Energy
Transitions
Commission

Power systems transformation: emerging conclusions from the ETC's work

ETC Representatives Meeting

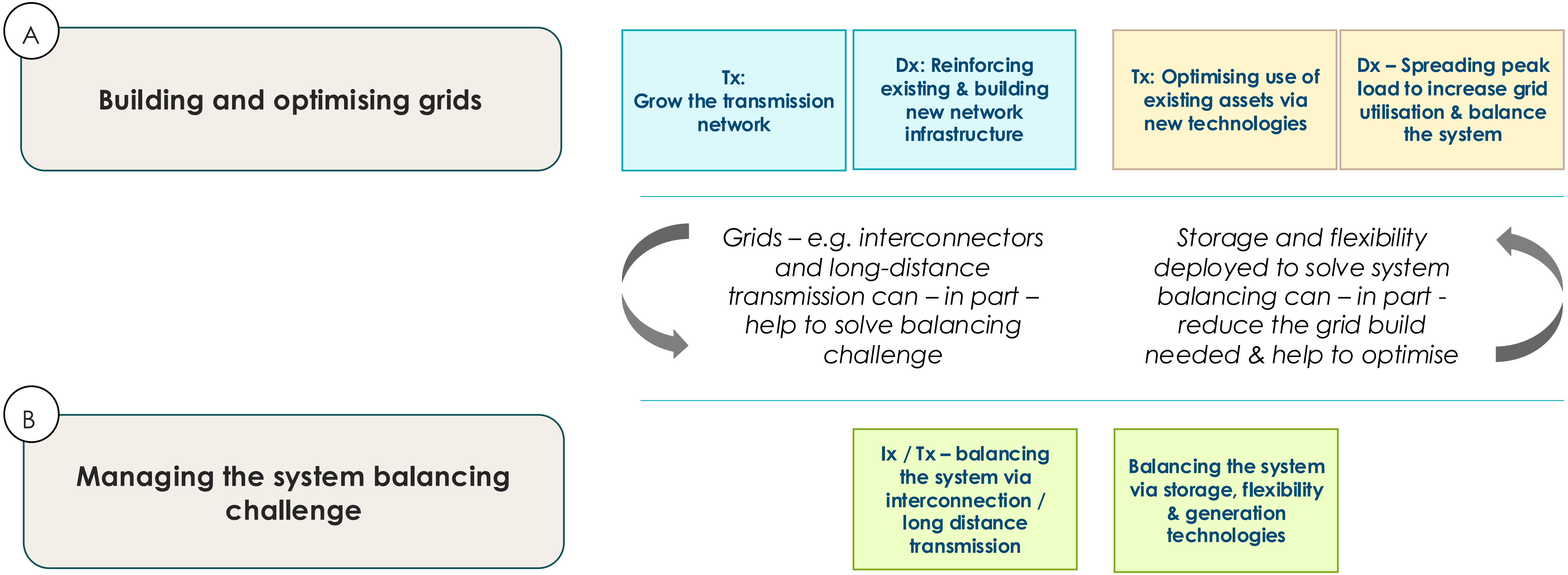
19th September 2024

Agenda

1. **The transformation of the power system is bringing new challenges: building & optimising grids, and managing system balancing challenge**
2. **A technological revolution is enabling this transformation**
3. **Key questions on managing the system balancing challenge**
4. **Key enablers & implications of the new system**

The transformation of the power system is bringing new challenges

There are two fundamental & interrelated key areas for power systems which the ETC is looking at this year



A

Building and optimising grids

Tx: Grow the transmission network

Dx: Reinforcing existing & building new network infrastructure

Tx: Optimising use of existing assets via new technologies

Dx – Spreading peak load to increase grid utilisation & balance the system

Grids – e.g. interconnectors and long-distance transmission can – in part – help to solve balancing challenge

Storage and flexibility deployed to solve system balancing can – in part - reduce the grid build needed & help to optimise

B

Managing the system balancing challenge

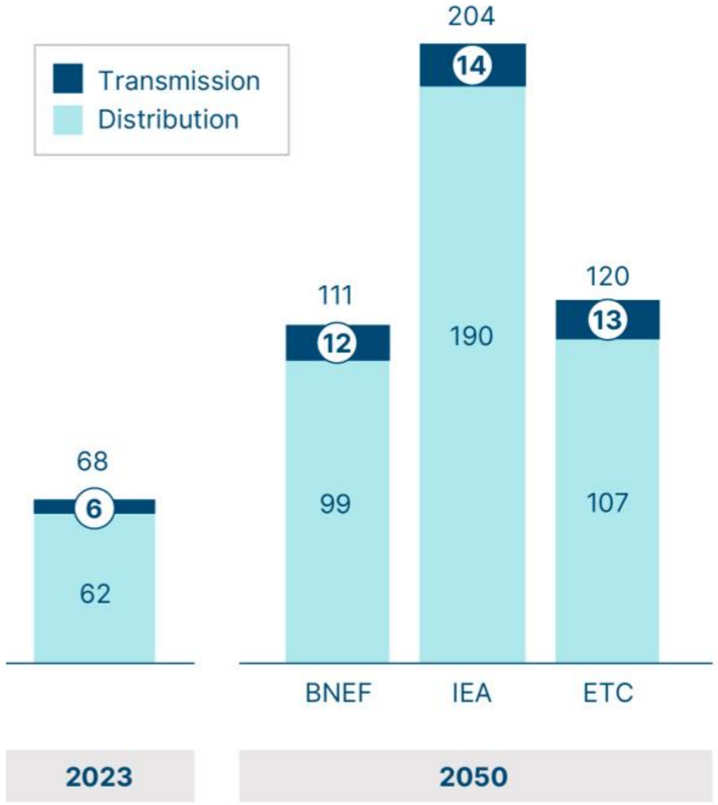
Ix / Tx – balancing the system via interconnection / long distance transmission

Balancing the system via storage, flexibility & generation technologies

Grids build must happen faster, but four critical challenge areas slow this down

Grid build must increase markedly

Million km



Significantly more transmission and distribution wires are needed

Key challenge areas must be resolved

i. Implement a strategic vision for network expansion by a future date

ii. Address slow permitting & approvals and societal acceptance

iii. Address skill, component and materials gaps

iv. Reform financing structures & increase access to finance

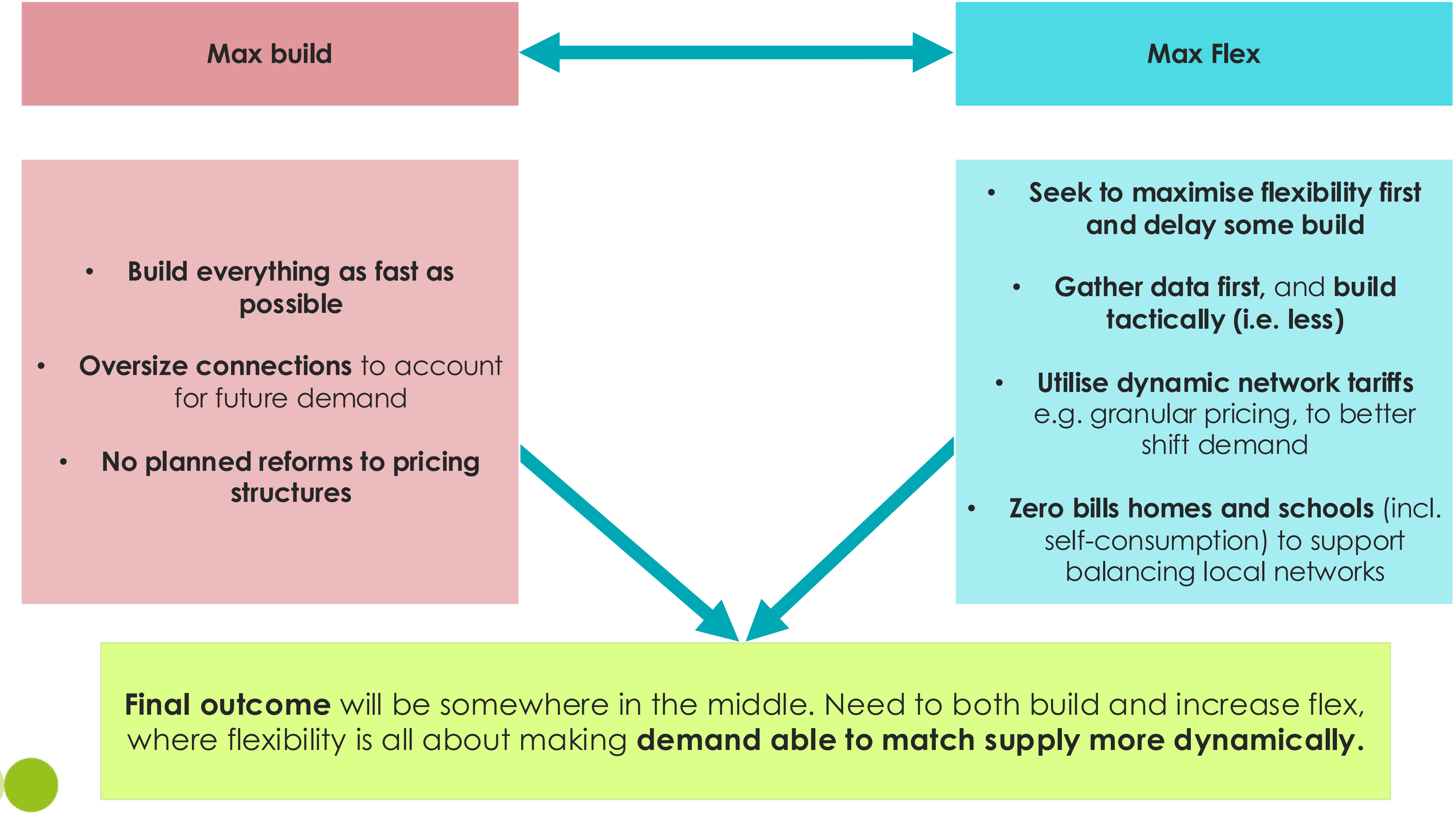
Notes: Tx = Transmission, Dx = Distribution, Ix = Interconnection.
Source: Systemiq analysis for the ETC

The scale of grid build can be partially offset by optimising grids – avoiding some overall build and buying time for wider reinforcements

There are several ways to optimise power flows across the grid:

- **Innovative grid technologies** could materially improve the efficiency of power flows on the system
- **Storage deployment** (in the right location) can reduce the need for new wires
- **Demand side flexibility** could reduce peak consumption in local areas
- **Long distance interconnection** deployed where optimal can reduce local transmission needs

