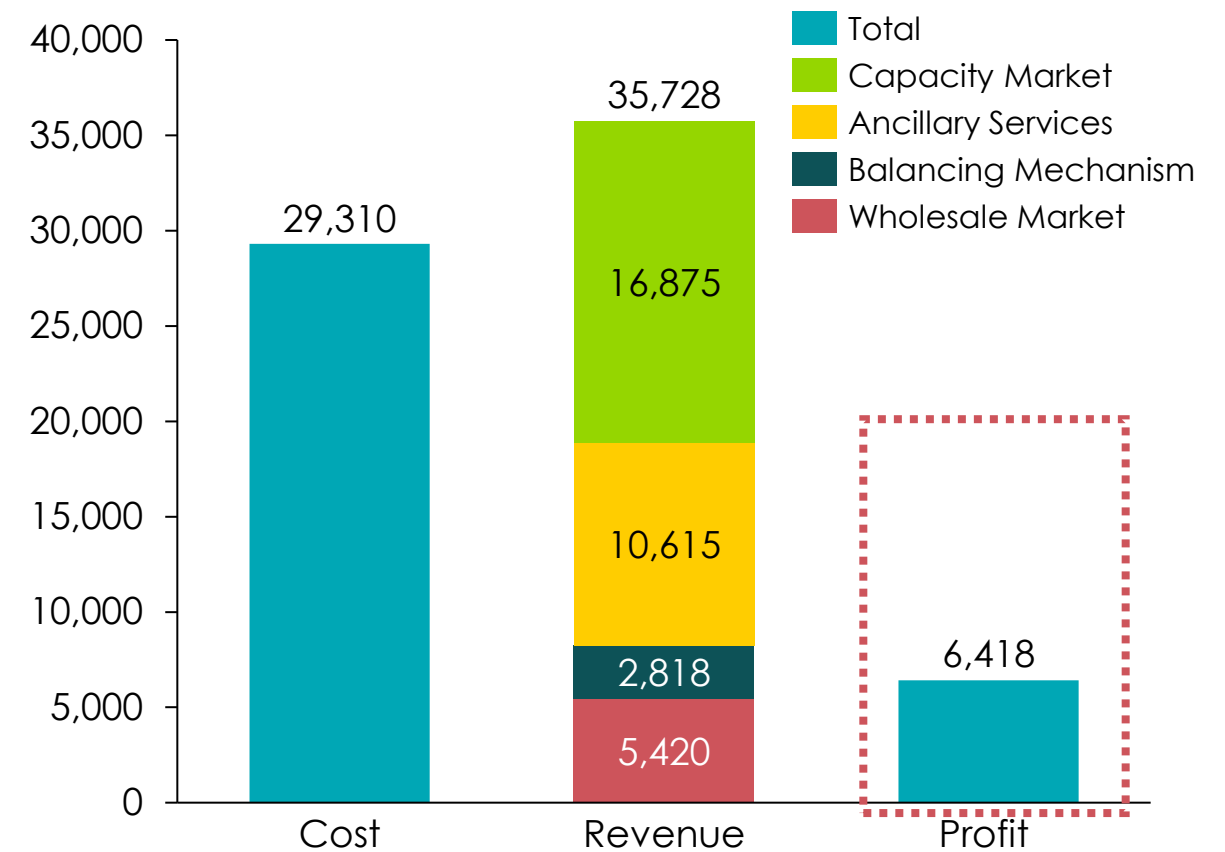


Why access to multiple markets is vital: UK case study showcasing that revenue stacking is critical to storage business case

UK battery storage with ancillary services, 2023, 80MW BESS (\$/MWh)



UK battery storage with revenue stacking, 2023, 80MW BESS (\$/MWh)



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



Ancillary services have expanded; but revenue streams for storage and flexibility also need to move beyond AS markets

Case Study: Evolving AS in the UK market

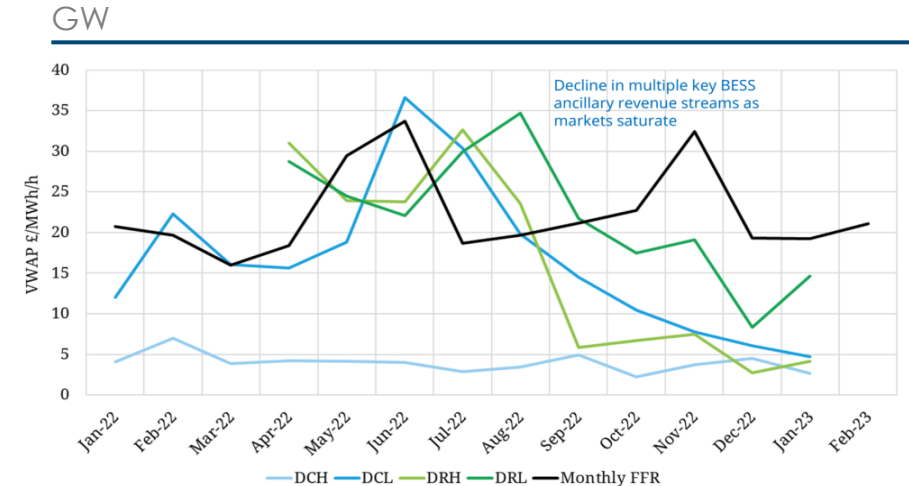


Category	Energy Storage Role with Old AS	Energy Storage Role Currently with New AS (Year market opened)
Frequency Control	Limited pilot participation	Core provider of Dynamic Containment (2020) , Dynamic Regulation (2022) , and Dynamic Moderation (2023)
Voltage Control		Supporting reactive power services through grid-scale batteries (Reactive Power Auction 2021)
Black Start		Energy storage enables Distributed Black-Start for decentralized grids (2019)
Inertia Support		Synthetic Inertia provision through advanced inverter-based storage (2020)
Reserve Services		Batteries participating in Optional Downward Flexibility Management (ODFM) (2020)
Fast Response	Limited pilot participation	Energy storage central to Enhanced Frequency Response (EFR) (2016) and Firm Frequency Response (FFR)
Harmonic Mitigation		Batteries equipped with advanced inverters to address harmonic mitigation (2021)

While AS is an important revenue stream, storage & flex also requires other markets

- Ancillary services markets offer short-term revenue opportunities for storage and flexibility because 1) their capacity needs are relatively small compared to broader energy markets, and 2) they can become quickly saturated as more storage assets are deployed
- However, as these assets scale, there must be multiple revenue streams available for storage and flexibility assets; As a result, we have seen a decline in revenues from this market in the UK

Ancillary services revenue, UK



There are a range of capacity market alterations that can be used, dependent on the case, to procure more short and long duration storage

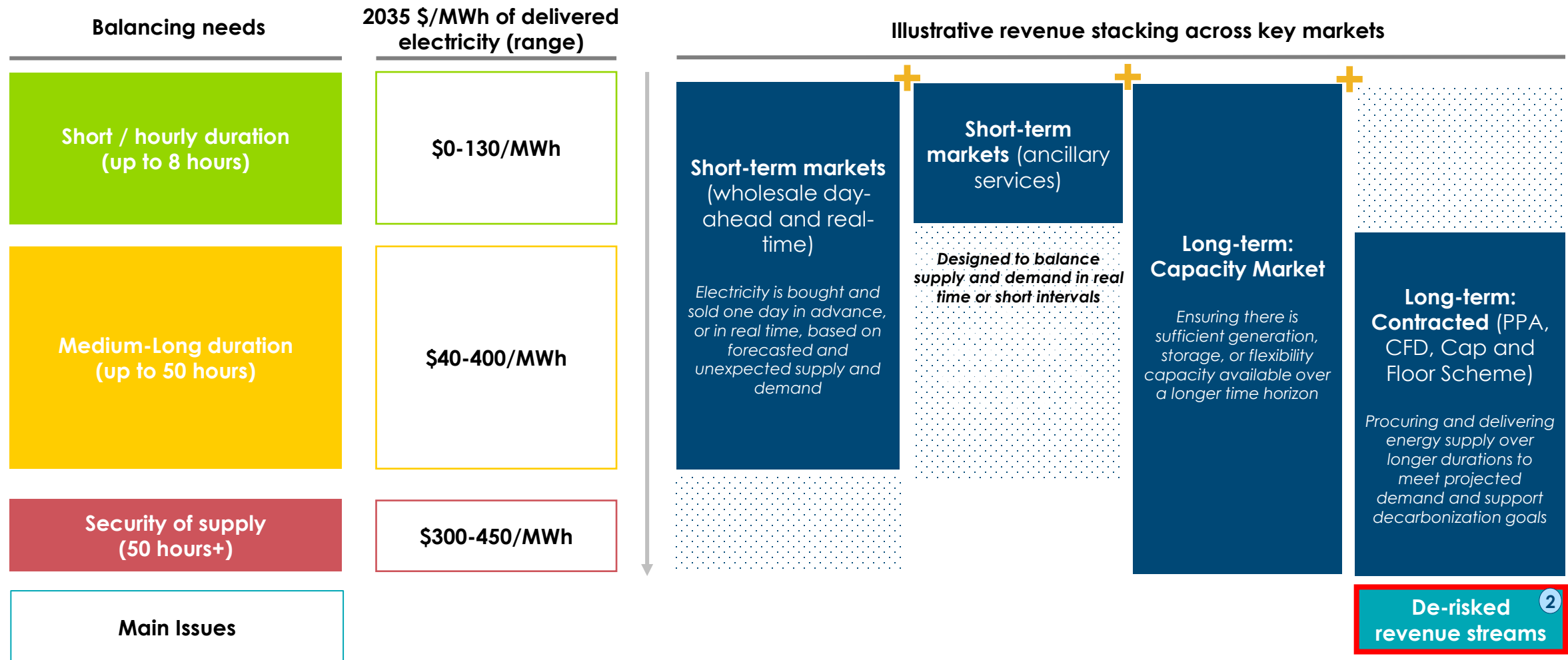
Capacity markets should introduce mechanisms to reward storage and flexibility, factoring in e.g. duration/speed, emissions, participation of BESS and their unique qualities in stress events, small scale flexible assets with lower capacity thresholds

Increasing complexity

- 1 Recommended**
Implement de-rating factors tailored for energy storage and flexible resources, ensuring fair compensation for their capacity contributions
- 2 Recommended**
Introduce metrics or market mechanisms to reward ramping speed, response time, and the ability to manage grid volatility e.g. block approach
- 3**
Alter auctions to encourage greater storage and flexibility in the CM
 - 1) Low Carbon Split Auctions
 - 2) Minimum Capacity Thresholds
 - 3) Multiplier Mechanisms
- 4**
Create a **separate Capacity Market** just for storage and flexibility assets



Technologies require a breadth of revenue streams to bridge cost gaps



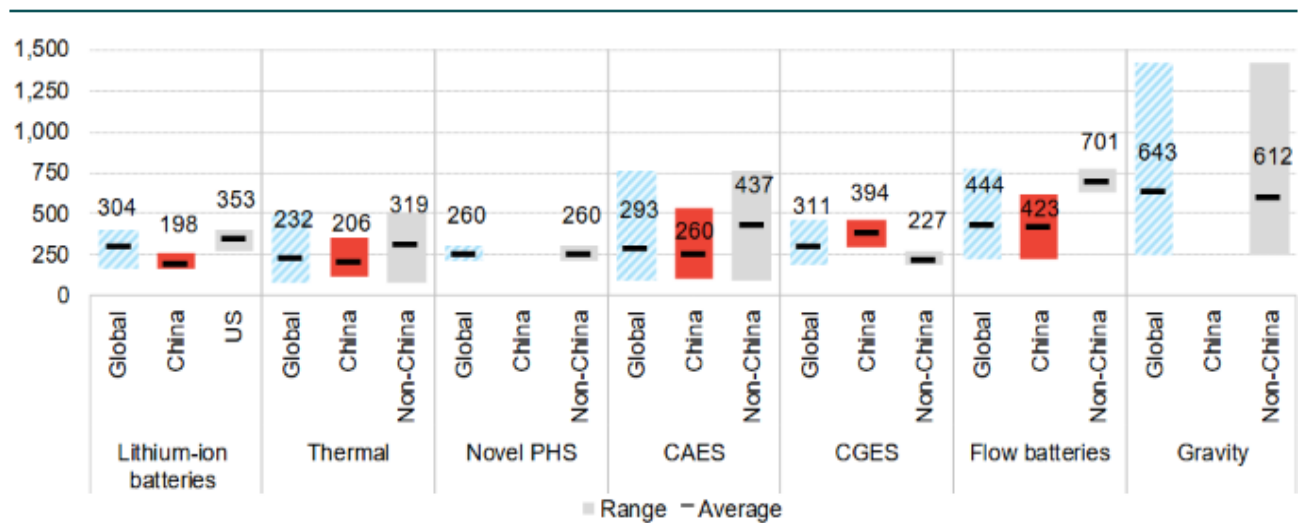
Note: Dotted areas indicates periods where technologies can play, but are less likely to due to the markets being less suited to the hourly duration being either too short or too long.

