Energy Transitions Commission

Integrated insights from buildings and power workstreams: the balancing challenge

ETC Commissioners Meeting

31st October 2024

Agenda

1. Key messages from the buildings work

- Heating
- Cooling
- New buildings

2. The balancing challenge

- Electrification – on the cusp of taking off
- Demand – new loads driving new patterns
- Supply – patterns in a high wind/solar system
- The balancing challenge

Key messages from our Buildings work

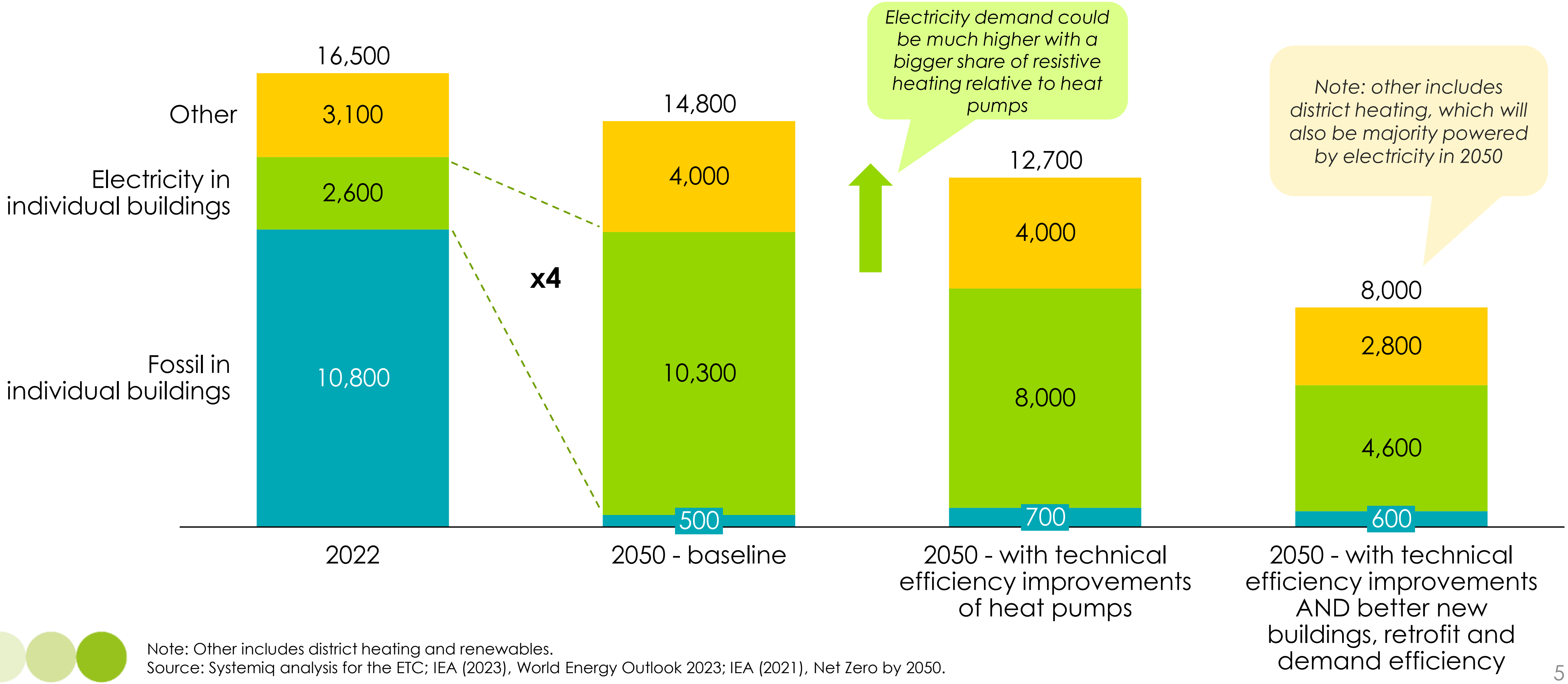
Heating: how electrification and cost-effective insulation can displace fossils