In theory, two potential extremes for evolution of the power system exist



Max build

Max Flex

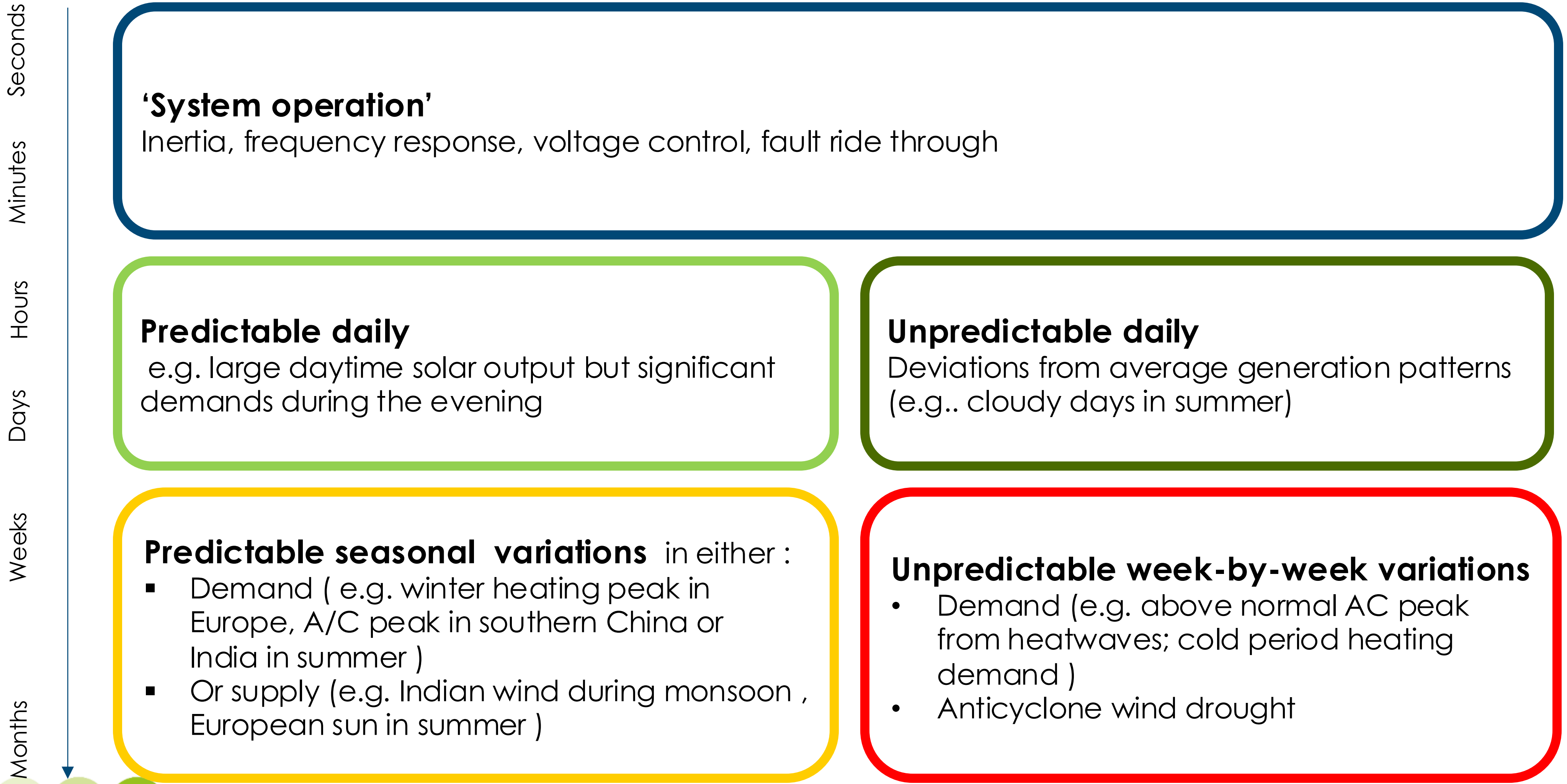
- **Build everything as fast as possible**
- **Oversize connections** to account for future demand
- **No planned reforms to pricing structures**

- **Seek to maximise flexibility first and delay some build**
- **Gather data first**, and **build tactically (i.e. less)**
- **Utilise dynamic network tariffs** e.g. granular pricing, to better shift demand
- **Zero bills homes and schools** (incl. self-consumption) to support balancing local networks

Final outcome will be somewhere in the middle. Need to both build and increase flex, where flexibility is all about making **demand able to match supply more dynamically.**

With variable renewables the system must be balanced across all time periods, this adds complexity

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



'System operation'
Inertia, frequency response, voltage control, fault ride through

Challenge that existed in fossil system, but now needs to be met with new technologies

Predictable daily
e.g. large daytime solar output but significant demands during the evening

Unpredictable daily
Deviations from average generation patterns (e.g.. cloudy days in summer)

Predictable seasonal variations in either :
- Demand (e.g. winter heating peak in Europe, A/C peak in southern China or India in summer)
- Or supply (e.g. Indian wind during monsoon , European sun in summer)

Unpredictable week-by-week variations
- Demand (e.g. above normal AC peak from heatwaves; cold period heating demand)
- Anticyclone wind drought

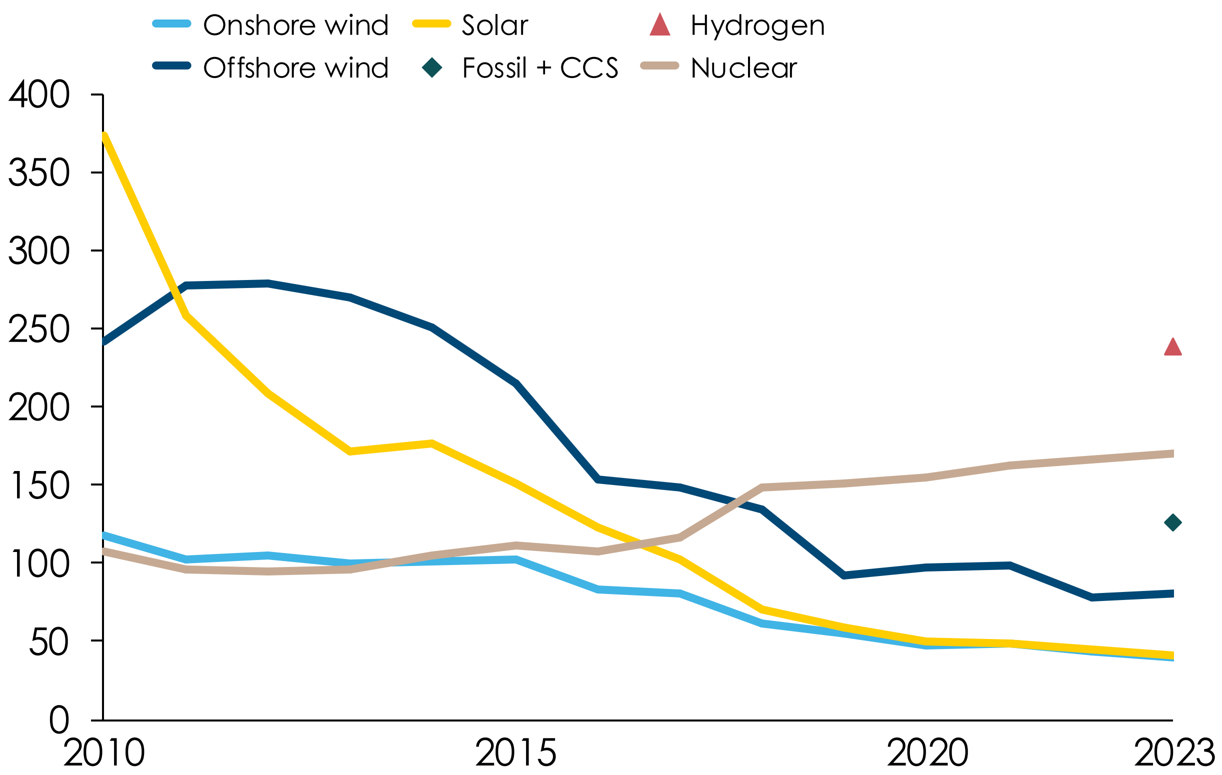
New challenges that must be met for high-renewables power systems due to intermittent nature of generation

Technological revolution is enabling the transformation of the power system

Wind, solar and batteries are continuing to get cheaper against fossil

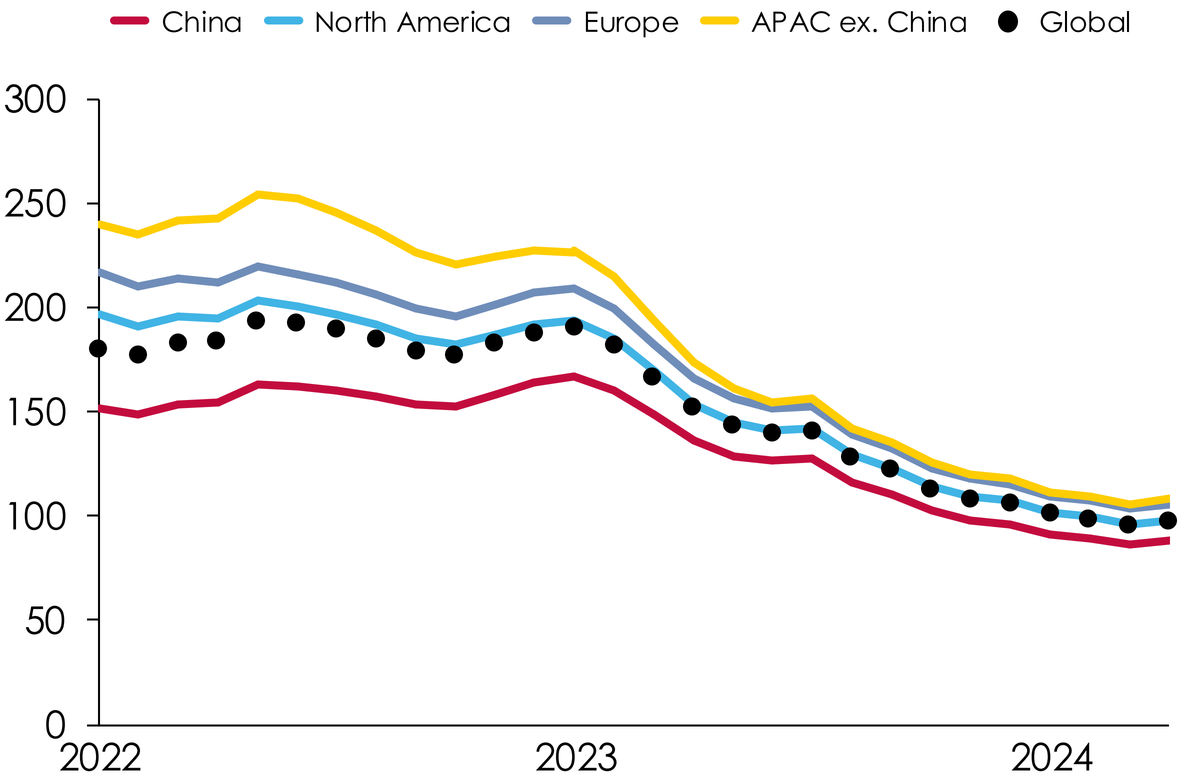
Global LCOE benchmarks for renewables remain competitive

$/MWh (real 2022)



Estimated average monthly lithium-ion battery pack prices

$/kWh (nominal 2024)



Notes: The global benchmarks are capacity-weighted averages using the latest country estimates – apart from nuclear, hydrogen and CCS, which are simple averages. Offshore wind includes offshore transmission costs. Fossil + CCS is the average of Coal- and gas-fired power include carbon pricing where policies are already active. LCOEs do not include subsidies or tax-credits. Solar refers to fixed-axis PV. Nuclear data from Lazard. Source: BNEF (2023) *2H 2023 LCOE Update*; BNEF (2024) *China Lithium-Ion Battery Supply Chain Update 2024;* Lazard (2021), *LCOE, Levelized Cost of Energy Comparison—Historical Utility-Scale Generation Comparison*

Technology exists both to better optimise and balance the system, with promising progress made in recent years

Better optimising grids

Managing system balancing

Innovative grid technologies

Flexible dispatchable generation

Long distance interconnection

Effective energy storage

Heat storage

Demand side management

Innovative Grid Technologies can help circulate power more efficiently

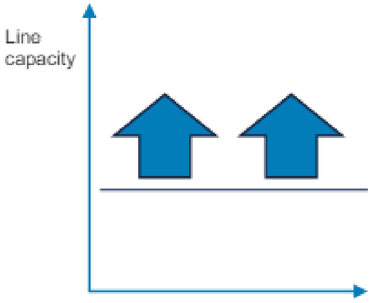
Innovative grid technologies

Existing rights of way
Changes to pylons and wires

Existing wires and networks
No changes to pylons and wires

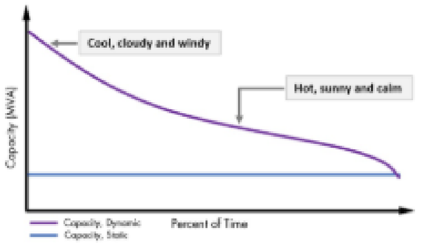
Main methods to increase grid capacity:

Capacity increase for a given line



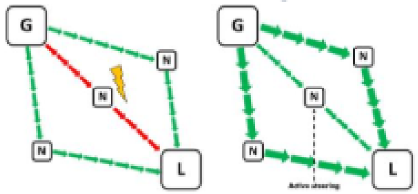
- Direct capacity improvement compared to conventional technologies