Cost gaps are preventing adoption of new technologies

There are **three areas** where **cost gaps** are most pronounced:

- 1) More **complex, larger technology** is particularly expensive (e.g. long duration energy storage, interconnectors) with long payback periods
- 2) **New technology** needs support in R&D phase to enable the CAPEX learning curve and compete in established markets
- 3) Consumers require **incentives** and access to financing to change energy habits

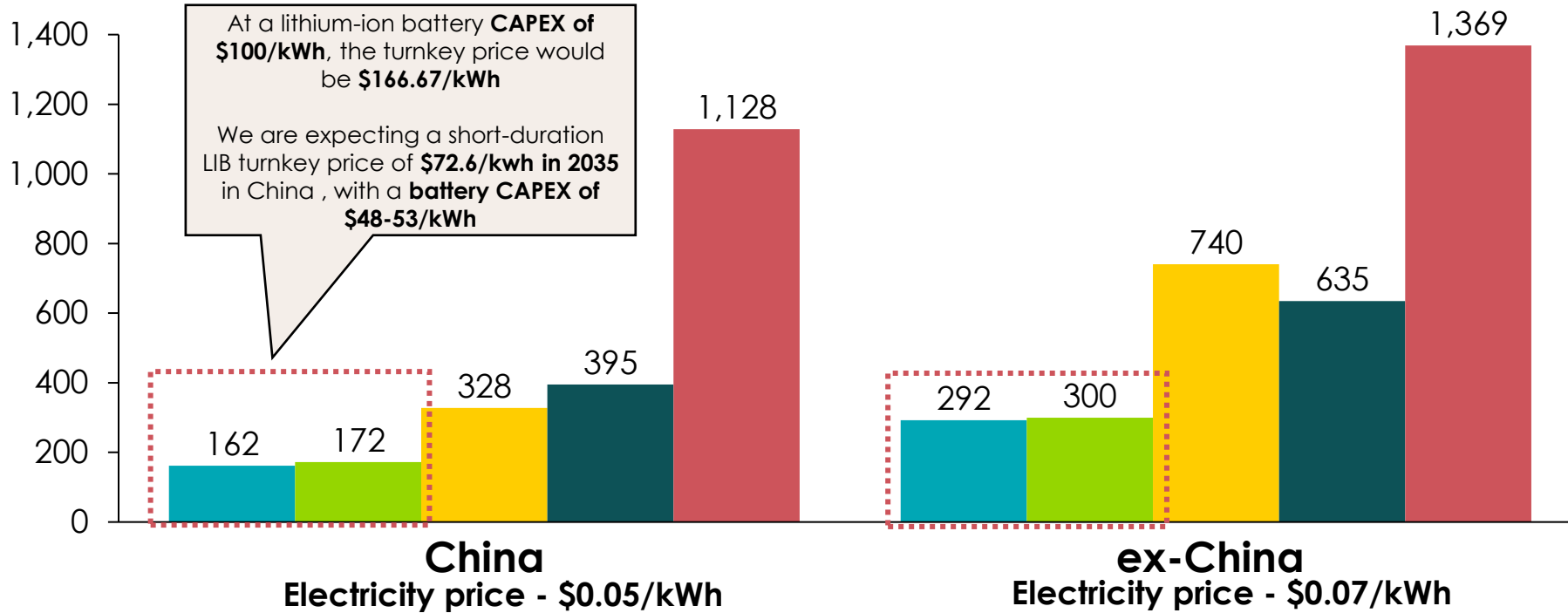
Fully installed costs of long-duration energy storage systems, 2023
\$/kW



Source: BNEF 2024 Long-duration energy storage survey

Short duration storage: lithium and sodium the leading choice for short-term flexibility due to low cost

LCOS costs for short-duration storage (including input electricity price), 2035
\$/MWh



Short / hourly duration
(up to 8 hours)

Lithium & sodium ion
batteries are by far the
most competitive energy
storage tech for short
duration

	Lithium	Sodium	Flow	A-CAES	Hydro
Capex (Turnkey \$/kWh)	72	70	508	130	130
Lifecycle efficiency	95%	93%	93%	70%	82%

	Lithium	Sodium	Flow	A-CAES	Hydro
Capex (Turnkey \$/kWh)	132	120	566	286	230
Lifecycle efficiency	95%	93%	93%	70%	82%

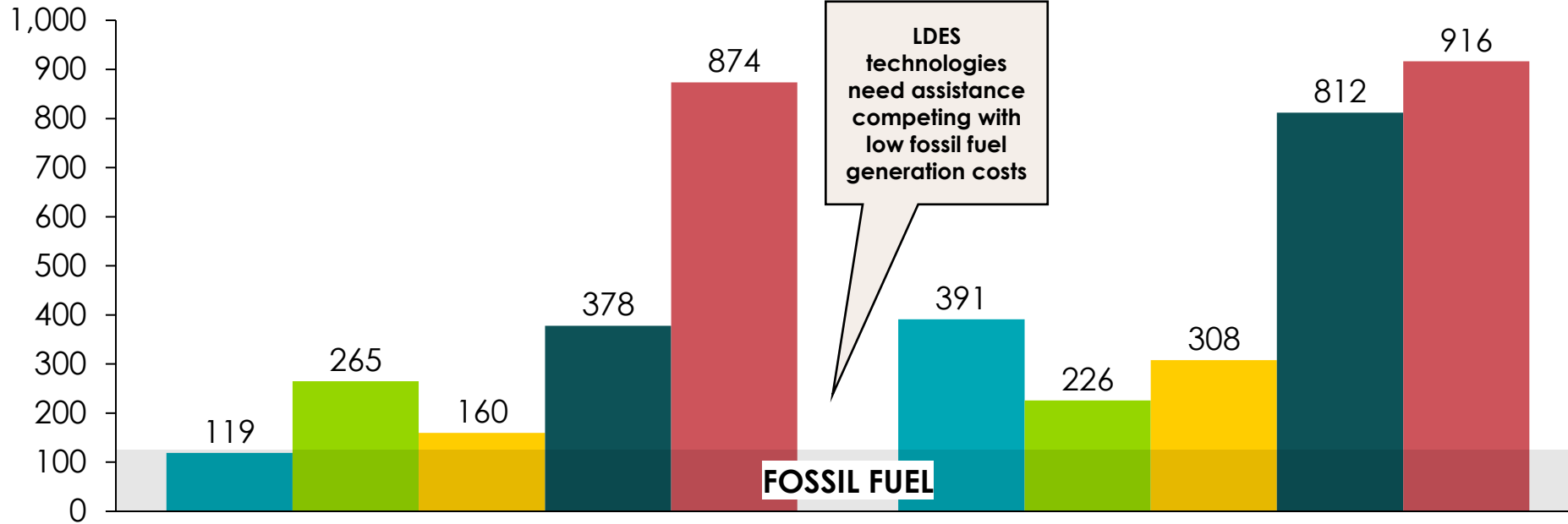
Source: ETC LCOS calculations. Note: Our CAPEX figures are turnkey prices, which include battery CAPEX, PCS, Balance of plant, and installation and labour. It excludes EPC and grid connection costs. In our LCOS calculations, we include figures for CAPEX, OPEX, Annualisation Factor, # of cycles per annum, lifecycle efficiency and cost of electricity input. Where available, we have used 2024 Capex figures from BNEF's Long Duration survey as a baseline.



Medium-long duration storage: technologies need assistance to bridge cost gaps when compared to fossil fuel generators

LCOS costs for long-duration storage (including input electricity price), 2035
\$/MWh

■ Lithium ■ Pumped Hydro ■ Flow
■ Sodium-ion ■ A-CAES



Medium-long/ hourly duration (8-50 hours)

Storage case study showcases that **high CAPEX solutions need financial support**

 Other high-CAPEX technology: **Interconnectors, innovative grid tech**

China

Electricity price - \$0.05/kWh

	Lithium	Sodium	Flow	A-CAES	Hydro
Capex (Turnkey)	90	65	360	100	40
Lifecycle efficiency	95%	93%	93%	70%	82%

ex-China

Electricity price - \$0.07/kWh

	Lithium	Sodium	Flow	A-CAES	Hydro
Capex (Turnkey)	180	90	380	220	80
Lifecycle efficiency	95%	93%	93%	70%	82%

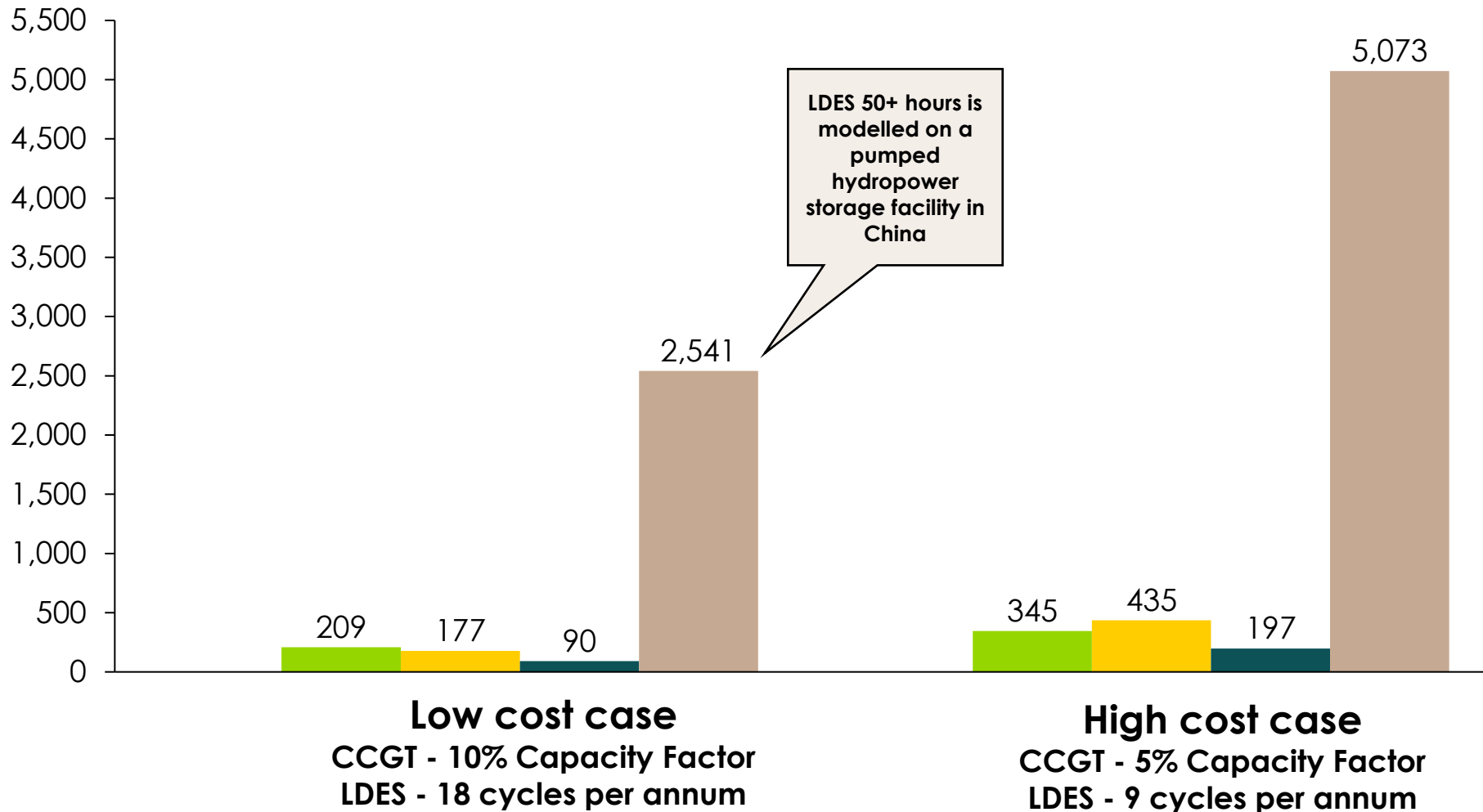
Source: ETC LCOS calculations. Note: Our CAPEX figures are turnkey prices, which include battery CAPEX, PCS, Balance of plant, and installation and labour. It excludes EPC and grid connection costs. In our LCOS calculations, we include figures for CAPEX, OPEX, Annualisation Factor, # of cycles per annum, lifecycle efficiency and cost of electricity input. Where available, we have used 2024 Capex figures from BNEF's Long Duration survey as a baseline.



Ultra-long duration storage has an even broader cost gap

LCOS costs for long-duration storage (including input electricity price), 2035
\$/MWh

- H2 in CCGT
- CCGT with CCS
- Unabated Gas
- Pumped Hydro



Ultra-long/ hourly duration (50+ hours)

Requires notable financial incentives in order to compete with generation from fossil fuel technologies



Source: ETC LCOS calculations. Note: Our figures for Pumped Hydro are based on a facility in China, with a CAPEX of \$40/kwh, Opex \$3/kWh, Annualisation factor of 6%, lifecycle efficiency of 82% and electricity input cost of \$0.05 per kWh. LCOE estimates are based on data from BNEF's 2H 2023 LCOE Data Viewer Tool and unabated gas assumes a carbon price of \$100/ton CO2.

Revenue stacking enables a de-risking of revenue. However, several drivers mean additional support mechanisms are required to scale storage at pace

Issues that lead to uncertain revenue streams

Price volatility or insufficient price signals: Extreme price swings, and negative pricing, can make revenues unpredictable, reducing investor confidence and complicating long-term financing

Price cannibalisation: The declining price spreads between peak and off-peak electricity prices due to increased deployment of storage that charge when prices are low and discharge when prices are high, thereby reducing market volatility and profitability

Market saturation: The point at which the total installed energy storage capacity meets or exceeds market needs, limiting new investment opportunities and making additional storage economically unviable



Key tools to address revenue uncertainty

Cap & Floor Mechanisms

CFDs for Storage

PPAs for Storage

Tolls

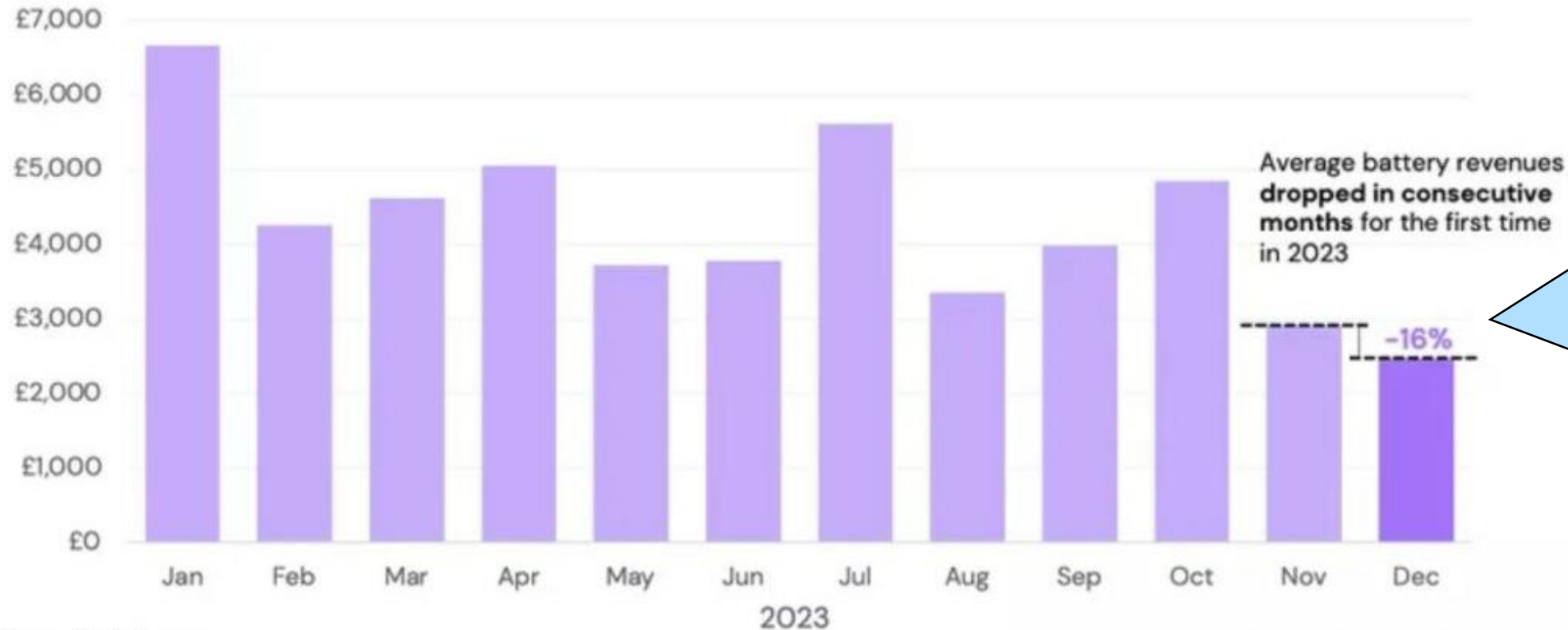
Feed in tariffs



Additional de-risked revenue streams required to 1) address market saturation and price cannibalisation