- A whole-building approach is required to create net-zero ready buildings:
  - Installing clean heating technologies which can be powered by clean electricity
  - Improvements to the building envelope
  - Considering a suite of smart and flexible technologies (e.g., smart system, solar and batteries)
- Building heating can and should be almost entirely electrified, primarily with a range of different types of heat pumps
- Insulating the least efficient homes must be a government priority. However, for the average home, deep retrofit is not a pre-requisite for installing a heat pump, as long as radiators and systems are appropriately sized
- All buildings must explore low-cost and easily accessible improvements (e.g., loft insulation and draught proofing) which can greatly improve living standards, reduce energy bills and ease peak energy demand
- Electricity used to heat buildings could still grow from 2,600 TWh today to 4,000-5,000 TWh in 2050. Without strong action on technical efficiency and insulation, it could be 10,000 TWh

Electricity demand from heating could be 4x higher than it is today, but with strong action on energy productivity, the increase could be less than double

Global final energy demand for heating by fuel in 2050

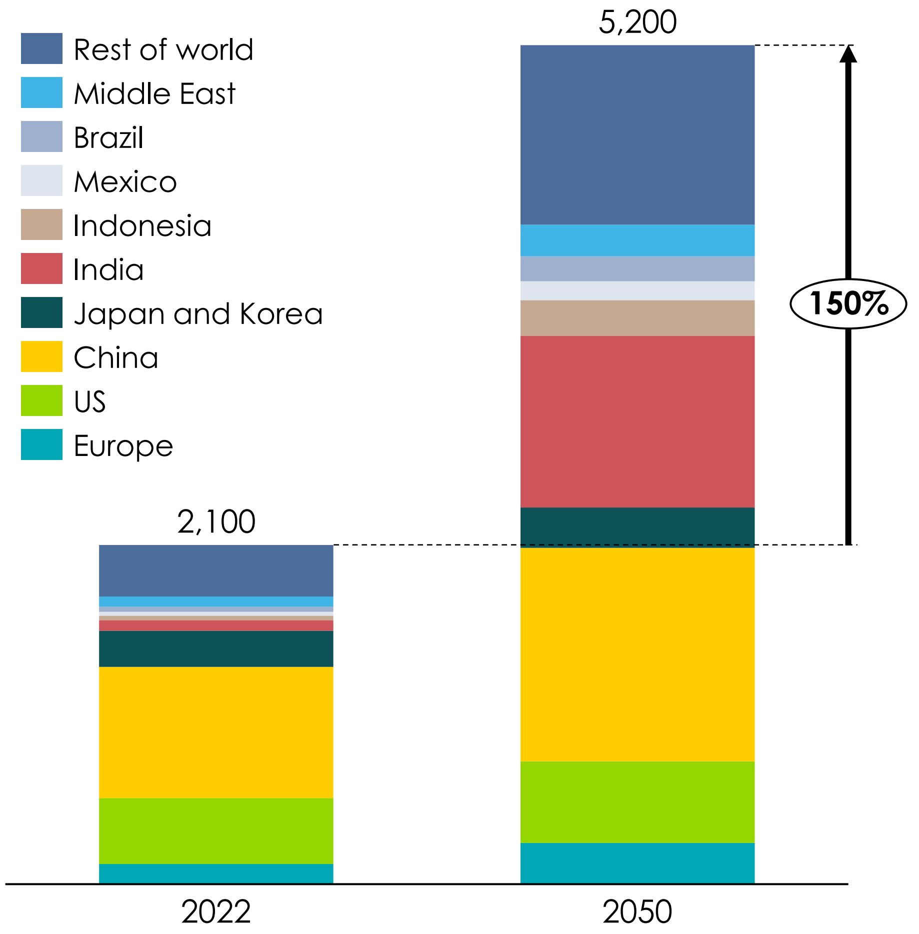
TWh



Note: Other includes district heating and renewables.
Source: Systemiq analysis for the ETC; IEA (2023), World Energy Outlook 2023; IEA (2021), Net Zero by 2050.