Better understanding of actual line limits



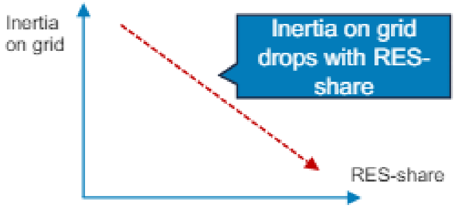
- A static limit must be very conservative, to not overload lines in adverse (hot) conditions;
- Dynamic ratings exploit natural line cooling

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**

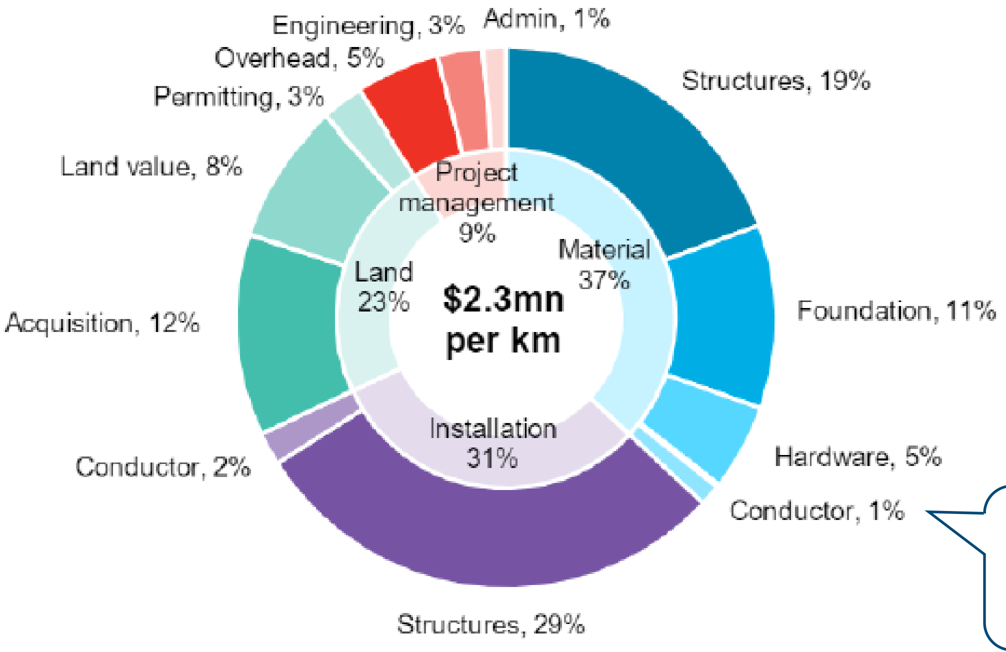
Notes: The term “Grid Enhancing technologies” can also be used to describe technologies that “maximise the transmission of electricity across the existing system through a family of technologies that include sensors, power flow control devices, and analytical tools”. This theoretical framework does not provide an exhaustive classification of IGTs, and of their effects. Other technologies and effects could potentially be considered. Substations and switching stations must be upgraded in tandem with grid capacity upgrades to manage the additional power in the system, key solutions here include gas-insulated switchgear and superconducting transformers. Source: *CURRENT (2024), Prospects for innovative power grid technologies*.

The relative low cost of conductors compared to other transmission components leaves room for novel solutions

Innovative grid technologies

Cost of new above-ground 400kV power line, US

Breakdown of key components per km



Advanced conductors could be a beneficial technology to increase the amount of power down existing rights of way

Next generation 'high temperature, low sag' conductors offer key advantages, including:

- **Higher capacity** (up to 3x during peak use)
- **Improved efficiency** (50% reduced line losses)
- **Stronger** (durable, lower sag, corrosion resistant)

Conductors make up **~3-10%** of the cost of a new above-ground high voltage power line. Advanced conductors are **2-3*** more expensive than conventional.

Could be beneficial, but coordination/regulation is required.

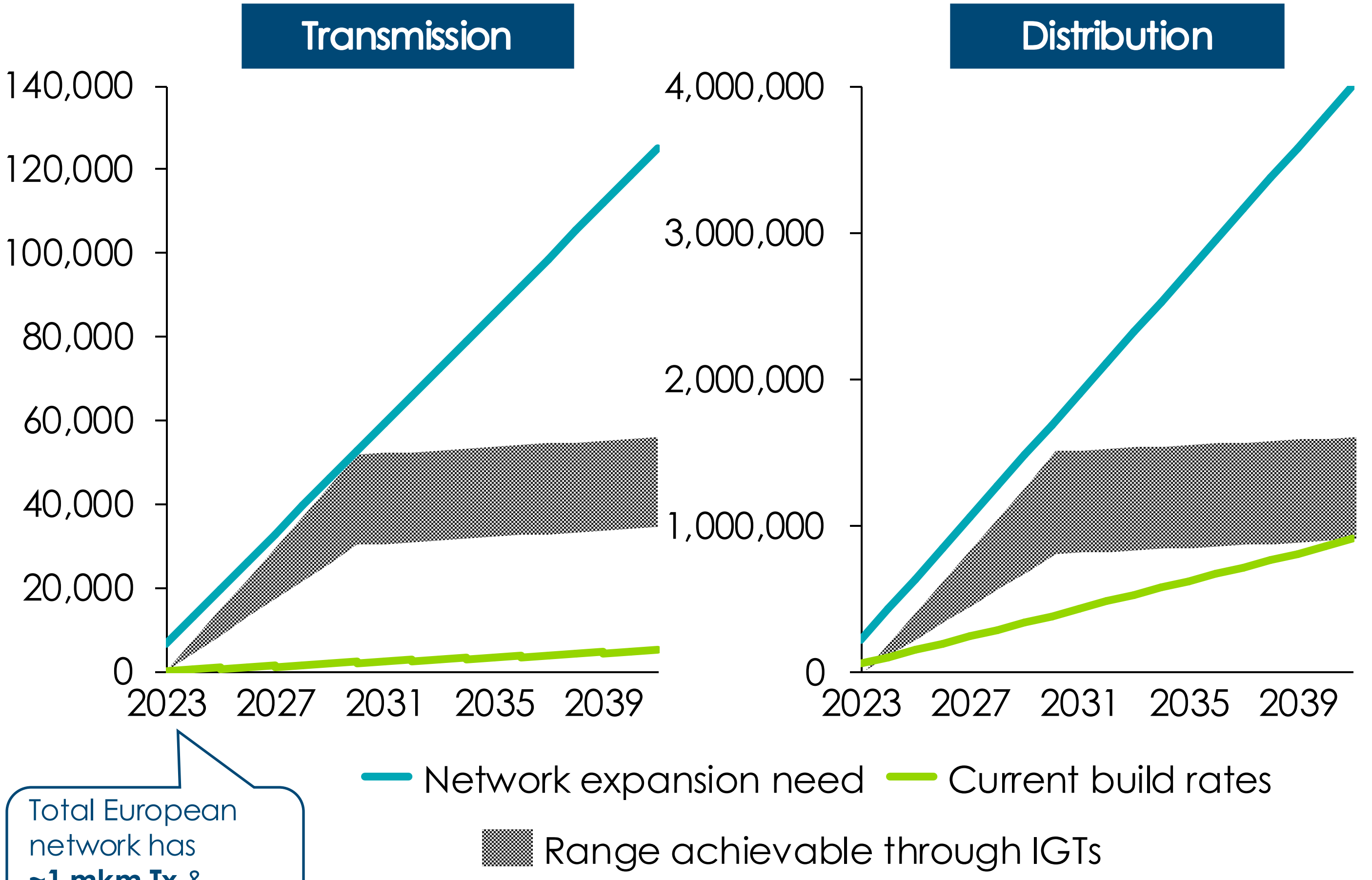
Each type of advanced conductor requires different tools and skills to install, and not all lines are suitable for upgrade.

Source: VW Cables (2024) *ACCC Conductor Aluminum Conductor Carbon Fiber Composite Core Reinforced*; 3M (2024) *3M™ Aluminium Conductor Composite Reinforced (ACCR)*; TS Conductors (2024) *Our Technology*; BNEF (2021) *Power Grid Long-Term Outlook 2021*

Innovative Grid Technologies could meet substantial portion of network expansion needs

Benefits of IGTs compared to expansion needs and past trends

Line length equivalent, FR, DE, ES, IT, DK, NL and GB



Total European network has **~1 mkm Tx** & **~7 mkm Dx**

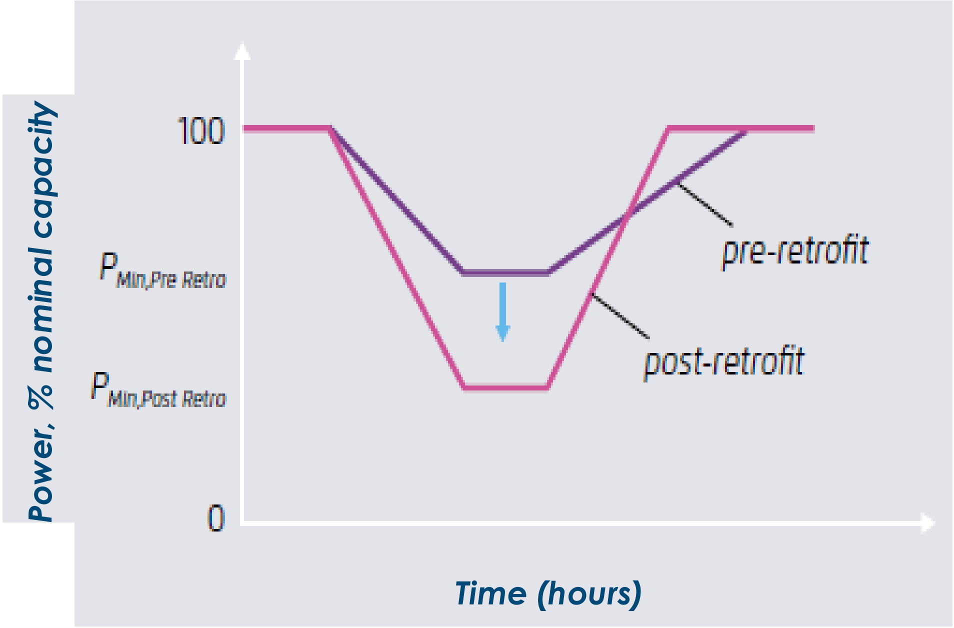
- A 2024 CURRENT study concluded **potential for current capacity to increase 20%-40%** from Innovative Grid Technologies on the wider network.
- Conservatively assuming that this could lead to 10-20% expansion of capacity via the current network, **over 40% of network expansion needs could be met by IGTs**.
- Key enablers need to be enacted to help rollout:
  - **Regulatory incentives for non-capex-intensive solutions** (current capex bias via regulated returns)
  - **New approach to T/DSO investment doctrine**, taking a technology neutral approach
  - **Better access to funding** for IGT deployment

Notes: Charts take conservative assumption of 10-20% capacity increase out of potential 20-40%. TSO = Transmission System Operator, DSO = Distribution System Operator. European countries included in study include France, Germany, Spain, Italy, Denmark, Netherlands, Great Britain. Source: *CURRENT (2024), Prospects for innovative power grid technologies*; BNEF (2023) *New Energy Outlook Grids*.

In some cases retrofit of existing coal plants is useful to increase renewables penetration, this is increasingly possible but comes with moral hazard

Flexible dispatchable generation

Load curves for pre- and post-retrofit of German Neurath Block E coal plant
% of nominal capacity



Coal retrofits key focus as gas is inherently more flexible. GB has transitioned from **500->150 gCO_2/kWh** from 2012->2023 using gas for flex.