Balancing Mechanism-registered battery revenues, 2023

£/MW



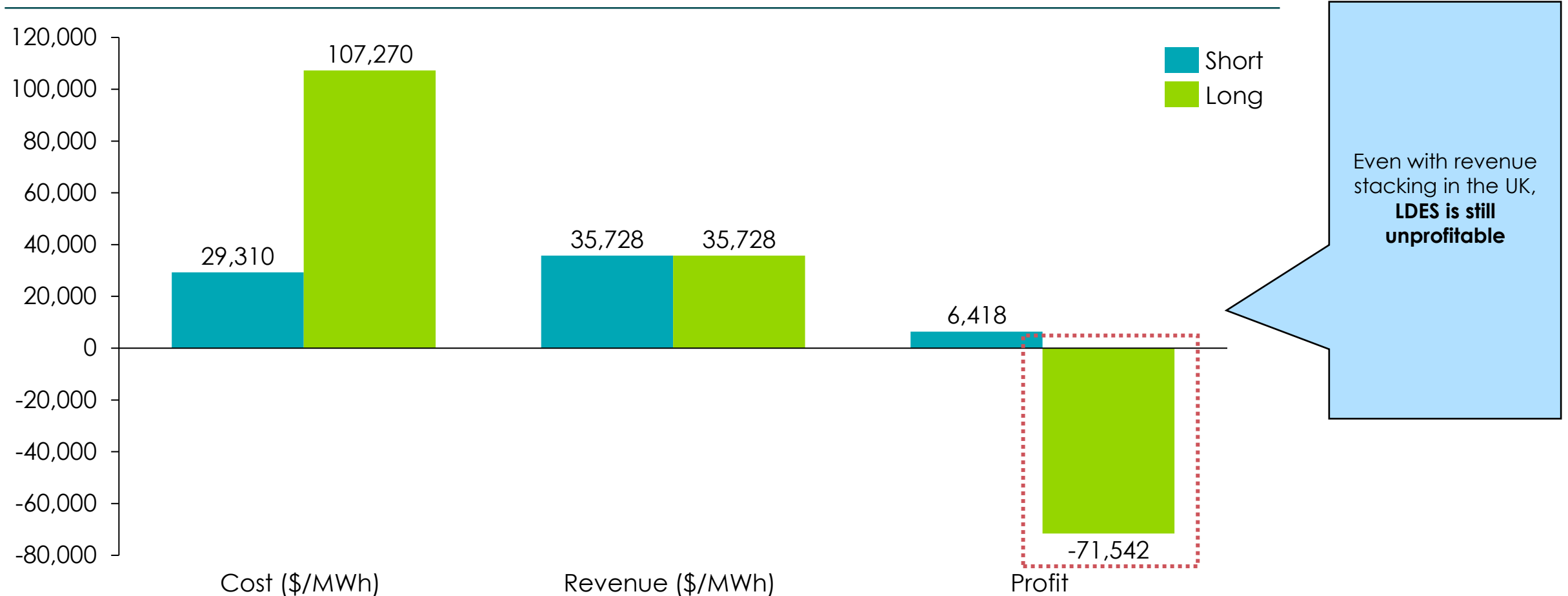
Fall in revenues a result of the **continual decline in ancillary services earnings** due to **market saturation**, creating reduced prices and limited opportunities to participate in these markets

Source: Modo Energy GB battery energy storage average monthly revenues in 2023

Additional de-risked revenue streams required to 2) address inability of revenue stacking to ensure profit for LDES projects

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

All markets stacked, £/MWh



Even with revenue stacking in the UK, **LDES is still unprofitable**

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



Options for de-risked revenue streams

Definition

Cap & Floor Mechanisms

Ensures storage projects earn stable revenues by setting a minimum (floor) and maximum (cap) price.

CFDs for Storage

Provide a stable revenue stream by guaranteeing a fixed strike price for energy, compensating the difference between market prices and the strike price

PPAs for Storage

Long-term contracts where storage assets get paid a fixed price for providing energy or services, improving investment security

Tolls

Payments from grid operators or utilities to storage providers for making capacity available and dispatchable when needed

Feed in tariffs





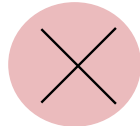
Fixed payments per unit of stored and discharged energy, ensuring early-stage storage projects receive predictable income



ETC Recommendations for de-risked revenue streams

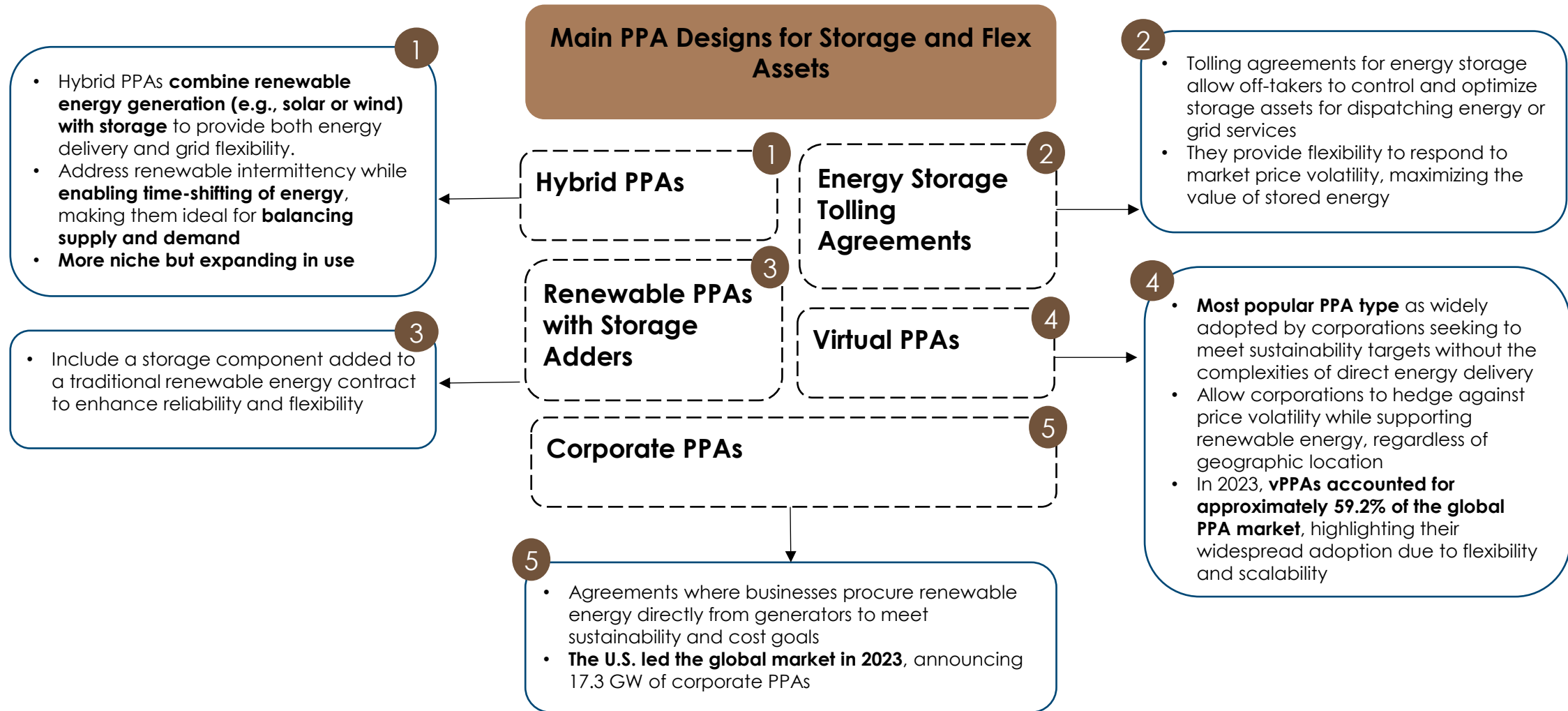
Revenue mechanisms must be adapted to account for the unique operational and economic characteristics of different technologies such as long-duration storage or fast-responding assets.

While the right revenue mechanism for storage and flex assets depends on market maturity, policy goals, risk allocation, and investor incentives, in general **we find that these mechanisms need the following design features:**

	Best use case	Market design ideal features	Recommended
Cap & Floor Mechanisms	Maturing markets	Must allow periodic price adjustments, align with capacity markets, and balance market-driven profits with investor security	
CFDs for Storage	Mid-stage markets	Shifting CFD's to be two-sided to compensate flexible assets for both charging and discharging cycles, and particularly in developed markets where negative pricing is more common	
PPAs for Storage	Large projects	Need long-term indexed contracts, competitive auctions, and regulatory support for corporate buyers to enhance investment certainty	
Tolls	Merchant projects	Must prioritize dispatchability, offer predictable cost recovery, and allow merchant market participation to align with grid needs	
Feed in tariffs	Early-stage markets	Should be phased out as market signals strengthen, structured to avoid distortions, and focused on early-stage technologies	



PPA design becoming more varied to ensure that they align with the energy profiles of storage and flexibility assets, particularly in the EU and US

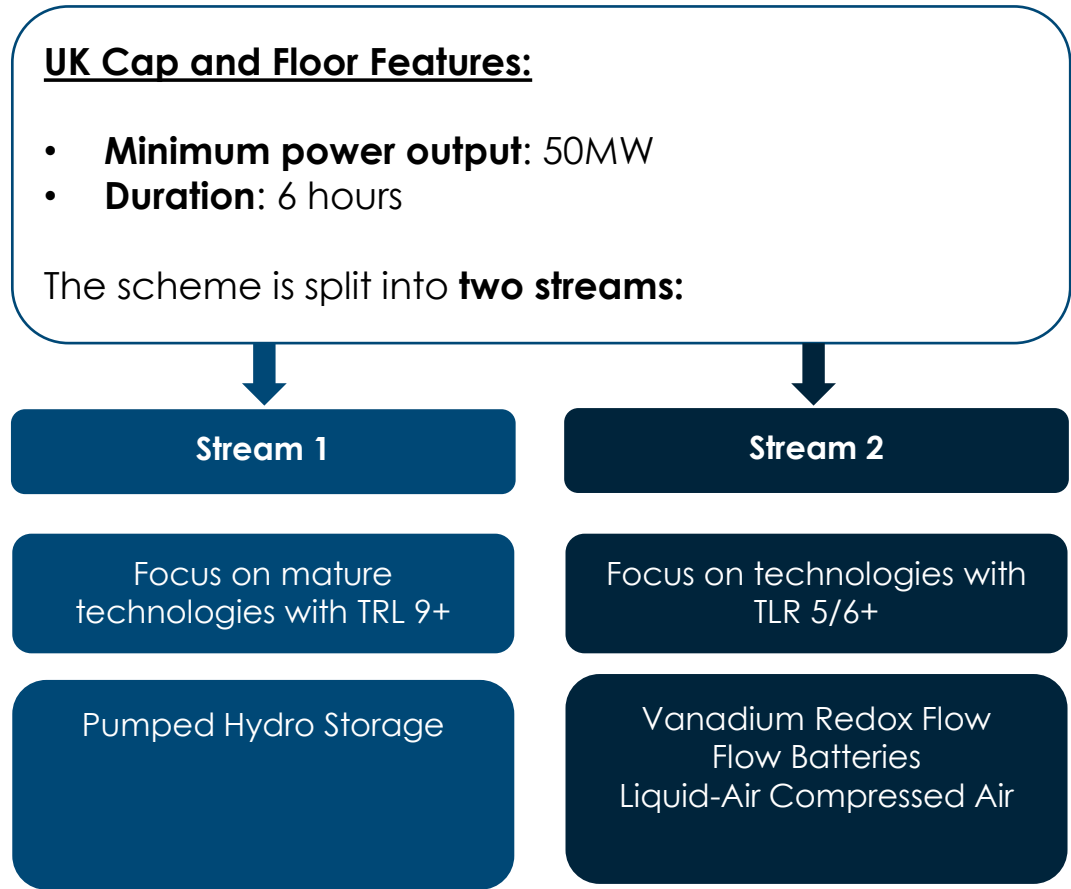


PPAs have also been essential in ensuring India's delivery of their unique round-the-clock auctions

		Unique Feature	Issues	Changes
Objective	Deliver firm, uninterrupted power by combining VRE sources with complementary generation (e.g., thermal, hydro) and/or ESS to achieve a high annual CUF	Tender process has clear, defined terms on availability, round-trip efficiency, degradation, and penalties.	Guidelines (from 2021) need updating and better application of battery storage outside of dual daily cycle	Guidelines updated to make market-entry more selective and penalties more severe
Capacity Utilization Factor (CUF)	Mandates a minimum annual CUF of 80-85% ensuring consistent power supply throughout the year			
Tariff Structure	Competitive bidding based on lowest price offered. The first RTC tender (RTC-1) resulted in a first-year tariff of Rs2.9/kWh with a 3% annual escalation for the first 15 years.	Feature a unique tariff escalation clause	Low price causes race to the bottom for pricing, making it unlikely that projects can be fulfilled and battery selection poor	Distribution companies should commit to tender prices to ensure projects go ahead
Contract Duration	PPAs spanning 25 years			
Penalty	Imposes penalties for supply shortfalls, with charges ranging from 300-400% of the tariff for deviations below the committed supply		Penalties need to be stricter to ensure bidders are committing to build-out of projects	
Technology Mix	Developers can choose from a mix of generation sources and storage solutions	Tenders typically focus on a single technology		



UK Cap and Floor for LDES, launching March 2025, an example of driving uptake of vital, but expensive, storage and flexibility technologies



Strength	Weaknesses
<p>In addition to providing clear revenue streams, the scheme:</p> <ul style="list-style-type: none"> • Encourages the deployment of emerging storage technologies like flow batteries and compressed air systems. • Reduces financial uncertainty, attracting private capital for cutting-edge flexibility projects. • Brings a wider range of advanced technologies onto the grid, ensuring a more resilient energy system 	<p>There are concerns that the mechanism:</p> <ul style="list-style-type: none"> • Could be complex and costly to implement • Could distort the market • Should be administratively allocated, rather than competitively allocated • Unfairly excludes Li-ion batteries from the scheme, creating an uneven playing field and potentially higher costs for consumers



Will CFDs, Cap and Floor Mechanisms, and PPAs be phased out or altered as time passes?