Coal retrofits can:

- **Extend life**
- **Increase efficiency**
- **Reduce minimum load**
- **Increase ramp rate**
- **Shorten start-up time**

Retrofitting plants comes with moral hazard from extending plant life, this varies by age of plant:

- **Young plants – less moral hazard** (likely beneficial)
- **Old plants – high moral hazard** (consider other options first)
- **New plants – max moral hazard** (choose different balancing tech)

Germany have demonstrated it is possible to retrofit a large portion of coal plants to effectively provide flexibility

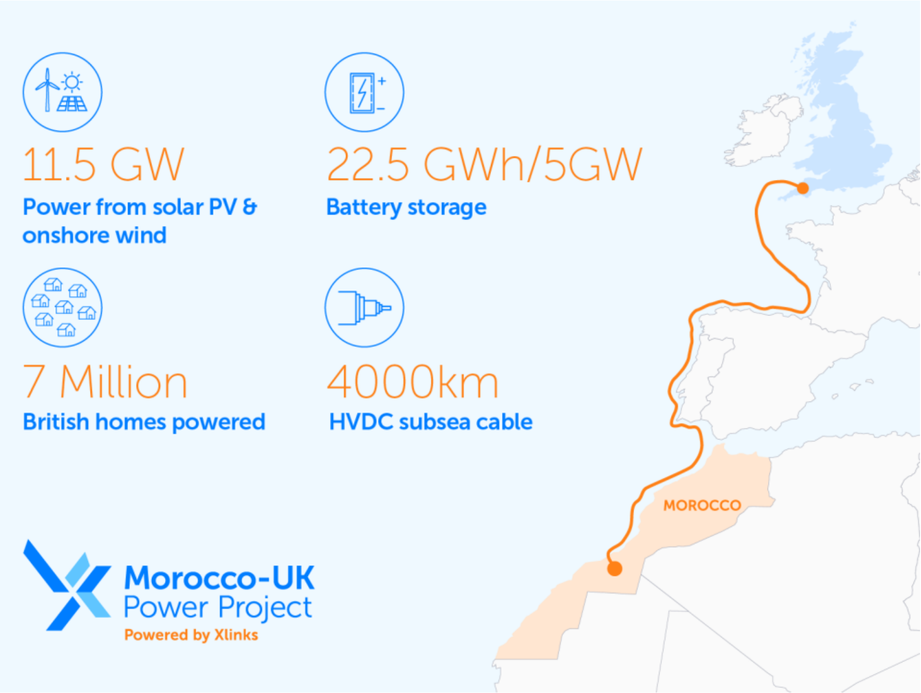
Retrofitting plants in coal dominated systems could be useful – however building new coal plants to balance should be avoided

Source: IESR (2022), *Flexibility Thermal Power Plant*

Interconnection will be possible at greater and greater distances – however some projects have been delayed due to international permitting issues

Long distance interconnection

X-Links 4,000 km cable from Morocco to the UK



Suncable 4,300 km cable from Australia to Singapore

ETC are conducting analysis to establish the global potential for interconnection, and will highlight the most effective potential new interconnectors according to cost, energy security, and emissions reductions

New energy storage technology options are emerging to enable balancing across different time periods

Effective energy storage

Lithium-ion battery (Li-ion)

Key players:

TESLA
LG Chem
SAMSUNG SAMSUNG SDI
northvolt
BYD
CATL
Panasonic

Iron-air battery (Fe-air)

Key players:

Form energy

Hydrogen in Combined Cycle Gas Turbines (CCGT)

Key players:

GE
SIEMENS energy
MITSUBISHI ELECTRIC
ANSALDO ENERGIA

Sodium-ion battery (Na-ion)

Key players:

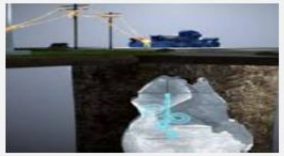
中科海钠 HiNa BATTERY
Natron Energy Energy Storage Innovations
CATL
faradion
TIAMAT

Compressed Air Energy Storage

Key players:

CEEC 中国能建
ENERGIEPARK BAD LAUCHSTÄDT
SIEMENS energy
HYDROSTOR
GC GENERAL COMPRESSION Compressed Air & Gas Specialists

In caverns



In high-pressure tanks

Heat storage in bricks

Key players:

RONDO

Preliminary

A range of tech can address entire balancing challenge

Very long-Duration

Seasonal balancing

Narrower range of technologies

Complex, with costs varying widely according to local conditions

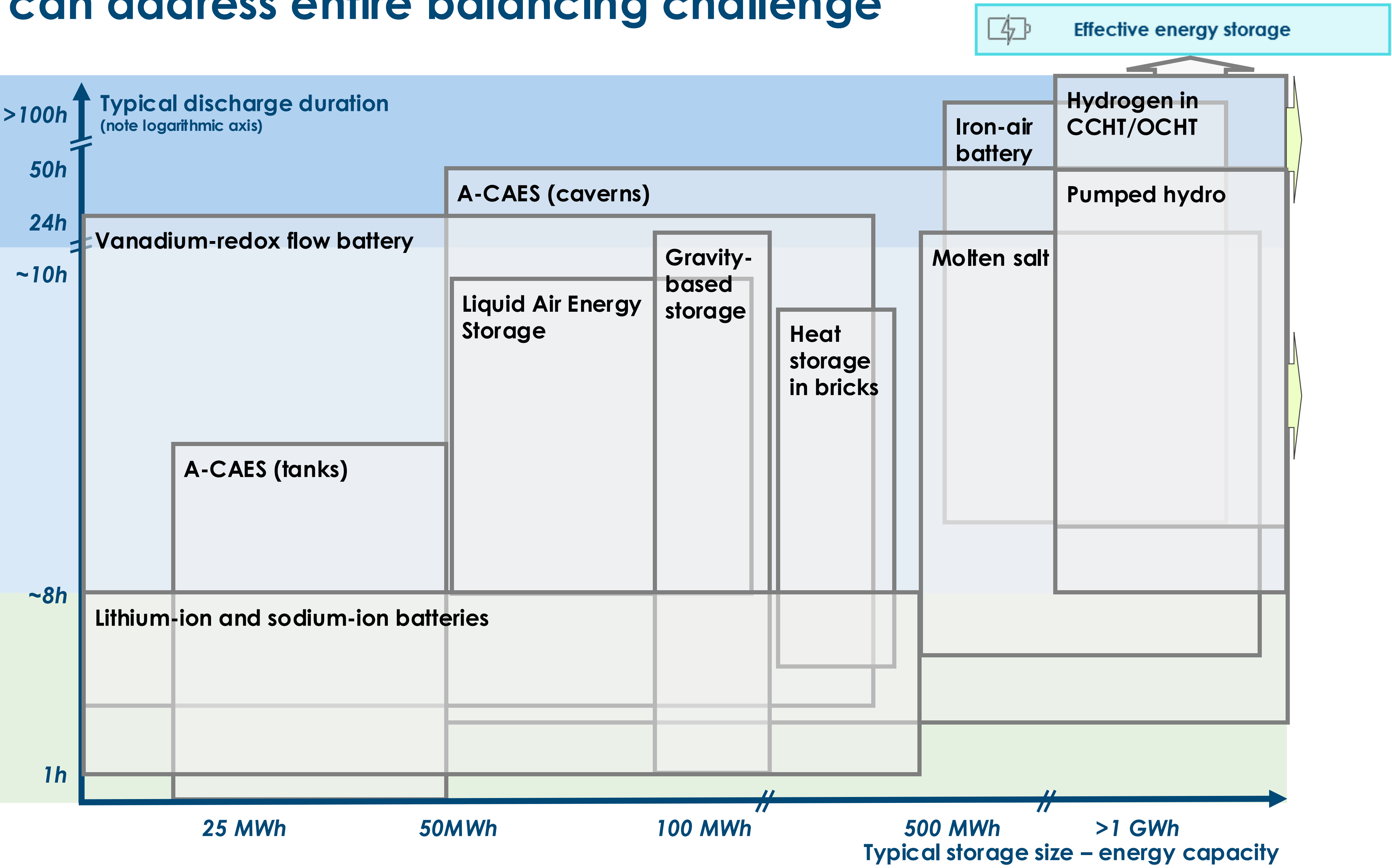
Long-Duration

Daily balancing

Wide range of technologies

Strong cost decrease (e.g. lithium-ion batteries) making zero- or low-carbon storage solutions competitive with fossil fuel peak generation

Short-Duration



Source: Data from BNEF (2024), *2024 long-duration energy storage cost survey*; Pacific Northwest National Laboratory (2023), *Energy Storage Cost and Performance Database*; IEA (2024), *ETP Clean Energy Technology Guide*; others from sources on deep dive slides;.
Note: Simplified visual description for improved readability.

Preliminary

ETC assessment points to key techs at given durations/sizes

Effective energy storage

Very long-Duration

Seasonal balancing

Narrower range of technologies

Complex, with costs varying widely according to local conditions

Long-Duration

Daily balancing

Wide range of technologies

Strong cost decrease (e.g. lithium-ion batteries) making zero- or low-carbon storage solutions competitive with fossil fuel peak generation

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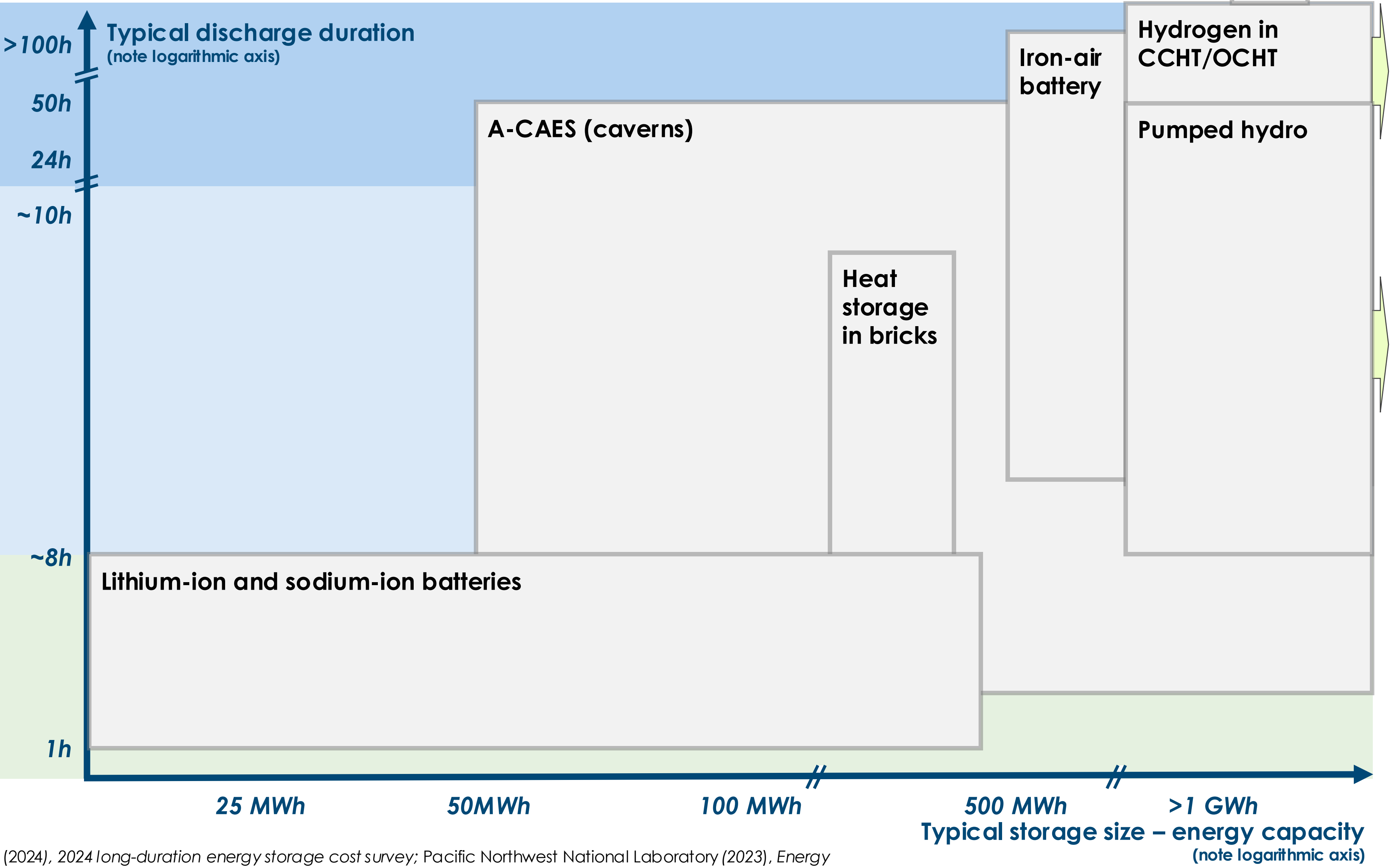

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Note: Simplified visual description for improved readability.