Why CFDs, Cap and Floor, and PPAs could be phased out in some contexts

- 1. Mature renewable energy markets:** as renewables and storage become cost-competitive, merchant markets may replace CFDs, cap and floor mechanisms, and PPAs in mature regions, reducing the need for long-term contracts.
- 2. Policy shifts away from subsidies:** Governments may prefer less interventionist tools as markets mature.
- 3. Emergence of real-time markets:** Greater market efficiency may reduce reliance on CFDs or caps.

Why CFDs, Cap and Floor, and PPAs are likely to stay

- 1. Risk mitigation for investors by ensuring project bankability.**
- 2. Corporate and community commitments:** Sustainability goals drive continued use.
- 3. Emerging markets:** Essential tools to de-risk projects in regions with underdeveloped markets.

The likely future of CFDs, Cap and Floor Mechanisms, and PPAs

- 1. Evolving design:** Mechanisms may integrate storage, ancillary services, or dynamic pricing e.g. **Two Sided CFDs and Hybrid PPAs becoming more common**
- 2. Shorter terms:** Reduction in contract length for all mechanisms as markets mature
- 3. Technology-specific measures:** Mechanisms designed to introduce specific technology types with greatest cost gaps e.g. Cap and Floor LDES and Interconnectors



Non-market financing: two support mechanisms are also available to support the production and deployment of new grid technologies



Short-term deployment support

- Tax credits e.g. US IRA tax credit for storage
- Subsidies and grants e.g. China's storage subsidies, Germany's innovation tenders

Why necessary?

- High upfront costs and limited contract lengths make it difficult to secure financing without tax credits and subsidies to de-risk early deployment
- Nascent markets, particularly in developing economies, may require support mechanisms to bridge the cost gap for technologies e.g. short duration storage



Long-term innovation enablers

- Loan guarantees e.g. EU infrastructure loans for interconnectors
- R&D funding e.g. US DOE funding for Form's Energy long-duration storage

Why necessary?

- Advances innovation by reducing technical risks and accelerating commercialisation
- De-risk investments by reducing lenders risk perception
- Without long-term public financing, market failures prevent the deployment of large-scale storage solutions needed for a net-zero grid



Storage: learning points from successful short and long duration storage funding programs vital for their roll-out in nascent markets

Some of the most successful short duration storage programs include:



California Long duration storage programme & US IRA tax credit



Germany KfW Scheme



Australia Home Battery Scheme



Maharashtra Solar-plus-storage scheme

Key short-duration programme features include:

- **Long policy duration** – long term commitments with 5-10 years
- Programmes structured to **phase down incentives** over time
- **Clear technology requirements** e.g. specify certain storage durations noted to align with policy goals
- **Geographic targeting** of low adoption regions and zones
- **Mandatory solar pairing** to drive renewable adoption

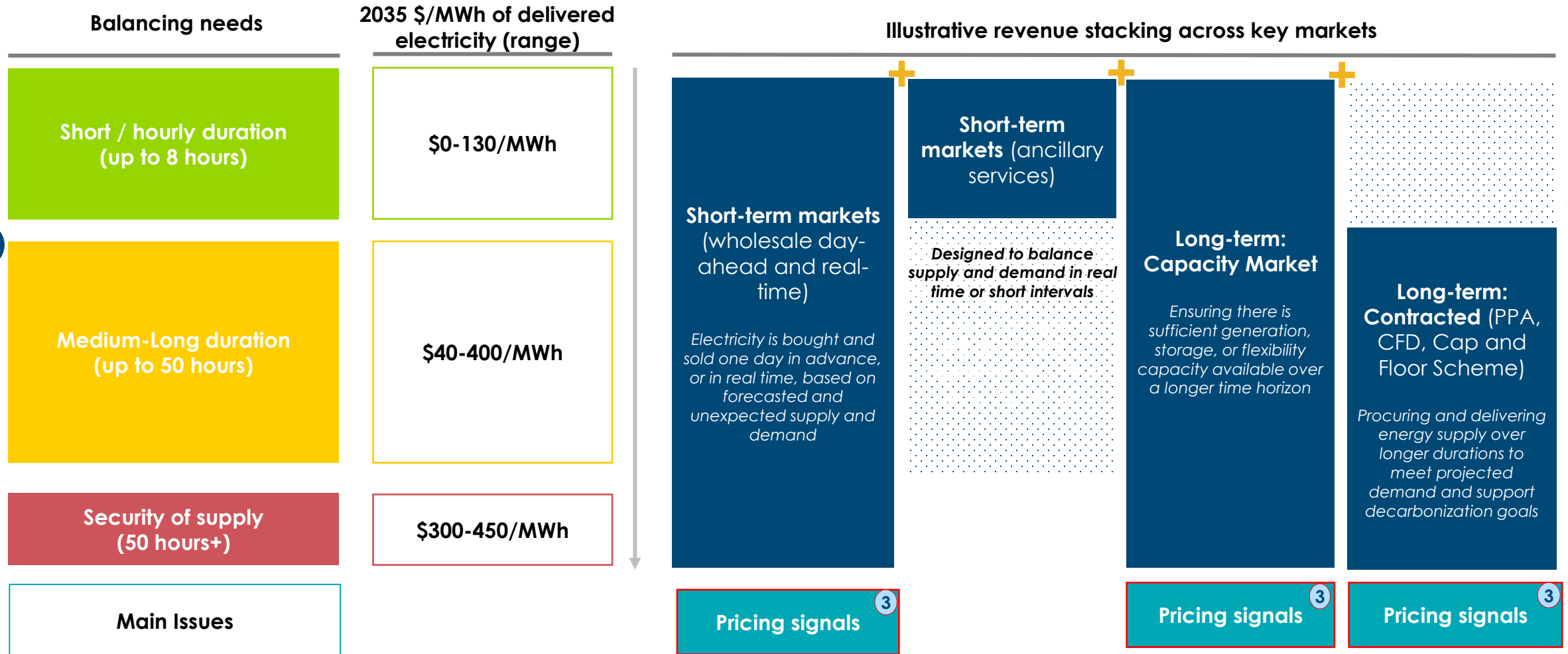
Key long-duration programme features include:

- Allocating **dedicated multi-year funding** to ensure long-term investment stability
- Technology agnostic and targeting **non-lithium storage technologies** to diversify grid reliability solutions
- Requiring **centralized procurement** to guarantee offtake agreements for developers
- **Integrating competitive bidding** to drive cost reductions and efficiency



Granular, real-time pricing required for dynamic responses to grid conditions

3

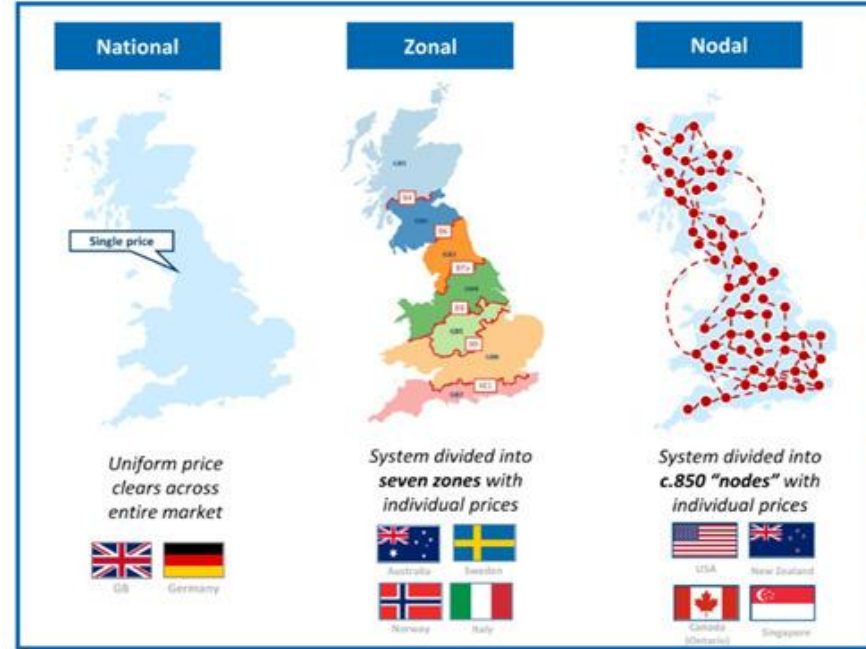


Note: Dotted areas indicates periods where technologies can play, but are less likely to due to the markets being less suited to the hourly duration being either too short or too long.

UK case study: Locational pricing is being considered

Ongoing issues:

- Current system does not **incentivize generation, flexibility, storage** in areas with the highest constraints
- This **worsens grid congestion and curtailment, resulting in high costs to consumers, and limits the full utilization of renewable energy**



UK Case Study

- REMA UK power market reform is considering options to move away from single into locational pricing
- However, UK government have **ruled out the implementation of full nodal pricing, and are yet to decide on whether zonal pricing will be introduced, and how it would be designed**

Single Market Pricing:

Sets one uniform price across an entire market, ignoring transmission constraints and locational differences

Zonal Pricing:

Divides the market into broader zones where a single price applies, averaging out localized grid constraints within the zone

Nodal Pricing:

Prices electricity at specific grid locations (nodes) reflecting local generation, demand, grid congestion, and transmission losses


Increasing granularity of pricing signals

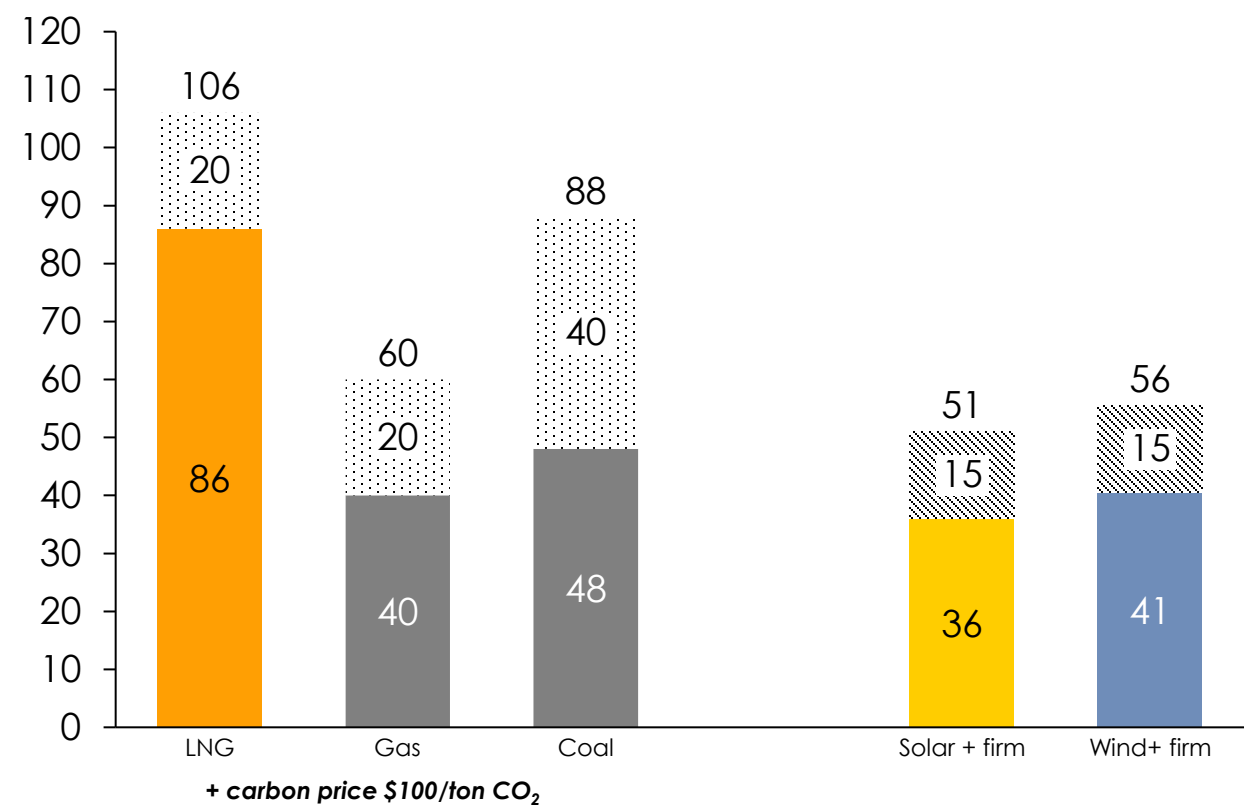
Several considerations around locational pricing

POTENTIAL ADVANTAGES	POTENTIAL DISADVANTAGES
Efficient cost-reflective pricing e.g. not compensating curtailed generation	Implementation challenges Transitional uncertainty, may affect transition to Net Zero
Investment signals: generation e.g. locate flexible generation assets near demand centres	Locational pricing may not be needed to achieve near system optimal dispatch Changes to balancing could achieve this ¹⁰
Investment signals: demand e.g. locate demand near generation sources	Limited groups able to respond Potentially difficult for existing gen, site-specific gen, CfD, and domestic consumers to move
More transparent, granular pricing	Difficult to forecast and 'bank' signals Cannibalisation of signal from other flexibility & reinforcements
Avoided network build More efficient siting of generation and demand could mean less network build is required	Increased cost of capital on investment If exposed, may increase system and consumer costs (through CfD and CM price increases)
	Market Power High scarcity pricing in constrained regions may have larger impacts on infra-marginal rents



Carbon pricing vital to storage and flex competitiveness

 **EU**
(USD/MWh for power)



Case Studies



Storage case study – **California**

California’s carbon pricing mechanism under the cap-and-trade program created a clear economic case for investing in energy storage to balance renewable generation.



Heat storage case study – **Sweden**

Sweden’s carbon tax (introduced in 1991 and steadily increased to over €110/ton by 2023) targeted emissions in the heating sector, encouraging shifts to renewable heating solutions.

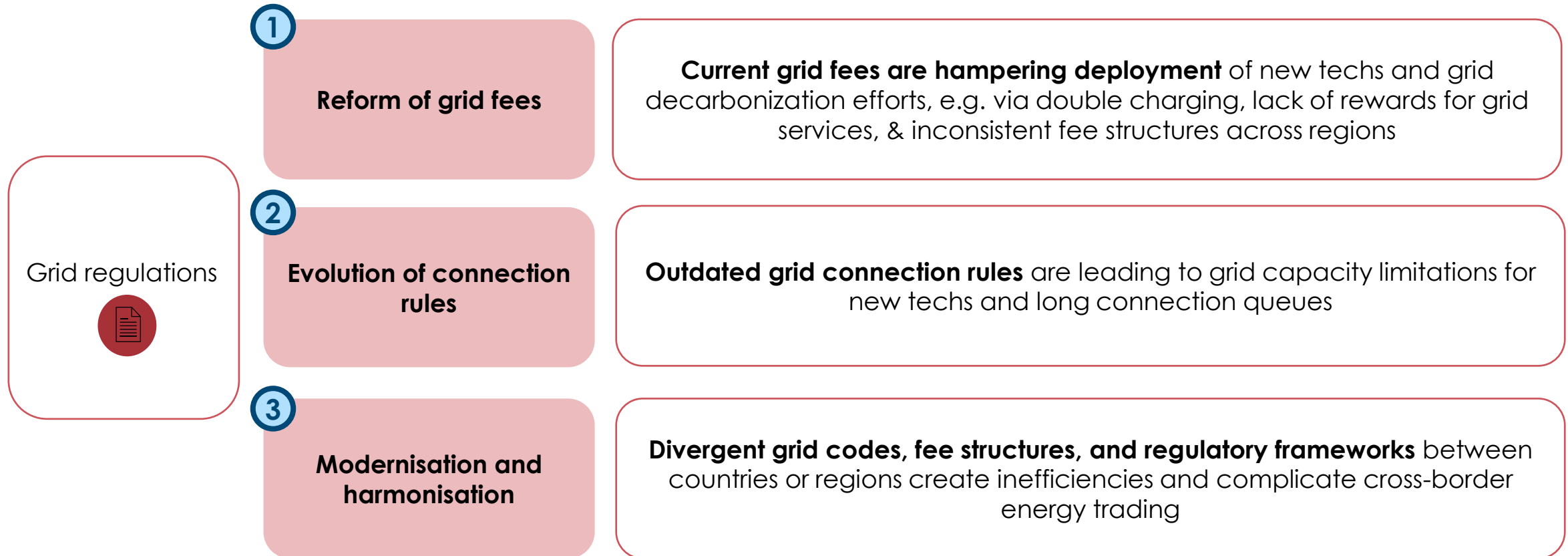


Note: Mix of solar/wind + firm depends on preliminary ETC analysis on balancing requirements in high-VRE systems.
Sources: ETC (2022) *Bioresources technical annex*. Data from S&P Global (2024), *Commodity Insights – LNG Analytics*; IEA (2024), *Price of US LNG*; Other fossil fuel data from World Bank (2024); Monthly Prices; BNEF (2023), *2H 2023 LCOE: Data Viewer v.1.0*; European Commission (2024), *Liquefied natural gas*

Grid regulation



Reform is needed on grid regulation



What are grid fees?



What are grid fees and who imposes them?

Grid fees (or network tariffs) are charges levied on electricity producers, consumers, and sometimes storage operators for the use of electricity transmission and distribution networks by TSOs and DSOs.



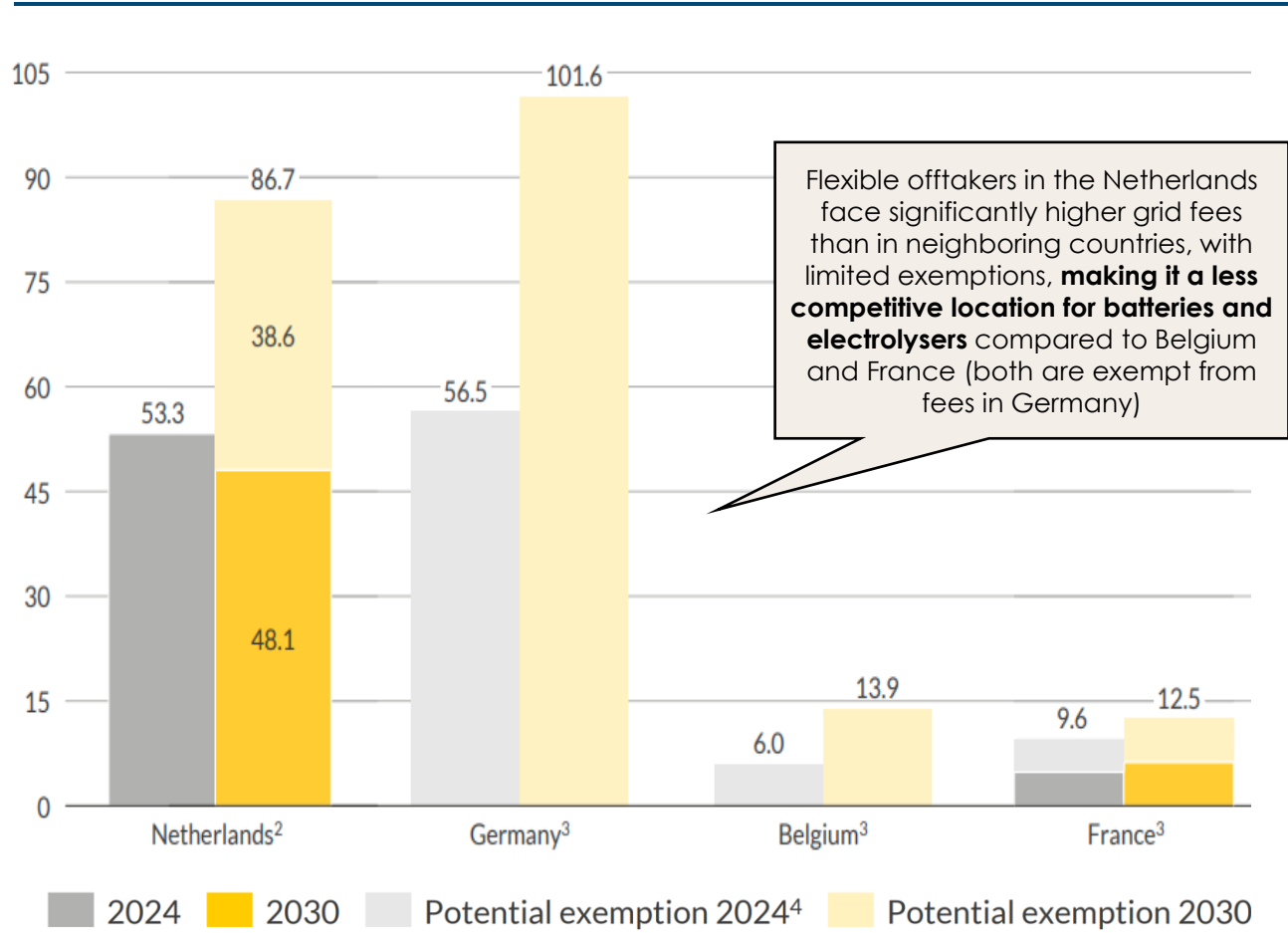
What are the issues with grid fees?

- **Double Charging:** Energy storage systems are often charged grid fees for both consuming (charging) and generating (discharging) electricity, inflating connection and fee costs.
- **Lack of Flexibility Incentives:** Grid fees rarely reward technologies like storage or demand-side flexibility for their role in stabilizing the grid and integrating renewables.
- **Regional Disparities:** Inconsistent grid fee structures across regions or countries create uneven investment opportunities and market inefficiencies.



Grid fees hampering development of storage in the Netherlands

Yearly grid fees for a 3000 fih offtake profile, excluding taxes
 €/MWh, real 2023



The Netherlands' energy storage sector has faced **significant challenges due to double grid fees**, where storage operators are **charged for both importing and exporting electricity**.

Key Issues:

- 1) Double charging for charging and discharging the battery
- 2) High grid fees compared to neighbours

The network manager, TenneT, has introduced the following interim policies aiming to reduce grid fees by 67%, but **these will need expanding to ensure more long-term, structural changes can be secured**.

- 1) Non-firm agreements
- 2) Time-weighted rates

Source: Aurora Energy, Grid Fee analysis 2024. Based on a 100MW asset connected to the high voltage grid; 2) From 2025, flexible offtakers can get an exemption from the contracted capacity part of the grid fees. See appendix for more details; 3) Based on methodology of E-bridge report; 4) Germany: batteries and electrolyzers, Belgium: batteries for first 10 years, France: batteries. Does not include time of use discounts.



Three main avenues being pursued to solve barriers created by grid fees

Technology classifications

Categorization of energy technologies (e.g., storage, renewables) to **determine their role in the grid and how grid fees are applied**, often defining assets as distinct asset classes.



Fee exemptions

The removal or reduction of grid access or usage fees for specific technologies or services



Tariffs

Adjustments to grid tariffs to reflect the actual costs and value of technologies in the grid



e.g. **Germany** has extended the grid fee exemption for energy storage systems until 2029, eliminating double-charging for storage operators, while **CAISO** also exempts energy storage from fees such as departing load charges to reduce the financial burdens created by legacy policies



Grid connection queues impacting a wide array of developed and developing markets

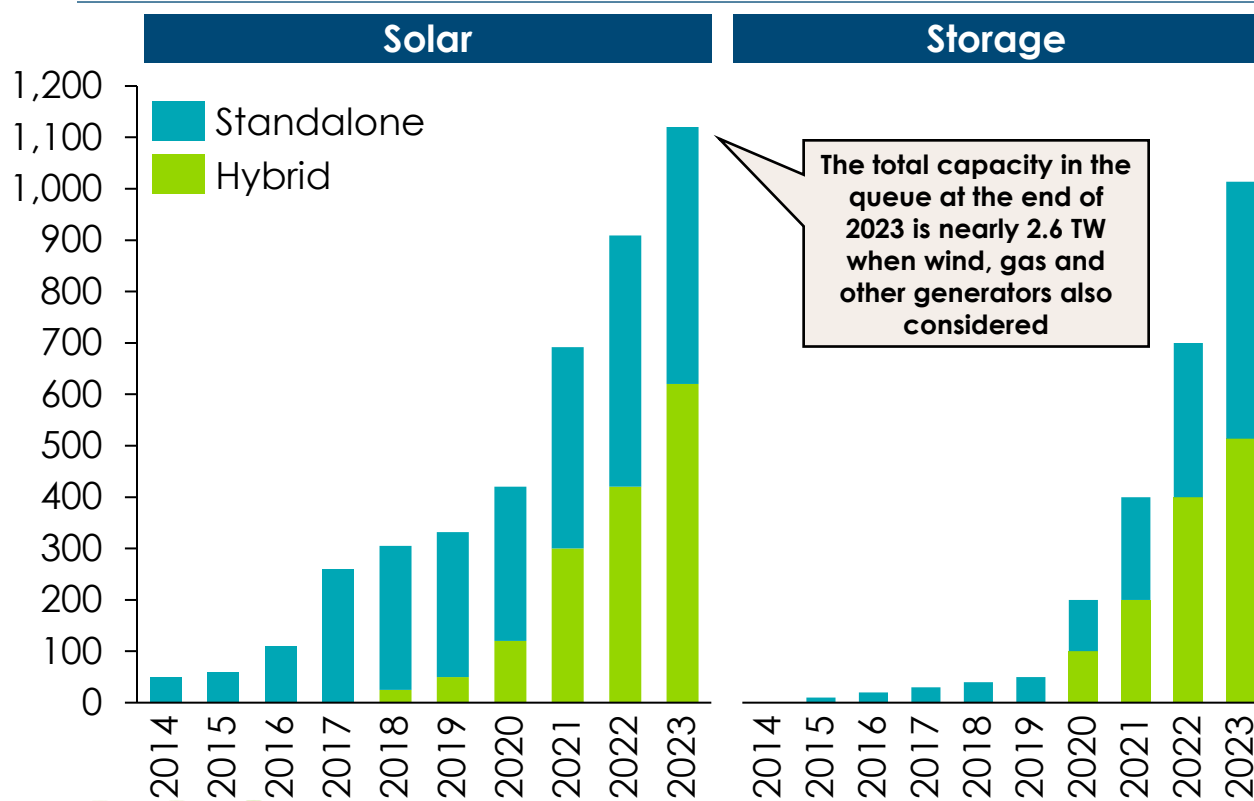
Solar (1,086GW) and **Storage (1,028)** make up ~75% of active capacity in grid connection queues in the US in 2023. Batteries make up 99% of storage capacity in the queue

The Net Present Value (NPV) of storage projects decreases as connection delays increase, **reducing the bankability** of the project, and heightening the risk, significantly

Total US capacity in connection queue sizes (2014-2023)



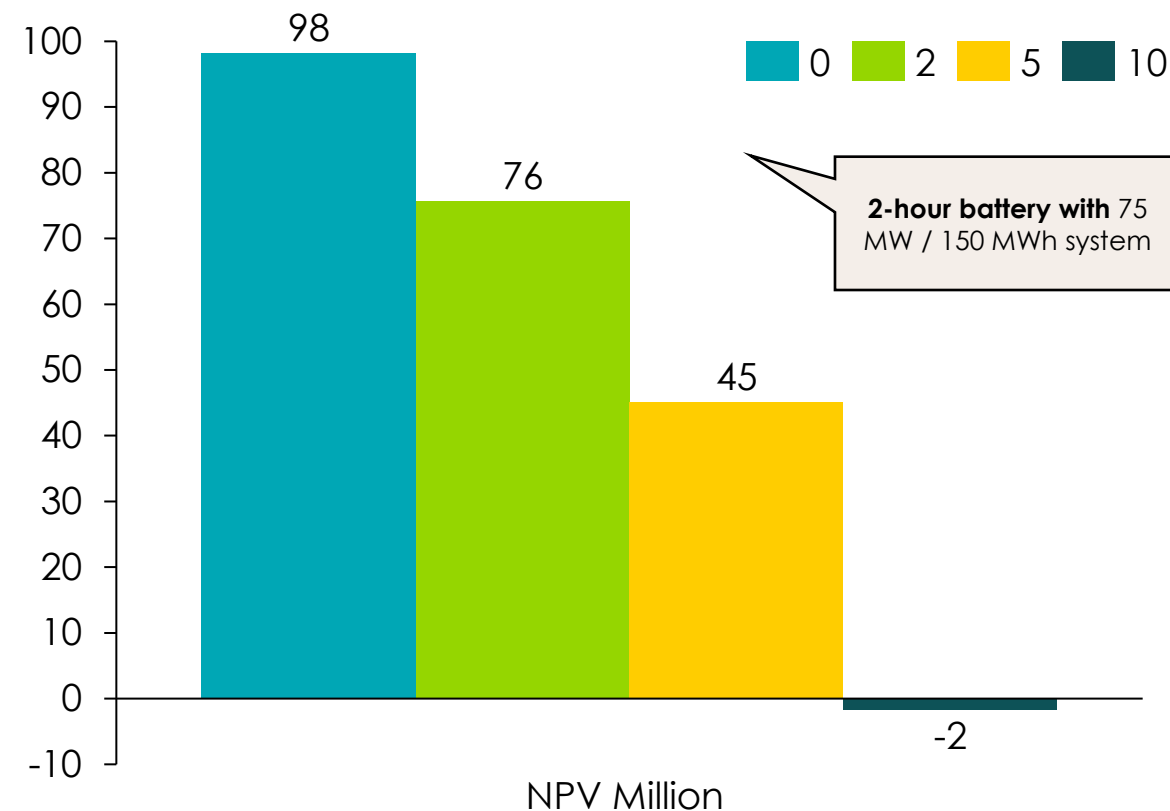
GW



NPV of UK storage project with delayed grid connection



NPV in £mn per kWh, number of years delayed



Source: LHS = Solar Power World, RHS ETC NPV Calculations assuming a project with: CAPEX £150mn, OPEX £3mn, Revenue of £20mn, Project lifetime of 20 years, Discount rate of 8% and Financing of £6mn.