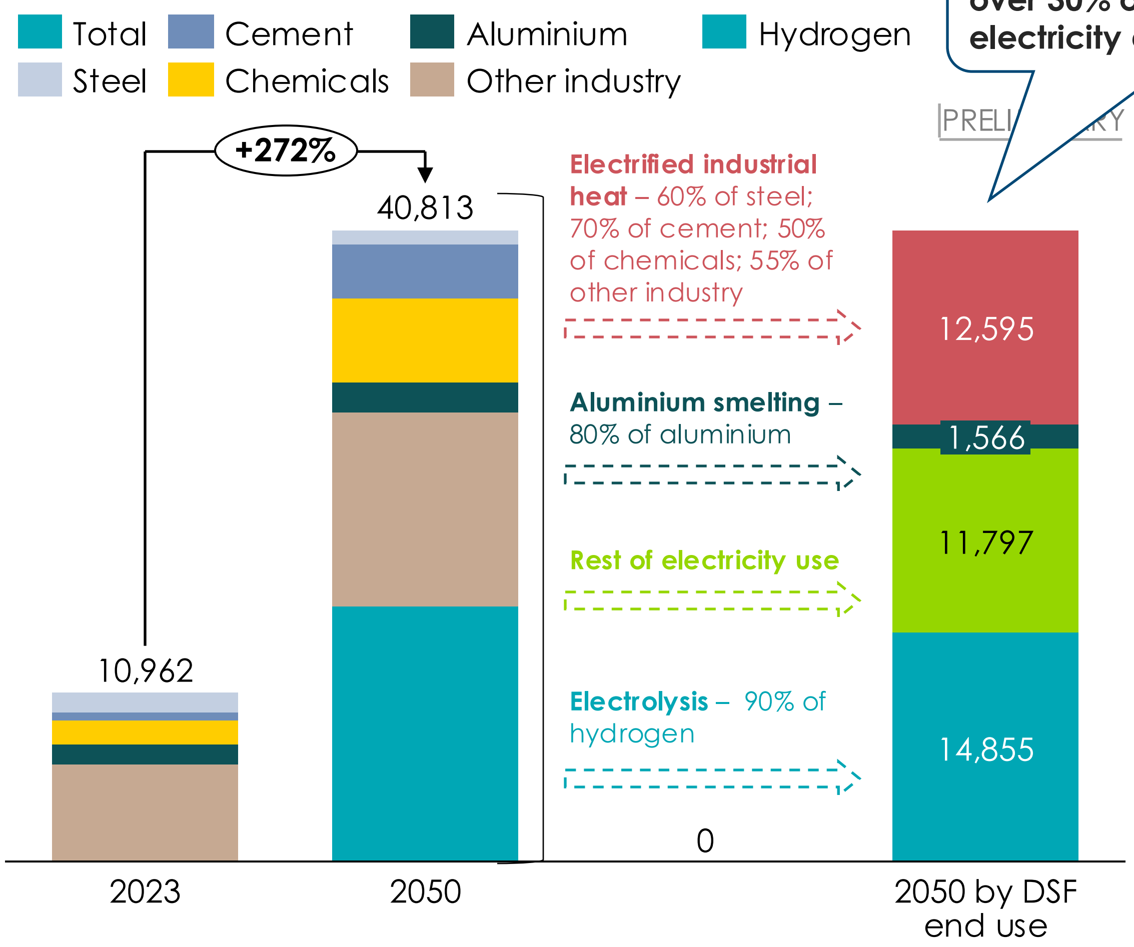
Heat storage is a very promising new avenue to balance industrial heat demand and optimise power flows

Heat storage

Global industry electricity demand by sector, 2050

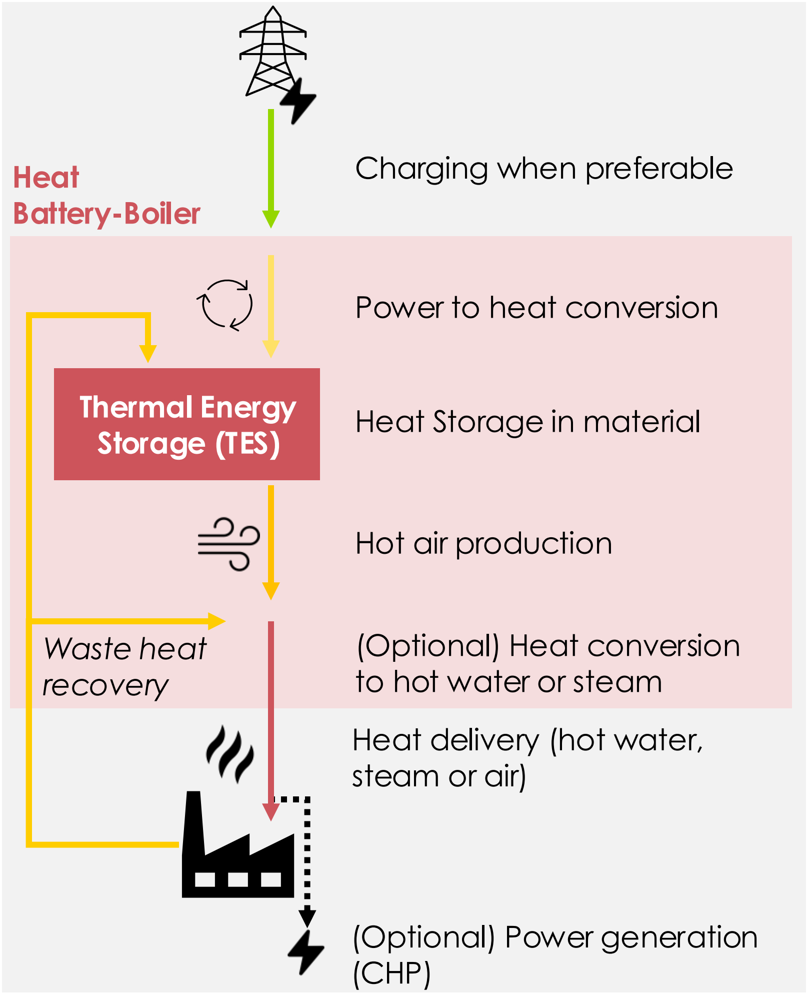
TWh

Electrified heat will make up over 30% of industrial electricity demand in 2050



New avenues are emerging which enable storage at all temperatures

A heat battery-boiler combines existing tech



Notes: [1] Combined Heat & Power; high pressure steam can drive a steam turbine to produce electric power and low-pressure steam, providing 95% efficient combined heat and power.
Source: Systemiq analysis for the ETC; NGFS (2024), Phase 4 Scenario Explorer – Latest 2024 GCAM Version

The Rondo heat battery can leverage 6-8 hours of cheap electricity and turn it into baseload steam or hot air

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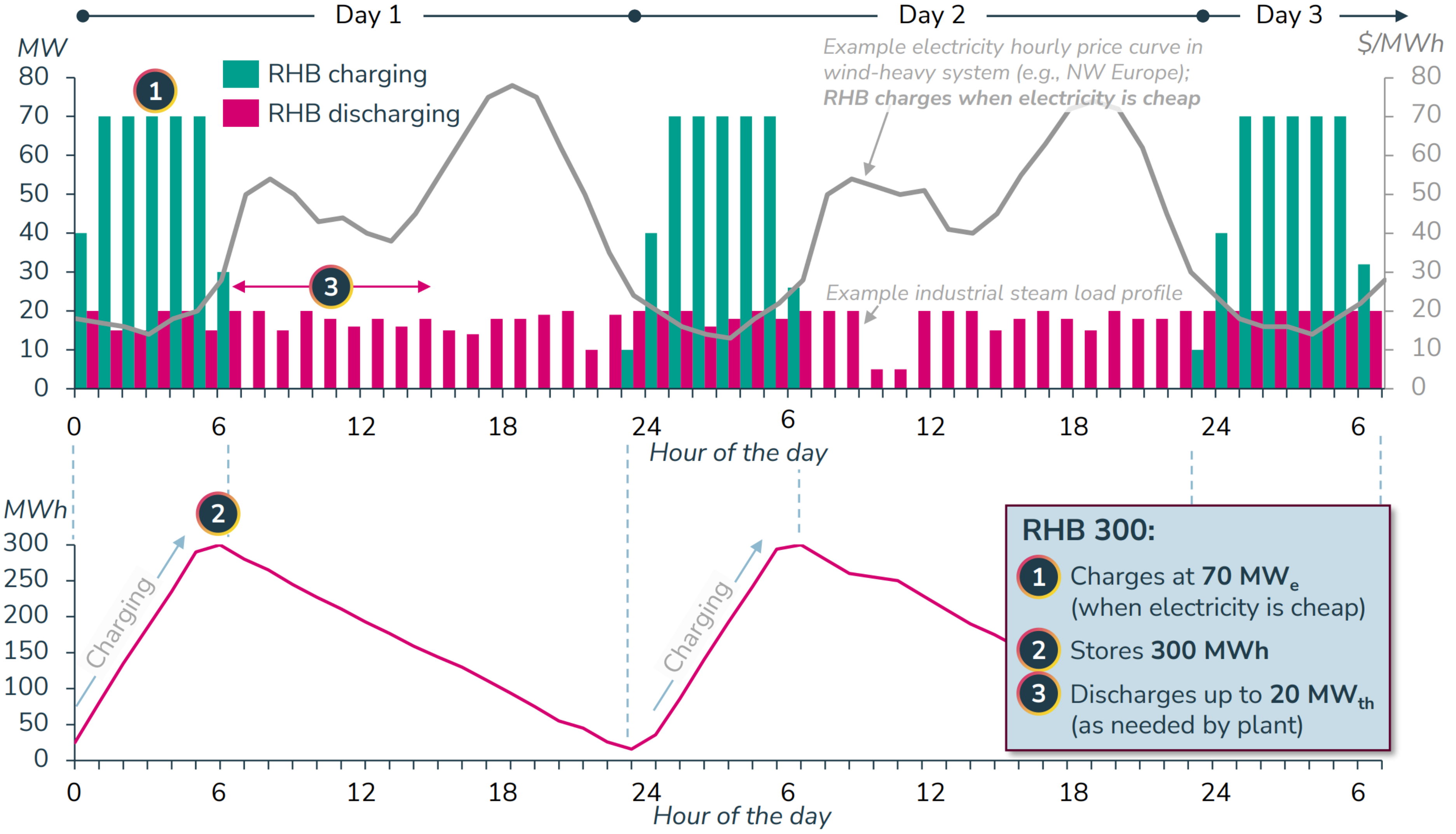
Heat storage

Rondo Heat Battery (RHB)
CHARGE & DISCHARGE

Example pattern for RHB300[1]

Rondo Heat Battery (RHB)
STORAGE

Energy stored in RHB



RHB 300:

① Charges at **70 MW_e** (when electricity is cheap)

② Stores **300 MWh**

③ Discharges up to **20 MW_{th}** (as needed by plant)

Source: Rondo (2024)

The Rondo heat battery could enable to companies to save money vs gas, depending on access to liberalised markets

RONDO

Heat storage

ILLUSTRATIVE
Relative scale of each element is highly country and site dependent

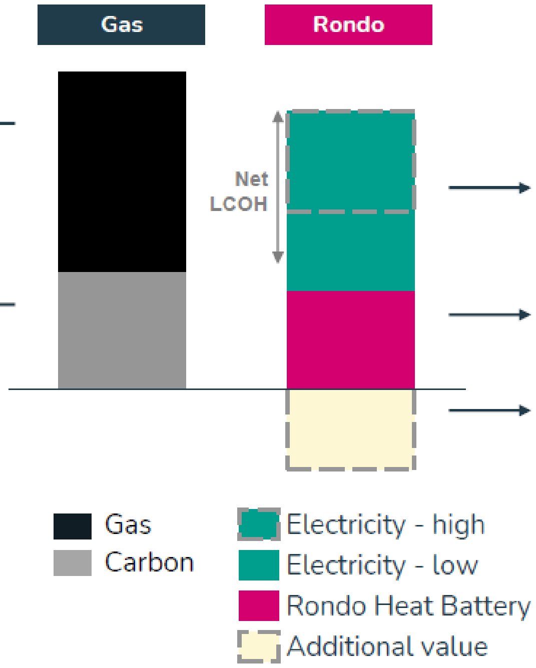
Gas cost

- [c.$40/MWh LNG price in 2024] ÷ [85%, gas boiler efficiency] = $47/MWh
- Risk of spikes in gas prices

Carbon cost

- 60-100 $/tCO$_2$ → $15-25/MWh
- Prices expect to rise in many geos, e.g., EU free allowances reducing from 2026

Levelized Cost of Heat (LCOH)
$/MWh



Electricity cost

- Low-cost hours (<$30/MWh) in the wholesale electricity market are become more frequent:
  a. Wind-regions (Germany, NL) overnight
  b. Sun-regions (Spain, Portugal) day-time
- Behind-the-Meter (on-site, near-site) is a good solution in many regions, e.g., Spain, California

Rondo Heat Battery (RHB)

- Far lower cost than Li-Ion

Additional value sources

- CHP: When the battery delivers baseload steam and power, this delivers savings for the customer on cost of serving existing site electricity needs
- Grid services: Markets by the system operator to balance frequency, e.g., DR programs, aFRR. Can be very material revenue though scale of value can change significantly year-to-year.