Solutions for grid connection queues

There are three specific actions for connection queues;

①

Streamlined permitting and approvals

Simplify and expedite the approval process via

1. One-stop permitting
2. Statutory deadlines
3. Integrating digital platforms to manage applications

e.g. Germany, US States

②

Milestone-based queue management

Quick-fix solution – non-firm grid connections

Projects must meet specific milestones such as:

1. Land acquisition
2. Permitting
3. Financial commitments

Inactive or **zombie** projects are removed or reauctioned

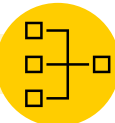




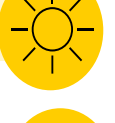
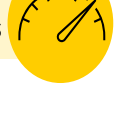
③

Grid modernization and expansion

Build, upgrade and optimise infrastructure to expand capacity (covering later in this deck)
Use storage to alleviate congestion



UK introducing impactful grid connection queue policies, though pushback from the industry noted due to increased complexity

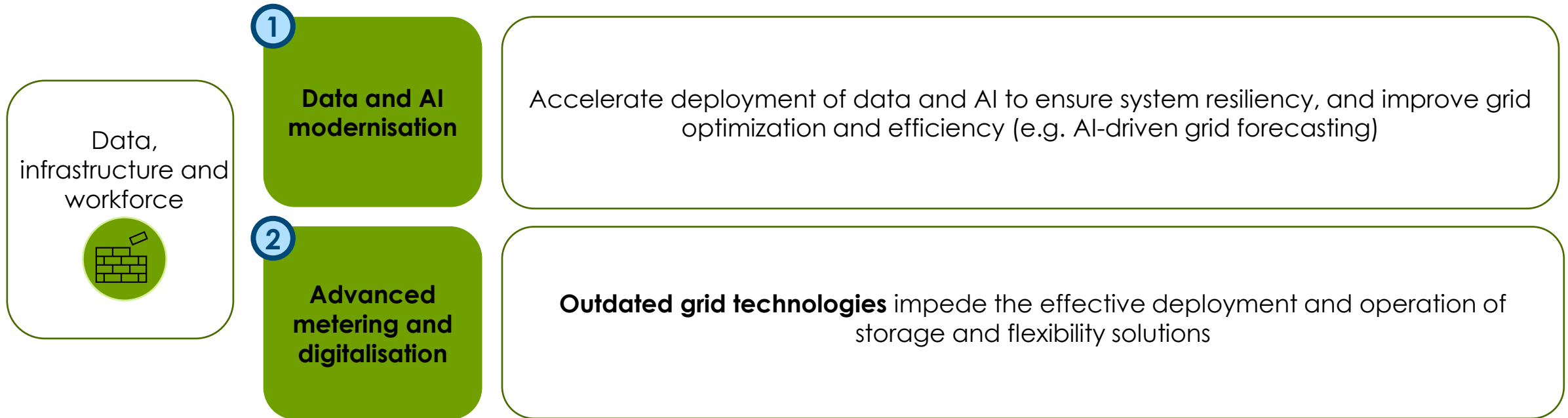
	← Old System	→ New system	\$ Cost	💡 Benefit
Queue structure 	First-come, first-served, regardless of project readiness	Projects must meet milestones , with deadlines to demonstrate progress	Increased complexity in managing milestone tracking for developers and grid operators	Eliminates speculative or "zombie" projects,
Land acquisition 	No requirements for land ownership or leasing before entering the queue	Proof of land ownership or lease required by a specific deadline	Land acquisition can be costly and difficult , especially for smaller developers	Streamlines the queue with serious applicants
Permitting and approvals 	Permits and approvals not required upfront, often delaying progress later	Developers must submit evidence of permits or local authority approvals by specified milestones	Developers may face delays in obtaining permits , potentially leading to removal from the queue	Reduces later delays
Financial commitments 	Minimal financial commitments required; speculative projects could enter easily	Developers must provide financial evidence , such as deposits or proof of funding	Higher financial burden for early-stage developers or smaller players	Deters speculative applications
Inactive projects 	No mechanism to remove stalled or inactive projects from the queue	Inactive projects are removed if milestones are missed , freeing up space for others	Valid projects with unforeseen delays may lose their queue position	Significantly reduces backlog
Transparency 	Limited visibility on queue status or project progress	Regular updates required from developers, ensuring visibility for grid operators and stakeholders	Administrative burden for developers to provide frequent updates	Improved queue management
Dynamic fees 	Fixed grid connection fees, no penalties for inactivity	Higher fees for speculative projects ; refunds for milestone-compliant projects	Higher upfront costs could discourage smaller developers	Incentivizes readiness and discourages speculative behavior,



Data, AI and smart grids

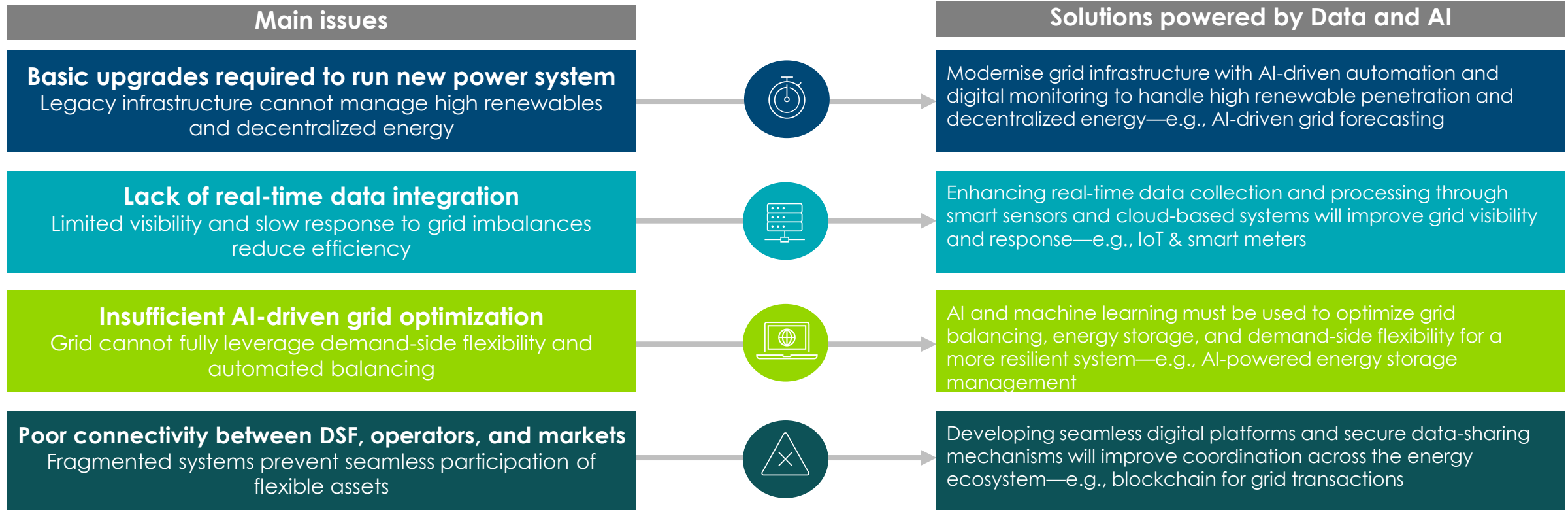


Data, infrastructure and workforce reforms to address 3 key challenges



What do we need to harness the opportunities presented by data, AI and Smart Grids for future power systems?

We **physically cannot operate a new grid system** with increased variable renewable energy **without updating the data systems and software within the system** due to the increased number of generators and technologies, requiring us to be better and quicker at responding to a larger amount of data points



Case study: Google X Tapestry and grids

Google X's Tapestry is an **AI-driven grid mapping** and **optimization** tool that **integrates real-time data** to improve grid resilience, renewable energy integration, and system planning efficiency. Tapestry **helped stabilize Chile's power grid** by using AI-powered forecasting and advanced grid analytics to predict renewable energy fluctuations, enabling better integration of wind and solar while reducing curtailment and improving reliability.



How Tapestry answers key data issues:

Developing advanced computational tools to create a holistic and dynamic view of the grid, enabling the integration of renewable energy sources and enhancing grid resilience



By weaving together diverse data streams, Tapestry provides a comprehensive, real-time visualization of how electricity is produced, distributed, and consumed, facilitating informed decision-making for grid operators



Using AI, Tapestry's Grid Planning Tool enables grid planners to run simulations 86% faster and explore 30 times more scenarios



Through partnerships with system operators and energy experts worldwide, Tapestry fosters collaboration and data sharing, bridging gaps between demand-side flexibility resources, operators, and markets



Advanced metering and digitalization

Demand side flexibility (DSF) offers opportunities for the digitalization of energy consumption for lighting, heating, electric vehicle charging, amongst others. This will introduce 1) greater data points and 2) deeper, trust-based relationships between the consumer, DSF platform operator and the transmission network.

Case study: additional data layers of DSF technology requiring data monitoring:

1

Driving optimization of demand-side flex assets such as home smart appliances, vehicles for vehicle-to-grid systems, heating and cooling appliances



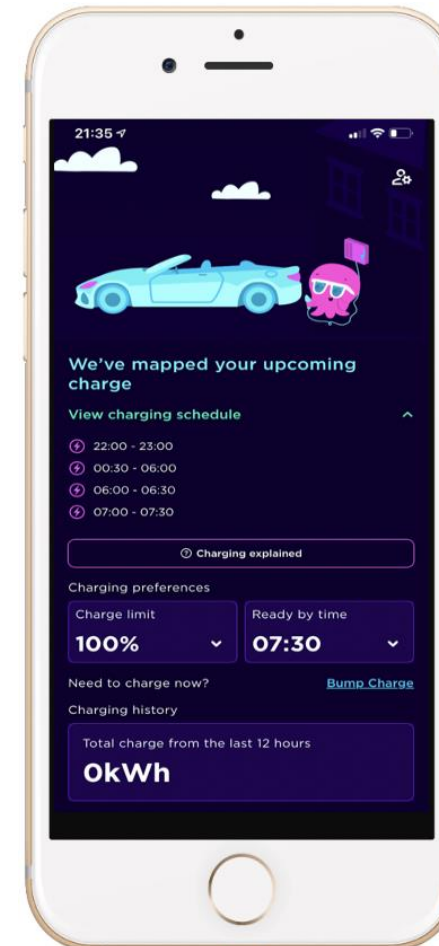
2

Software connecting DSF to operator e.g. Octopus



3

Software connecting operator to the DSO/TSO



Advanced metering, plus investments into digital infrastructure, required to enable better grid management

Why Advanced metering and digitalization matter?



Enables accurate tracking of electricity generation, consumption and behaviour

Allows batteries and flexible demand to respond to price signals and grid conditions

Smart meters allow users to participate in flex markets and manage energy efficiently

Key technologies enabling digitalization



Smart Meters: provide real-time usage data for accurate billing, demand response and system balancing

Advanced Metering Infrastructure: Supports two-way communication between consumers and grid operators

Edge Computing: Processes grid data at the source, reducing latency in response times

Virtual Power Plants: Aggregates distributed energy resources into a single grid asset e.g. Tesla Autobidder, Next Kraftwerke

Policy reforms needed



Enabling greater advanced metering on the grid

- 1) Mandate universal smart meter adoption – Set a national rollout deadline to ensure all consumers have real-time energy tracking
- 2) Require time-of-use pricing – Encourage flexible consumption and incentivize battery storage use
- 3) Standardize interoperability – Ensure smart meters, inverters, and flexibility platforms use common communication protocols for seamless integration.

Accelerating grid digitalisation

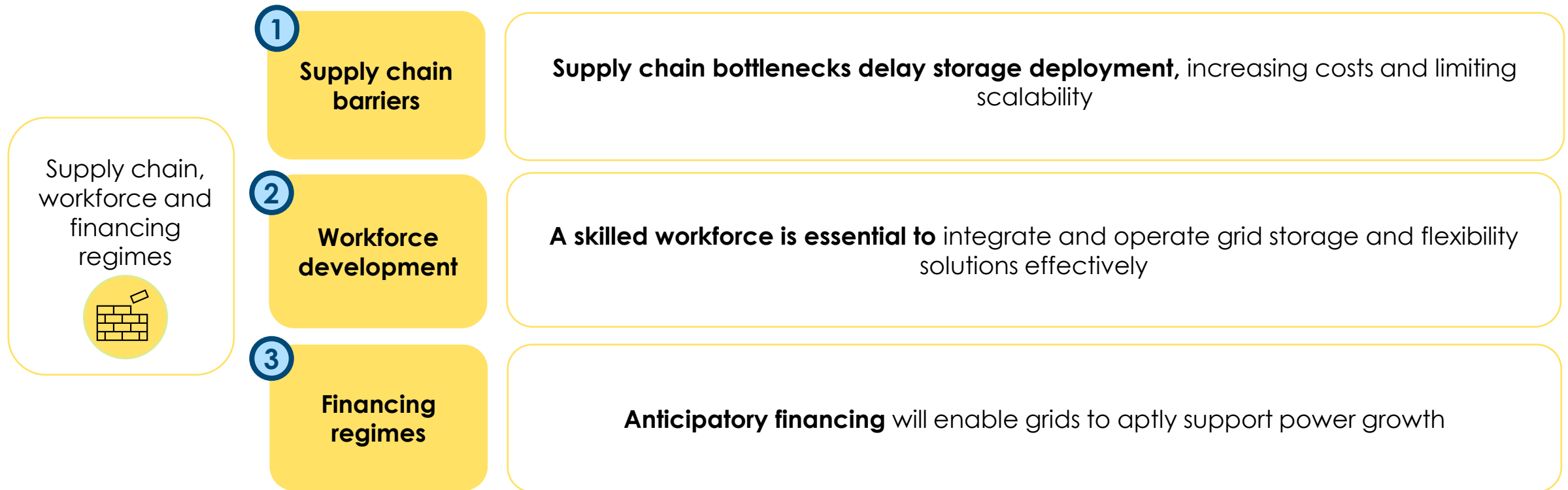
- 1) Expand data-sharing frameworks – Improve access to metering & grid data for energy storage providers and demand response aggregators.
- 2) Create digital flexibility markets – Enable storage, EVs, and smart appliances to bid into flexibility markets using automated demand response