Liberalised markets make **access to cheap wholesale prices** more readily available.

Outside such markets, **off-peak tariffs** or **PPAs with generators who “see” the wholesale price** can suffice.

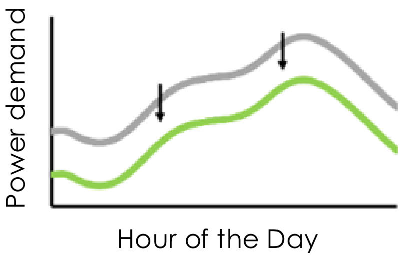
Locational pricing can open up particular opportunities of **extremely low pricing near congestion points**

Source: Rondo (2024)

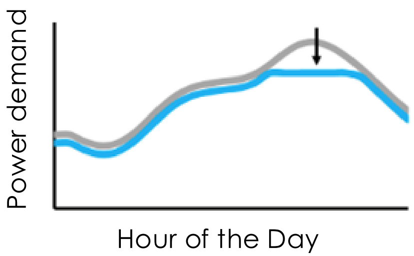
There are five key demand side management (DSM) strategies to provide flexibility, which can be implemented either manually or automatically

Demand side management

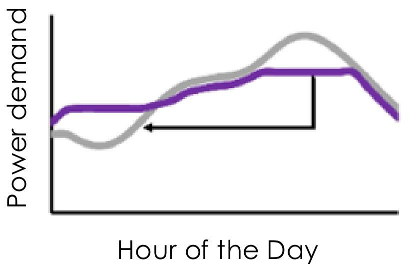
Efficiency



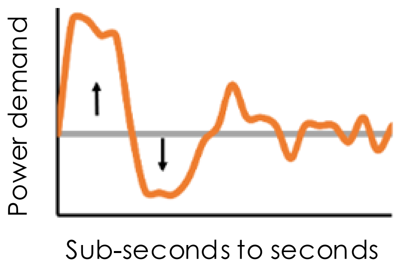
Modulate



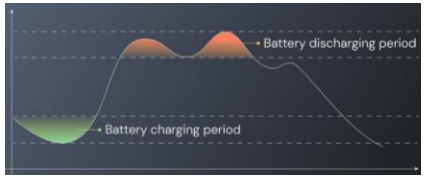
Load shed



Load shift



Distributed storage



	Efficiency	Modulate	Load shed	Load shift	Distributed storage
Details	• The ongoing **reduction in energy use** while providing the same or improved level of building function	• The ability to **reduce electricity use** for a short time period and typically on short notice • Shedding is typically **dispatched during peak demand** periods and during emergencies	• The ability to **change the timing** of electricity use (intra-day, inter-day and seasonal) • In some situations, a shift may lead **to changing the amount of electricity** that is consumed	• The ability to **balance power supply/demand** or **reactive power draw/supply autonomously** (within seconds to sub-seconds) in response to a signal from the grid operator during the dispatch period	• Provide flexibility by **storing excess energy** (e.g., electricity, heat) during low-demand periods and releasing it during peak demand, helping to balance the grid
Example	• **Manual**: Replacing old appliances new models • **Automatic**: Building management systems optimising energy use	• **Manual**: Turning off lights during peak times • **Automatic**: Smart plugs cutting power to non-essential devices	• **Manual**: Running washers at late night instead of during peak times • **Automatic**: schedule EV to charge in off-peak	• **Manual**: Adjusting thermostat to reduce heating during peak • **Automatic**: Fridges adjusting compressor cycles to off-peak	• **Manual:** Configuring home batteries/EVs to charge and discharge • **Automatic:** Software controlled storage responds to price signals

Changes to consumer behaviour and at grid level

Change at grid level but not to consumer behaviour

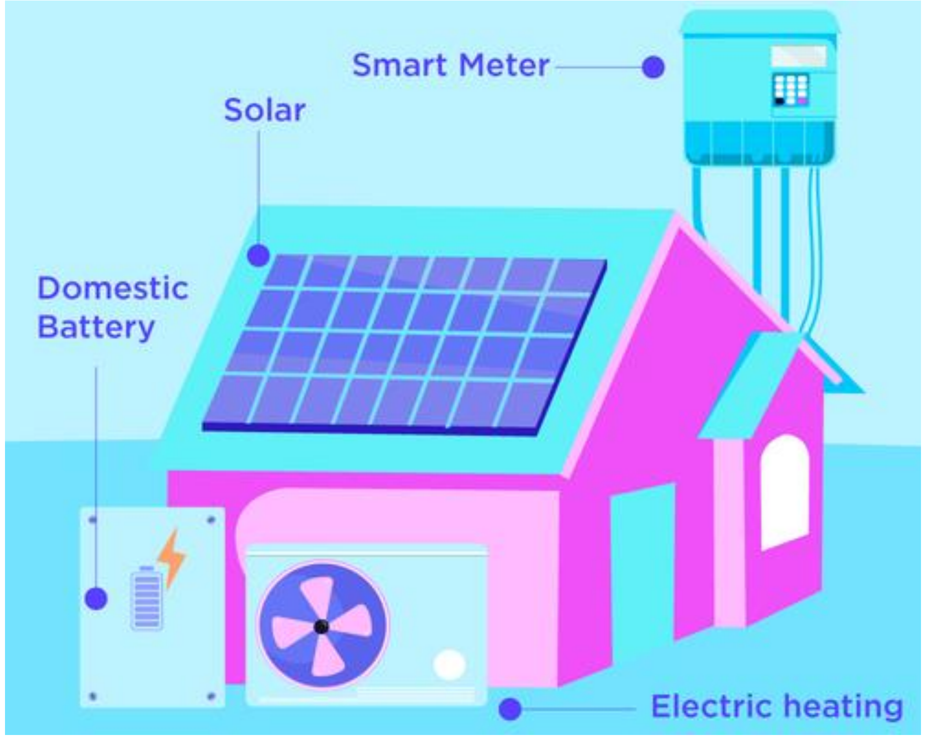
Source: US Department of Energy (2019), Grid-interactive Efficient Buildings Technical Report Series

DSM can be coupled with distributed solar and storage to reduce drain on grid and optimise local networks – requires effective pricing structures

Demand side management

- Effectively designed distributed solar and storage could have dual benefits of:
  - **Reducing overall grid demand**
  - **Optimising power flows** by soaking up excess power at times of abundance and distributing at times of scarcity
- Octopus have recently developed the concept of a **'zero-bills home'** via effective insulation, solar, storage and heat pumps. They plan to deliver 50,000 by 2025.
- Having one zero-bills home per street or one zero-bills school per neighbourhood **can help slow demand for local network reinforcement** and make the pace of build more manageable.

Octopus 'Zero-bills home'



'Zero-bills homes' can help better manage local grid demand, but may require dynamic network tariffs to effectively charge and discharge when required

Source: Octopus (2024) *Let's make Zero Bills homes the new standard*

Key questions on managing the system balancing challenge

ETC is currently exploring three key questions

1. **Size of balancing requirements by duration**
    - Different countries/regions will have different balancing needs, e.g. depending on daily fluctuations and seasonal variations driven by supply and demand (e.g. Northern latitude countries have higher demand in winter, lower latitude countries primarily have a daily balancing challenge due to high solar penetration).
    - To understand the need for balancing, looking at weather patterns to understand 'low' renewable supply years is critical. The ETC is using a modelling approach looking at the past ~40 years of weather data in key country archetypes, as a basis to size balancing needs.

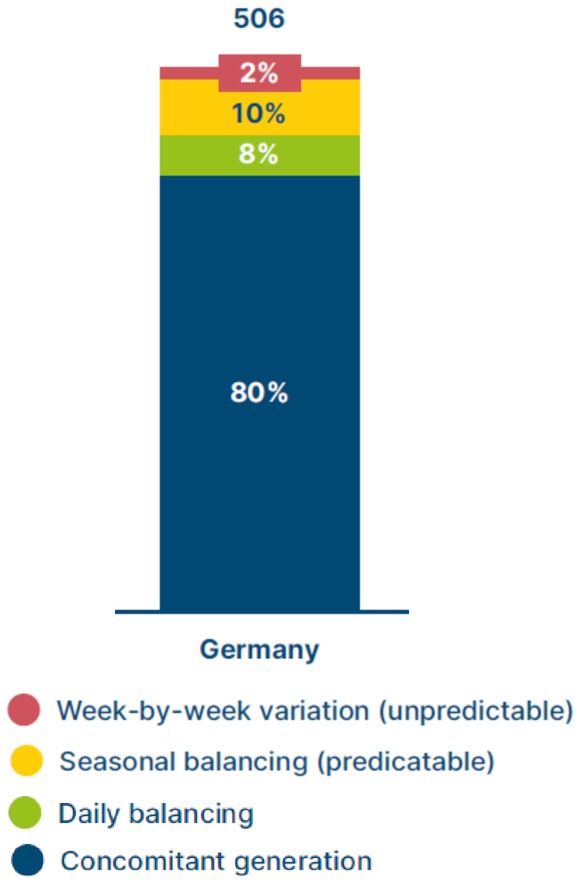
2. **Total system cost by region**
    - ETC work will look at evolution of total system generation costs, which depend on balancing needs and technologies to solve for these; additionally, critical to understand the evolution of grid costs.

3. **Potential for interconnection**
    - Longer distance interconnectors are increasingly being demonstrated (with X-Links set to be 4,000 km), whilst some countries are limited in space to host renewables domestically. ETC is undertaking a deepdive to understand where the most impactful interconnectors should be located, and how much these can help with local balancing challenges.

1) Size of balancing requirements by duration

Existing ETC work – 2017 analysis

Balancing variability across markets in a near 100% VRE system



New analysis for 2024

Updated ETC analysis will assess 2050 energy balance requirements based on renewable generation from offshore wind, onshore wind, and solar PV. It will match a view of:

- **Supply,** via realistic 2050 wind and solar generation profiles, which will be derived using weather data from the past 40 years to create minimum, average and maximum scenarios over 2 hourly generation periods.
- **Demand,** via 2050 hourly demand forecasts obtained from expert models (i.e. Imperial College for UK), accounting for new loads (e.g. EVs, heat pumps) and load patterns.

In order to determine country-specific balancing requirements across time periods. The model will illustrate the size and duration of balancing requirements across daily, weekly, and seasonal needs.

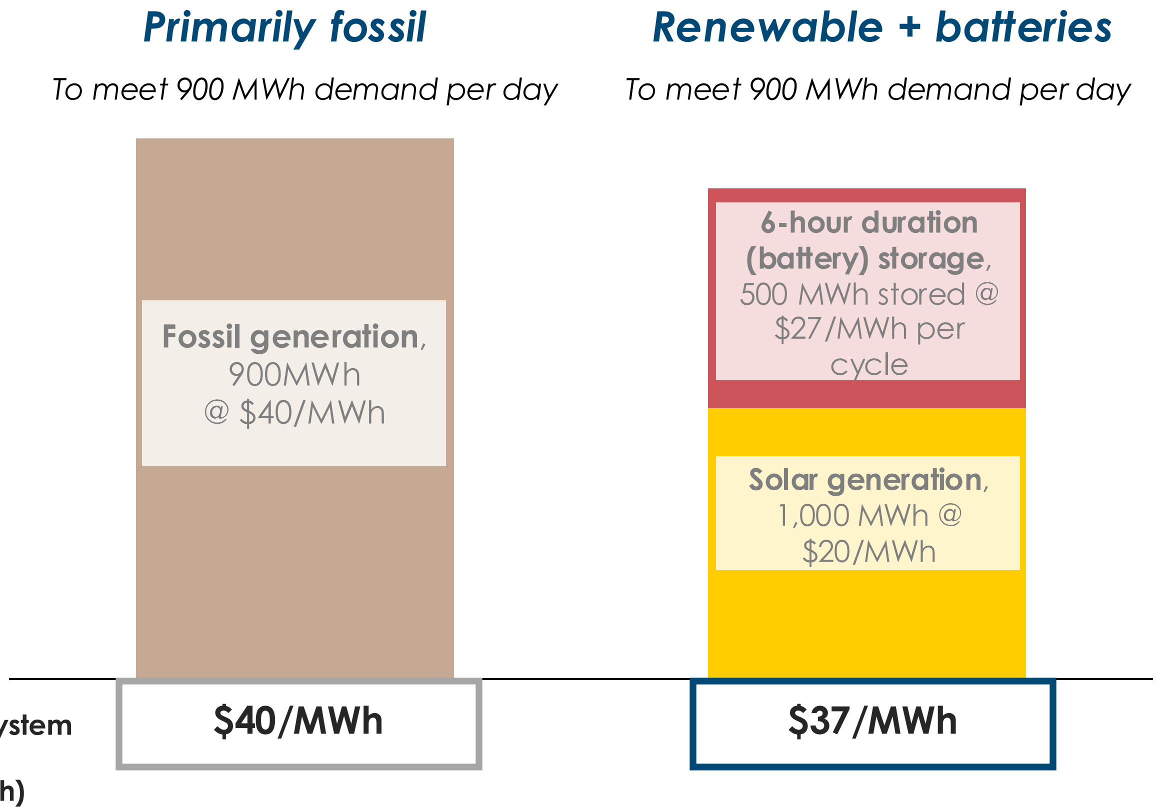
This will be done for key country archetypes.

Notes: 2% week-by-week variation is approximate, and range will vary by market. Generation scaled up to meet 100% demand based on current VRE ratio: Wind (64%), solar (34%) and run of river hydro (2%). Potential countries in scope are: UK, India, Indonesia, USA, Germany, China, Chile, Colombia, Australia, Kenya.
Source: Adapted from Climate Policy Initiative for the Energy Transitions Commission (2017)

2) Impact on total generation costs likely to be cheaper than current system in regions with a primarily daily balancing challenge

Illustrative generation profile and LCOE

Total generation stack with balancing needs, $/MWh



Primarily fossil

To meet 900 MWh demand per day

Fossil generation, 900MWh @ $40/MWh

Renewable + batteries

To meet 900 MWh demand per day

6-hour duration (battery) storage, 500 MWh stored @ $27/MWh per cycle

Solar generation, 1,000 MWh @ $20/MWh

Total system cost ($/MWh)

$40/MWh

$37/MWh

400 MWh of generation needs to be time shifted nightly (45%)

500 MWh of generation coincides with daily demand (55%)

Geographies with primarily a daily balancing challenge likely to have lower total system costs, thanks to cheap solar & batteries

Notes: Supply and demand at 900 MWh per day, of which 500MWh is during sunshine hours, 400MWh at night. Supply can be met by either:

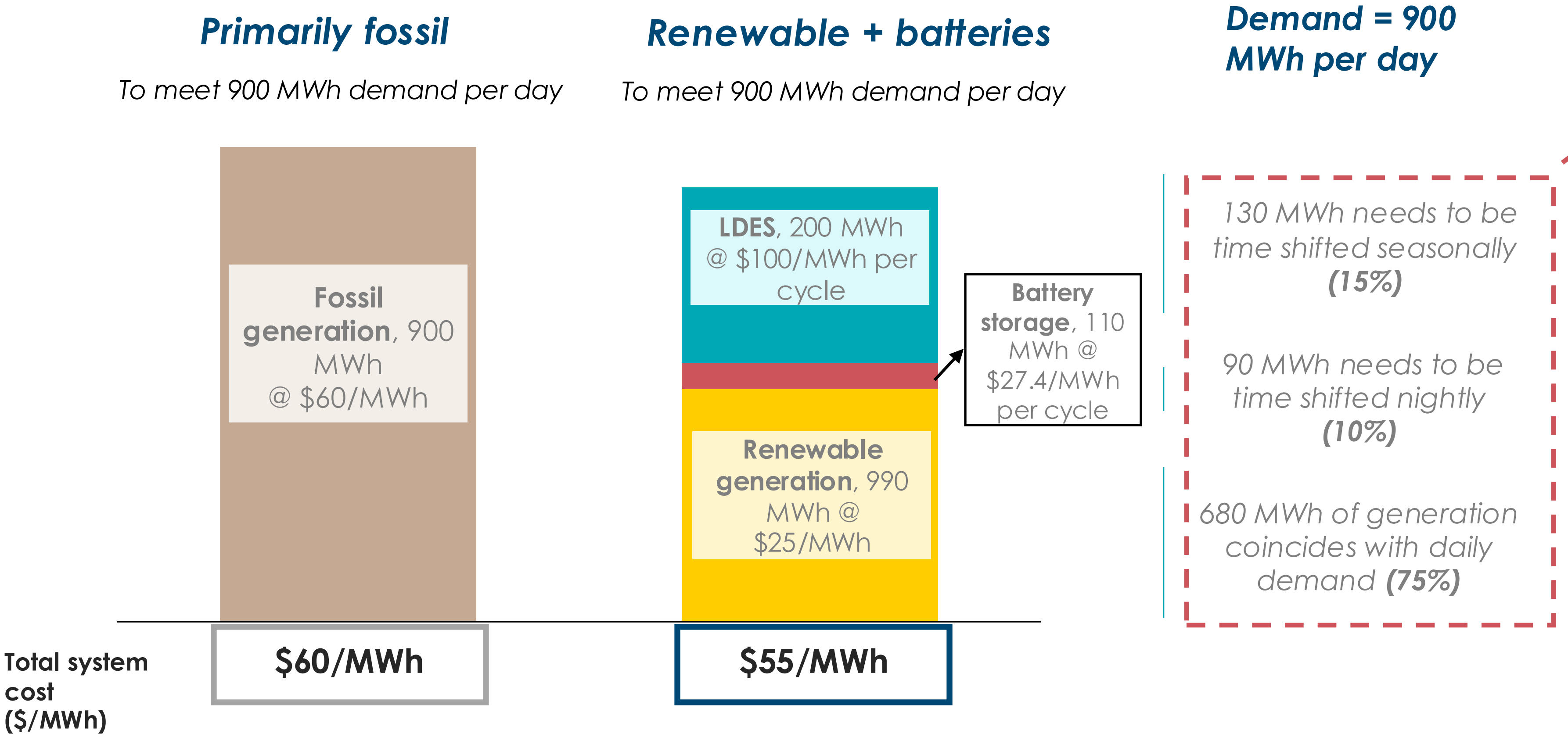
- Dispatchable gas producing 900 MWh per day;
- Solar producing 1,000 MWh per day, of which 500 MWh consumed, and 500 MWh stored in a battery, with 80% life cycle efficiency, discharging 400 MWh overnight

Cost of gas generation assumed to be $0.04 per kWh, Solar $0.02 per kWh. Battery capex $100 per kWh: $10 per kWh annualized; $2.74 per cycle at 365 cycles per annum.

2) Impact on total generation costs could be cheaper than current system in regions with a daily and seasonal balancing challenge

Illustrative generation profile and LCOE

Total generation stack with balancing needs, $/MWh



ETC analysis in (1) is working towards accurate breakdowns of balancing needs by country

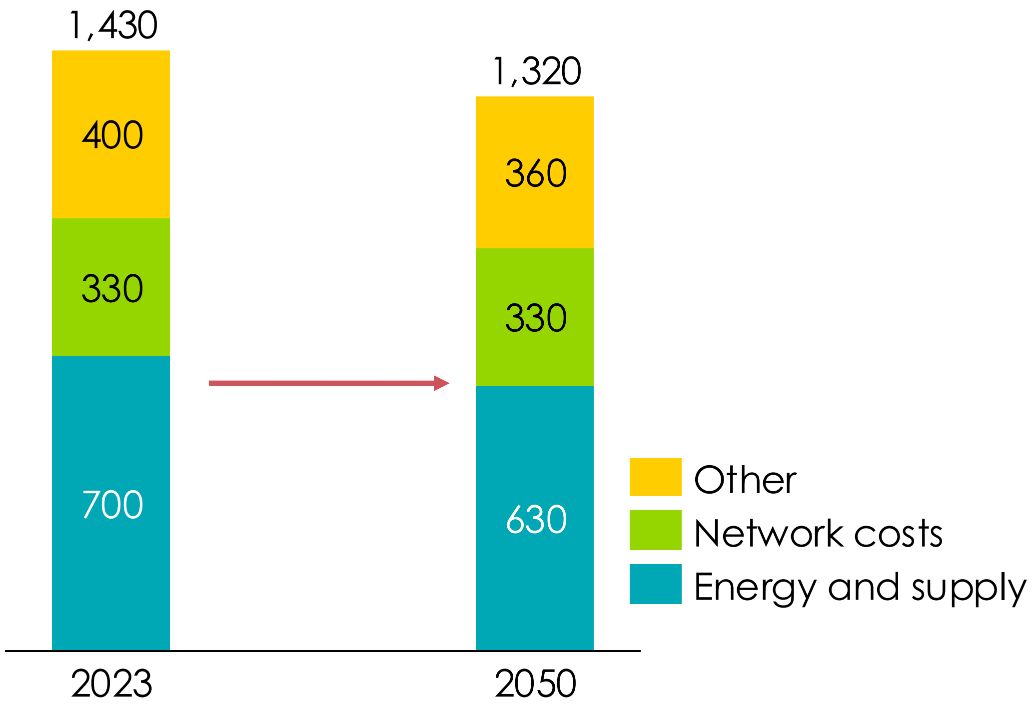
Geographies with a seasonal balancing challenge could have lower total system costs, but will be dependent on LDES costs

Notes: Supply and demand at 900 MWh per day, of which 680 MWh is during wind and solar generation hours, 220 MWh when renewables not generating. Supply can be met by either: Dispatchable gas producing 900 MWh per day; Wind and solar producing 1,060 MWh per day, of which 680 MWh consumed simultaneously, 110 MWh stored in a battery, with 80% life cycle efficiency, discharging 90 MWh overnight, and 200 MWh stored in LDES, with 65% life cycle efficiency, discharging 130 MWh daily equivalent. Cost of gas generation is $0.06 per kWh, Solar and wind at $0.25 per kWh. Battery capex $100 per kWh: $10 per kWh annualized; $2.74 per cycle at 365 cycles per annum. LDES capex @ $200: $10 per kWh annualized, $0.1/kWh per cycle at 100 cycles per annum.