Supply chain, workforce and financing regimes



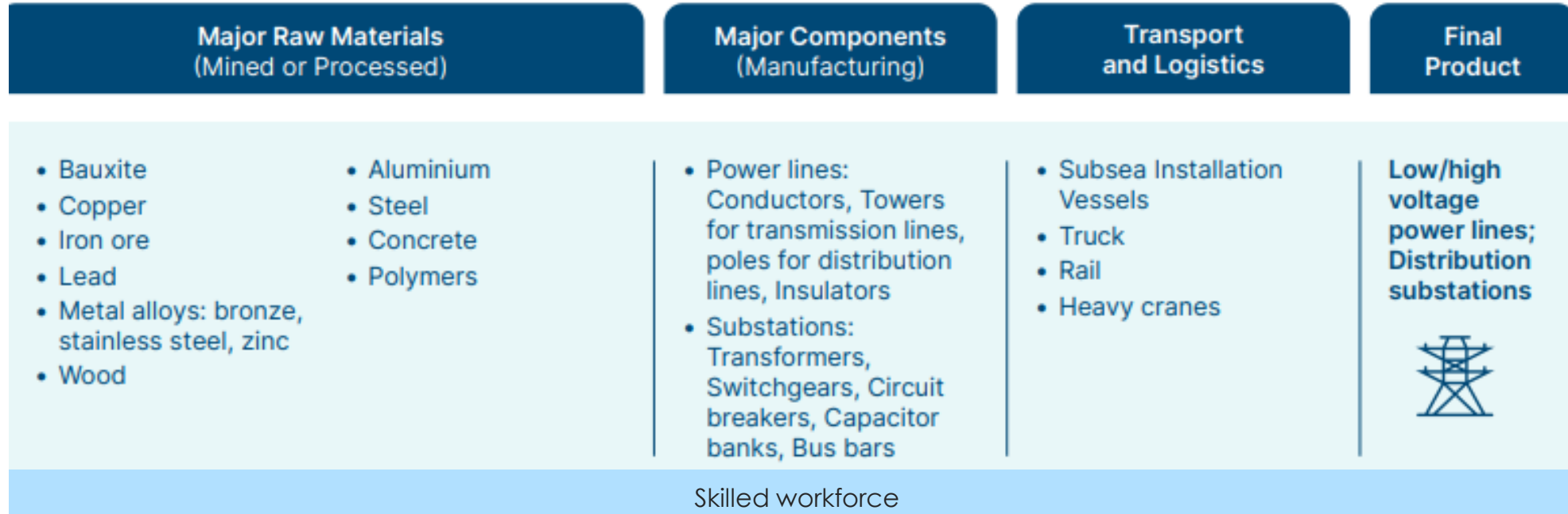
Structural features require tracking and upgrades to prevent bottlenecks



ETC 2023 work on supply chains identified key pressure points for grids

Transmission & Distribution Grids

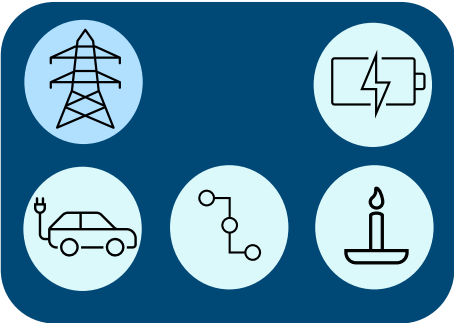
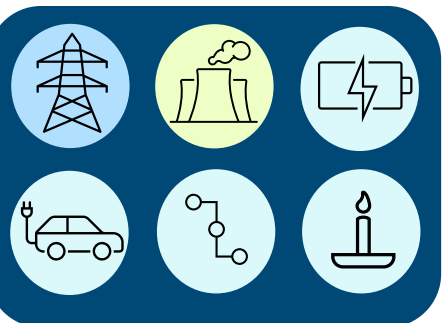
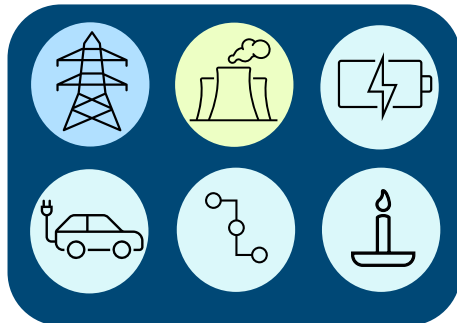
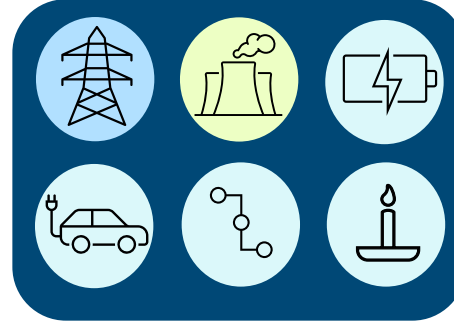
Key areas often cited as major concerns, deep dives on next slides



Grid supply chains are characterized by **high material needs for copper and aluminium**, globally competitive markets for components, and relative ease of global transport. Overall, grid supply chains are not expected to face major impediments to scaling, though there could be a **higher risk of bottlenecks in some specialised areas**.



For 6 emerging technologies, the following supply chain risks emerge

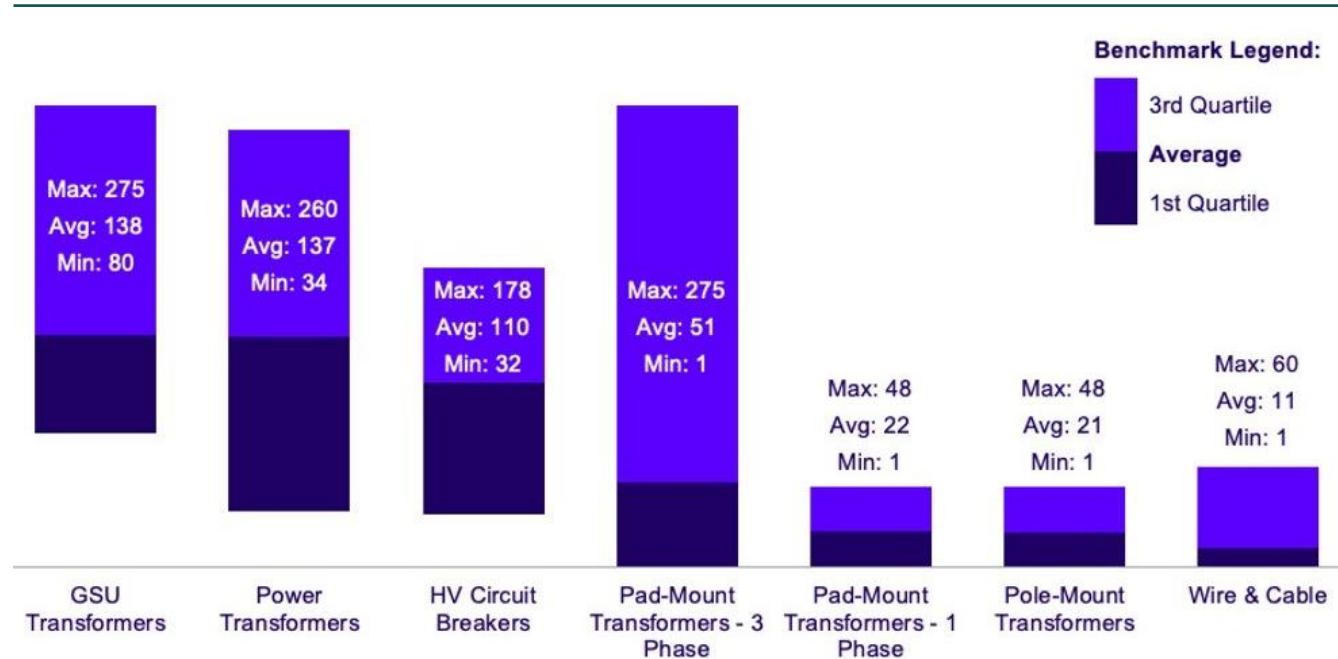
Risk	Raw Material Constraints	Geopolitical & Trade Risks	Cybersecurity risks	Infrastructure bottlenecks
Description	Lithium, rare earths, copper, and HVDC components face long-term supply bottlenecks	Dependence on China, DRC, and rare mineral exporters threatens security of supply	Increased digitalisation makes systems more vulnerable to cyberattacks and data breaches	Transformer, interconnector, and HVDC cable supply chains need major expansion
Technology impacted				



Infrastructure bottlenecks: transformer lead times have been rising impacting storage project timelines, but market is starting to respond

Grid equipment delivery lead times by component, Q2 2024

Weeks



Growing lead times driven by:

- 1) **Supply chain tightness** key material inputs & lack of skilled workforce
- 2) **Bottlenecks deriving from production concentration in highly specialized manufacturers**, given need for special facilities (e.g. drying ovens for windings, high power testing laboratories, etc.).
 - Concentration across a few companies (E.g. ABB, Hitachi, General Electric) for large transformers
 - Long timeframes for break even, manufacturers reluctant to invest to expand production.

Transformer lead times have been **increasing for the last 2 years, with some large GSU power transformer production being quoted as high as 4-5 years.**



Key supply chain bottlenecks need to be addressed as part of holistic strategy around supply chains & materials, three key areas

Fundamental driver: a strategic vision for the energy transition established by governments, including net-zero targets, supporting sectoral targets (e.g., GW capacity deployment, ICE phase out ban dates), policies that send clear signal on the pace and scale of clean energy deployment and clear volume needs

Addressing supply-demand imbalances

1

- **Demand:** Accelerate improvements in **materials and technology efficiency** through targeted incentives and research and development, as well as support for circular economy business models
- **Demand:** Create economic incentives for **scaling recycling** and the secondary supply of critical materials.
- **Supply:** Accelerate permitting, expand and de-risk investments, and engage with local communities to **expand supply from the mine site to manufacturing**
- International **engagement and data sharing** to understand demand and supply forecasts and potential constraints and increase transparency, e.g., via IEA outlooks and round-tables with governments and industry

Developing sustainable and responsible supply chains

2

- **Strong regulations on environmental and social impacts** of clean energy technologies, starting with **carbon intensity**. Aim to decarbonise and decrease impacts at the mine site and throughout manufacturing value chains, by driving clean energy procurement, increased process efficiency and best-practice environmental standards.
- **Use purchasing power to drive projects** with high environmental and social standards.
- **Define and adopt high-quality voluntary** environment and social standards.
- **Improve and require supply chain traceability** through industry-wide engagement and trusted third-party auditors.

Ensuring diversified, resilient and secure supply

3

- **Adopt strategies to diversify supply** for mining, refining and manufacturing:
 - This can include friend-shoring, signing joint ventures and off-taker agreements, and agreeing strategic partnerships with key companies and countries.
 - **Focus action on location of production**, not ownership – to allow strong competition across markets.
- **Where near-shoring is assessed as strategically beneficial**, develop a suite of actions to **maximise benefits of near-shoring** of value chains, including alignment of near-shored industries with domestic growth areas.

Grid workforce challenges; challenges around lead times for training and new skills required require clear vision & signals

- **Long training lead times could lead to short-term bottlenecks of skilled workers.** For example, training to become a journeyman line workers can take up to 7 years. High percentage of older workers leads to additional pressure.
- **Changing nature of the grid** will require 1) new skills, e.g. with greater IT competency and 2) skills in new locations

Proper communication of workforce needs is critical to ensure correct signals for the job market, allowing any skills shortages to be short-lived.

Proper planning around retraining opportunities will also be critical.

Typical electricity workforce roles and required education/training

Job Category	Job Description	Required Education						
		High School	Vocational	Apprenticeship	Associates	Bachelors	Masters	Doctorate
Lineman	Responsible for the installation and repair of overhead and underground distribution and transmission lines, poles, transformers, and other equipment.							
Power Plant Operator	Responsible for the maintenance and operation of all primary and auxiliary equipment required to generate electricity or meet natural gas customers' demands.							
Technicians (Transmission and Distribution)	Responsible for the repair of both electrical and mechanical equipment. This includes inspecting and testing electrical equipment in generating stations and substations.							
Technicians (Generation)	Responsible for the construction, assembly, maintenance, and repair of steam boilers and boiler house auxiliary equipment.							
Pipefitters and Pipelayers (Generation)	Responsible for the installation and maintenance of pipe systems and related equipment for steam, hot water, heating, sprinkling, and industrial production and processing systems.							
Power Engineers	Focus on electrical systems, equipment, and facilities rather than on mechanical systems and other non-electrical systems involved in electric and natural gas energy services. It includes people involved in planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation, transmission, distribution, consumption, and control of electricity.							
All Other Engineers	Focus on non-electrical systems, processes, equipment, and facilities involved in electric energy services. It includes people involved in the planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation/supply, transmission, distribution, consumption, and control of electricity.							

UK currently has 200 linesmen, but will need 1,200 to deliver on expansion plans

Many workers need years of experience before they can work on major projects (i.e., 5 years of experience needed before engineers can work on a substation.)

The electricity workforce includes several job categories, each with specific educational requirements (shown in green). The gray boxes show where a specific level of education is sometimes required or infrequently required.