2) ETC Hypothesis – overall consumer bills should remain broadly consistent with long term averages in 2050

Illustrative German household electricity bill

Annual bill, €



Based on evolution of:

Other costs – expected to decline once legacy payments for transition to expensive early renewables expire

Network costs – expected to remain broadly similar per unit of electricity, as increase in electrification increases the user base so rates/bills do not change, even as overall network costs rise due to growth of the system

Wholesale costs – expected to decline slightly with the shift away from fossil fuels towards renewables + balancing options

Notes: Values calculated from 2023 costs of ~41 ct/kWh, assuming 3,500 kWh annual consumption.
Source: Eurostat (2024), *Electricity prices components for household consumers*

Key enablers & implications of new system

Current processes won't make the most of innovation, enablers are required

Strategic vision & planning

- **Smart targets for deployment –** including renewables, energy storage, and size of gas turbine fleet
- **Accurate models and forecasting** – to help set targets and provide rationale for market design changes
- **Political will for the transition** – To enable both phasing down of fossil, and quicker interconnection agreements

Market design

- Need **to incentivise energy storage / capacity / kWh at specific hours** of need; market and contract mechanisms currently missing
- **Potential evolution of electricity price mechanisms** – to provide locational signals to help optimise power flows
- **Consumer pricing**: Need to incentivise demand-response; even with a growing renewable portfolio, **gas prices are still likely to set majority of market prices**

Deepdive on next slide

Grid regulation

- **Network reinforcements** – anticipatory investment required to build ahead of bottlenecks, particularly to reinforce Dx system
- **Reform of grid fees** - often paid by storage companies for both storing and discharging energy, making them pay twice for services which are beneficial to the grid

Consumer behaviour

- **Behavioural change** – In some instances may need to change to pursue flexibility, can be better enabled through effective pricing structures

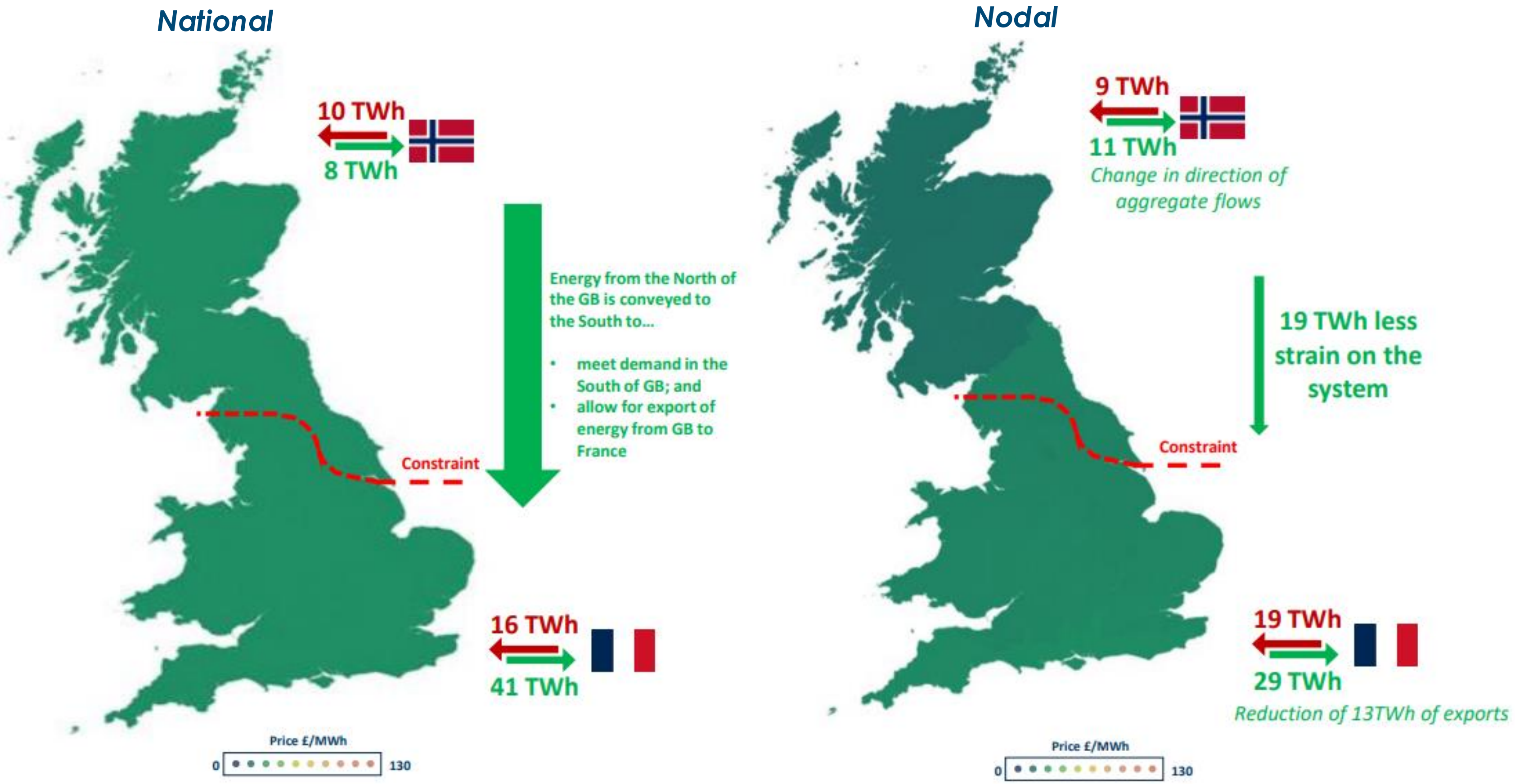
Several key market design areas required to incentivise full transition

Key debates	Issue	Potential solutions
Timing: Decided by system operator or by individual market players?	Need **to incentivise energy storage / capacity / kWh at specific hours** of need; market and contract mechanisms currently missing	• **Capacity markets** (i.e. payments to generators for being available) • **Quantitative targets for storage** across key durations (i.e. 5 GW of 100hr+ storage) • **Clean energy contracts across all/most time periods**, (i.e. India Round the Clock) • **Contracts for constant import of clean power** (i.e. X-Links Morocco-UK link) • **Energy markets short settlement blocks** (i.e. US MISO region 5-minute blocks)
Location: Single national wholesale price, an evolution of this, or narrower locational prices?	**Single wholesale price may give the wrong signal** to low carbon flexible assets and worsen network constraints	• **Zonal** divides electricity markets into regions, setting prices based on supply and demand (i.e. has Australia 5 zones, where generators & retailers use zonal price) • **Nodal** with further divides zones into nodes, allowing more granular price adjustments based on local supply and demand (i.e. Texas has 17,000 nodes) • **Evolutionary reforms** to single national wholesale market (i.e. giving ESOs more control; amending grid use charges; redesigning balancing system)
Consumer pricing: How to incentivise demand response and reflect low-cost renewables?	Need to incentivise demand-response; even with a growing renewable portfolio, **gas prices are still likely to set majority of market prices**	• **Time of use tariffs** which are cheaper when supply exceeds demand (i.e. Octopus' agile tariff in the UK, or at a local level via dynamic network charges) • **Reform consumer pricing to ensure pass through of low renewables costs** (i.e. growing proportion of bills linked directly to CfDs/PPAs, remainder resolved by wholesale market e.g. recent Draghi report for EU Commission)

Case study -> Locational pricing could be effective at better directing flows of cross border power to reduce strain on local networks

Locational pricing could reduce strain on the GB network

National pricing regime (unconstrained) vs nodal pricing, 2030 estimates



National

Nodal

Energy from the North of the GB is conveyed to the South to…

- meet demand in the South of GB; and
- allow for export of energy from GB to France

Change in direction of aggregate flows

19 TWh less strain on the system

Reduction of 13TWh of exports

Under national pricing in 30% of hours in 2030 UK power is **more expensive than Norway (importing)**, and **cheaper than France (exporting).**

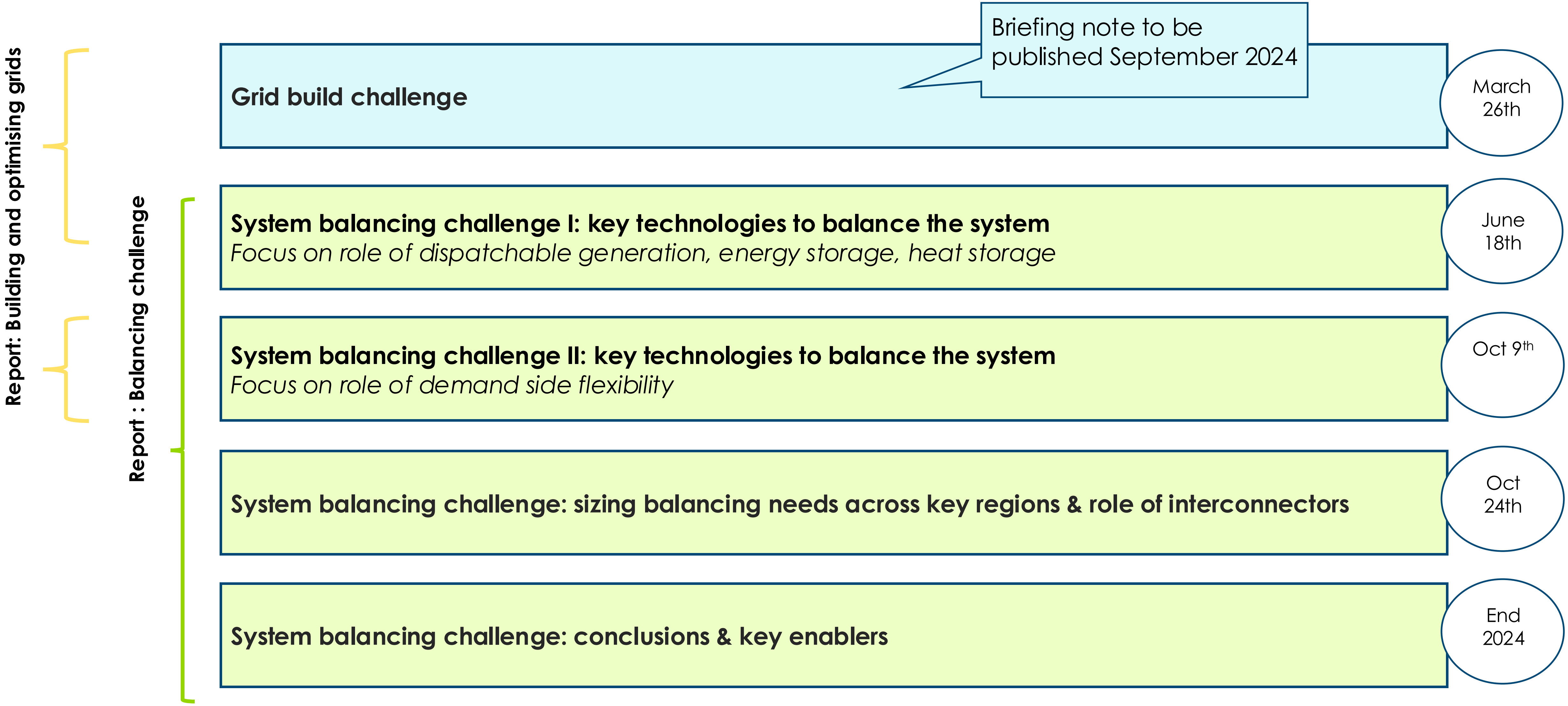
This effectively **uses the UK's transmission network as a highway**, paid by consumers, to **send power from Norway to France.**

Nodal pricing could remove **19 TWh strain on the system in 2030** by providing more representative cost data at points of interconnection.

Allowing the North of GB to export excess supply to Norway, and the South of GB to export less to France, reducing stress on the system and the magnitude of additional transmission

Notes: Modelling from FTI Consulting and Frontier Economics, showing the difference between the GB ESO's 2030 'Leading the Way' Scenario vs a locational model. 54% of the time GB price is higher than Norway price, inducing imports, and GB price is lower than France 65% of the time, inducing exports. Source: Mann, Perkins and Roberts (2024) *Transmission investment, flexibility and locational pricing*; Energy Systems Catapult (2024) *Location, Location, Location*; Cleaning up (2024) *The Kraken Wakes: Creating the Utility of the Future | Ep175 - Greg Jackson.*

Next steps in power systems transformation workplan



Report: Building and optimising grids

Report : Balancing challenge

Grid build challenge

Briefing note to be published September 2024

March 26th

System balancing challenge I: key technologies to balance the system
Focus on role of dispatchable generation, energy storage, heat storage

June 18th

System balancing challenge II: key technologies to balance the system
Focus on role of demand side flexibility

Oct 9th

System balancing challenge: sizing balancing needs across key regions & role of interconnectors

Oct 24th

System balancing challenge: conclusions & key enablers

End 2024