Workforce engagement solutions across technologies to improve grid efficiency

Developed Economies

1. **Advanced Training Programs:** Emphasize the development of specialized skills to manage and integrate advanced technologies such as smart grids, digital tools, and renewable energy systems.
2. **Industry-Academia Collaboration:** Foster partnerships between educational institutions and the energy sector to ensure curricula align with evolving industry needs, facilitating a steady pipeline of qualified professionals.
3. **Continuous Professional Development:** Encourage ongoing training and upskilling opportunities for the existing workforce to adapt to technological advancements and shifting energy landscapes

Solutions

International collaboration

Developing Economies

1. **Foundational Skills Training:** Focus on building basic technical and vocational skills to support the deployment and maintenance of energy infrastructure, particularly in rural and underserved areas
2. **Capacity Building Initiatives:** Implement programs aimed at enhancing institutional and human capacities to plan, finance, and manage energy projects effectively
3. **International Support and Knowledge Transfer:** Leverage global partnerships to access technical assistance, best practices, and funding mechanisms that facilitate workforce development in the energy sector

Funding frameworks must be revised to enable anticipatory investment in storage and flexibility

Current state

- **Shorter term planning cycles** (e.g. 5-7 year windows agreed in advance with regulator)
- Current grid investment models place the **cost burden on individual developers or consumers**
- **Piecemeal approach to new funding mechanisms**, adding new codes for individual issue-areas without synthesizing efforts

Low risk, but no capacity for anticipatory investment

A low-risk approach prioritizes cost efficiency, but leads to incremental grid upgrades that fail to unlock new technologies

This results in delayed investments, curtailment of renewables, and increased reliance on fossil backup generation

Future needs

- **Longer term planning cycles** that proactively factor in storage growth and DSF
- Socialize costs to remove barriers for new flexibility assets
- **Whole-system planning approaches** that optimize the role of batteries, thermal storage, and demand-side flexibility in reducing grid constraints and balancing renewables

Higher risk, but can enable anticipatory investment

Increased tolerance for risks which enable decarbonization, even if elements are not later fully utilized and costs for consumers/taxpayers therefore rise; critical to avoid network bottlenecks



**Consumer
engagement
necessary to
enable transition**



Consumer engagement to address one key challenge

Consumer and
end-user



**Consumer
engagement
and trust-
building**

Lack of consumer awareness and participation limits the adoption of storage and flexibility technologies



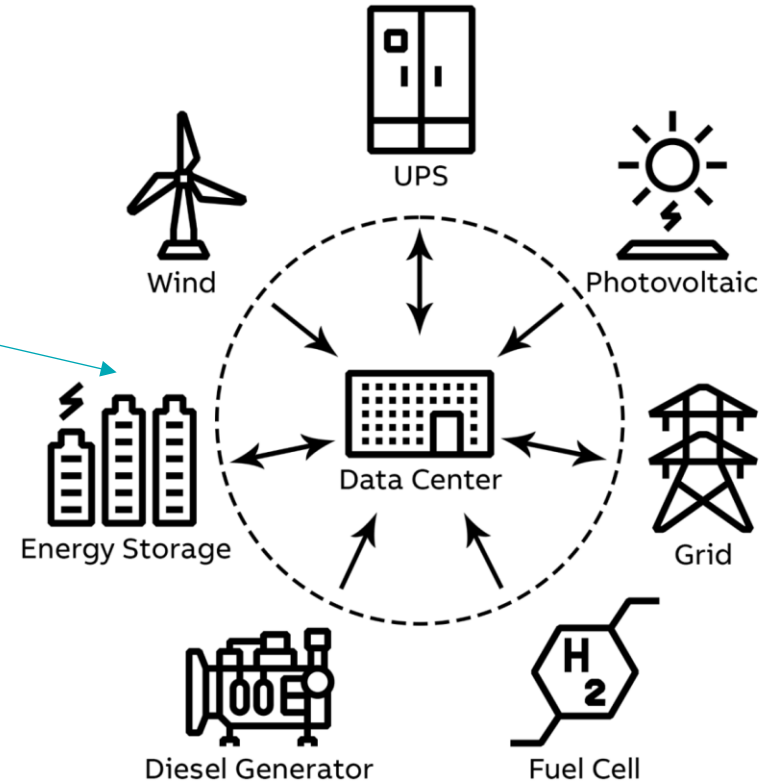
Shift in relationship between energy generator and consumer prompts need for greater trust building and consumer engagement

As we see more energy consumers take greater responsibility for their energy production (on-site renewables and storage with commercial and industrial consumers) and usage (DSF with residential consumers) we see relationships between energy producers, suppliers and consumers become more **interactive**.

As a result, we need to improve the ways in which consumer engagement takes place, with an emphasis on education, and moreover, to ensure we build trust across actors .



The build-out of commercial and industrial energy storage (LHS) and on-site renewable energy generation + storage with data centers (RHS) highlights that **new actors will need to build relationships with storage developers and optimizers to best manage their systems and trust that they are managing them to accrue them sufficient revenue**



Consumer engagement in demand side flexibility is particularly vital

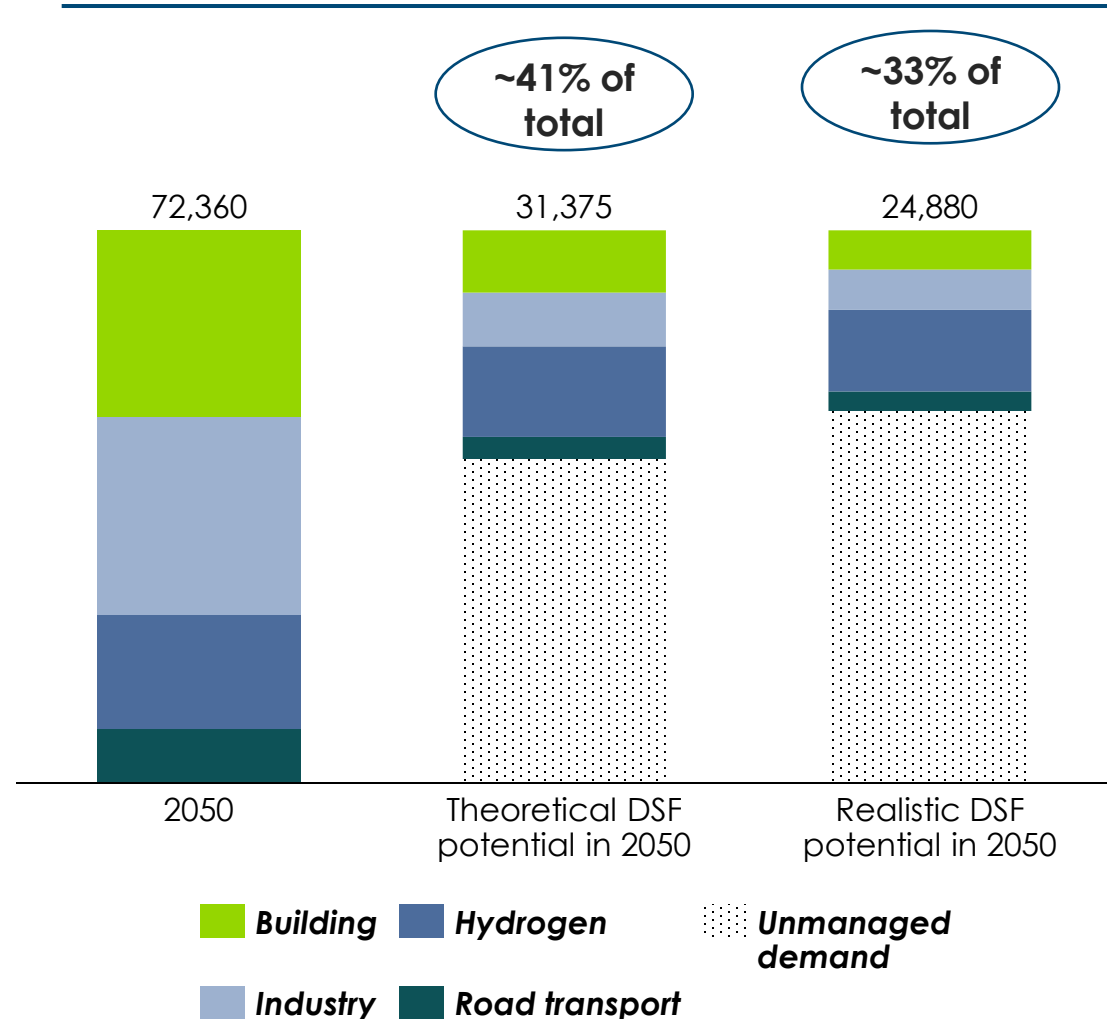
Consumer empowerment and market participation are vital to introduce new technologies onto the grid

DSF transforms passive consumers into active participants, empowering them to make informed energy decisions, reduce costs, and contribute to decarbonization

Programs like the UK's Demand Flexibility Service engaged over 1.6 million households, demonstrating the potential for mass-scale consumer involvement

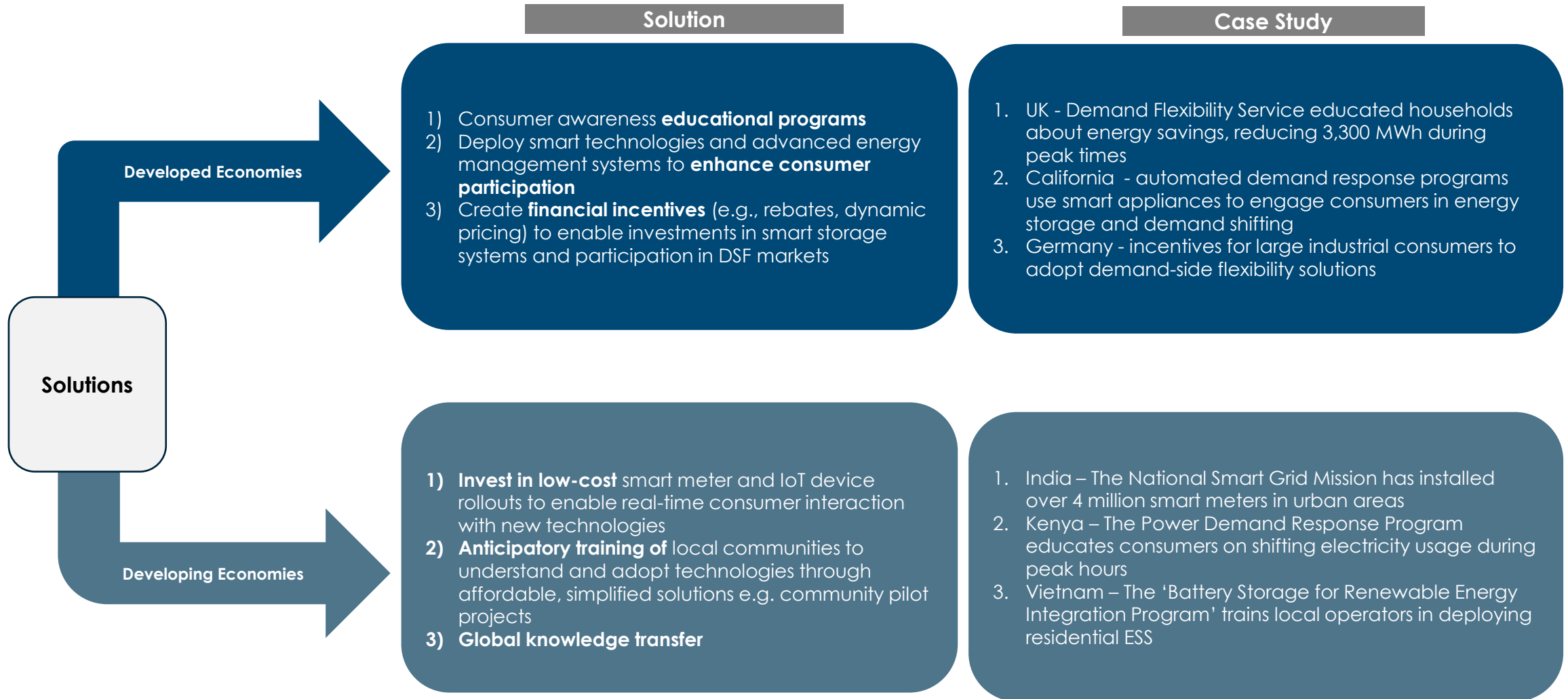
Global electricity demand and DSF potential, 2050

TWh



Source: IEA

Consumer engagement solutions across storage and flexibility technologies to improve grid efficiency



Source: BNEF, National Grid

Conclusions



For emerging technologies, scaling requires addressing several areas

Strategic vision & planning

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



Market design

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



Grid regulations

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



Data, AI and smart grids

- Data and AI modernisation
- Advanced metering and digitalisation



Supply chain, workforce and infrastructure

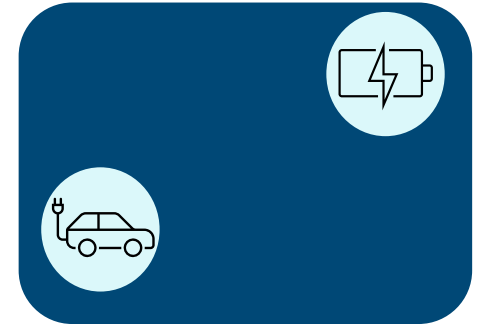
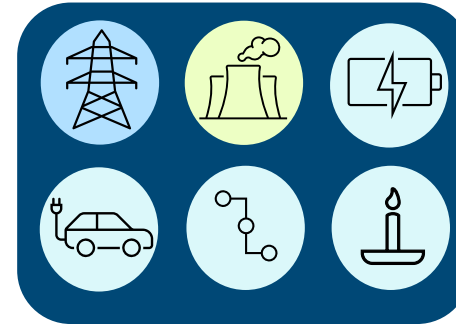
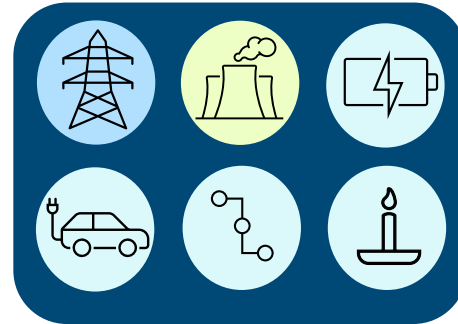
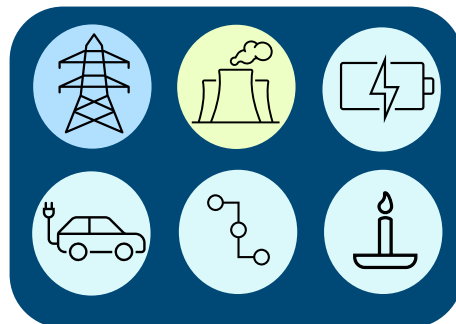
- Supply chain concerns
- Workforce education
- Grid build (e.g. expansions and upgrades)



Consumers

- Consumer engagement and trust-building

Technology:



Recommendations on priority actions



Market design

- **Ensure fair market access to enable revenue stacking for storage & flexibility** (e.g. rewarding technologies on the basis of their unique characteristics); for technologies **where required** (e.g. long duration storage) **develop well-designed market mechanisms to de-risk revenue streams** (e.g. Cap-and-Floor, two-way Cfds, etc)
- Additional considerations for developing markets:
 - **Ensure basic market access** for new technologies in existing markets; **introduce ancillary service offerings** to enable technologies to have access to simple revenue streams. **Mechanisms to de-risk revenue streams may be required for a wider set of technologies** (e.g. short duration storage) to offset higher risks/higher costs



Grid regulations

- **Focus on streamlining grid connection rules** for new clean energy assets, and enforcing project milestones; **reform grid fees** by defining storage as a distinct asset class ensuring fair treatment and market access



Supply chain, workforce and infrastructure

- **Tackle the most pressing supply chain barriers by providing clear signals for investment in new capacity** (e.g. transformers, long distance cables, new jobs/skills) by clearly outlining deployment targets and ensuring coordination across major private sector actors