Cooling: managing rising demand in a warming climate with passive cooling and efficient air conditioning

Space cooling (residential + commercial) energy consumption by region, IEA baseline scenario
TWh

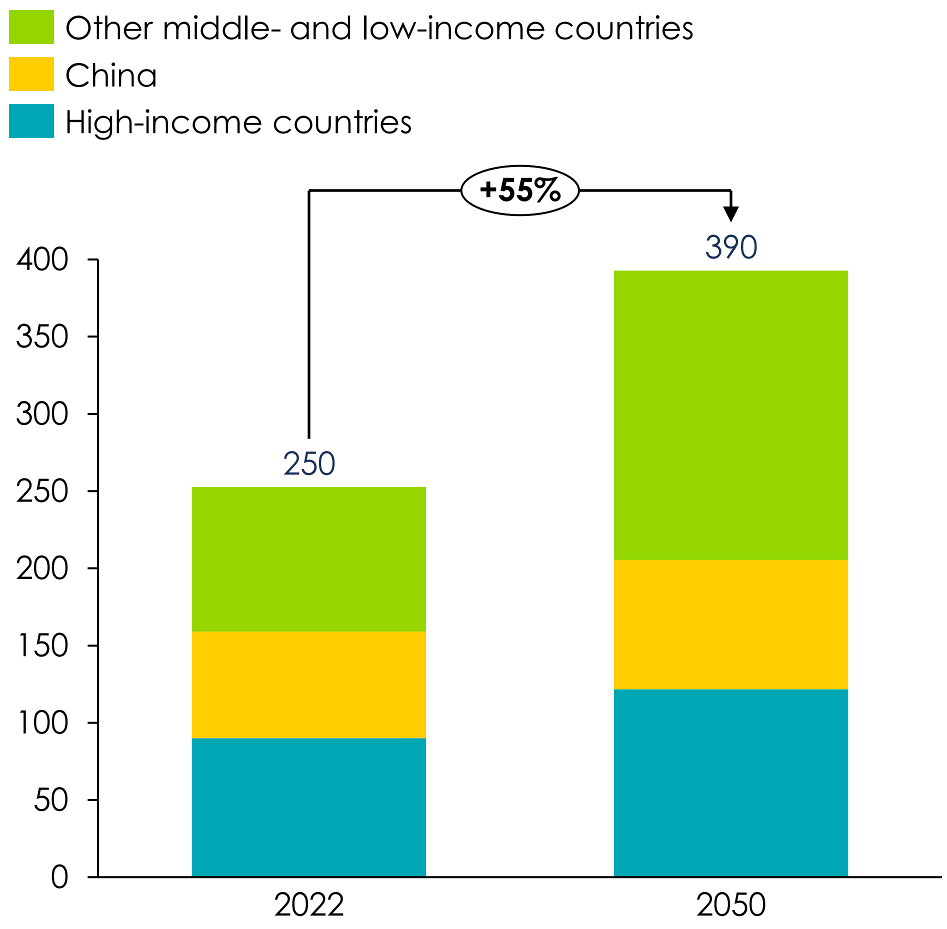


- Demand for cooling is set to more than double by 2050 from 2,000 TWh to 5,000 TWh, but current projections may actually be underestimating the potential increase
- Passive cooling and better urban planning can reduce a building's cooling energy needs by 25-40%.
- Many of these are low-cost, such as external shading by planting trees and painting roofs white.
- Getting this right in new buildings is critical; better building codes could reduce global electricity needs in new buildings for cooling by around 20%
- The single most effective lever to reducing electricity needs for cooling is to improve the efficiency of the stock of ACs. Combined with behaviour change (e.g., turning thermostats up to reasonable levels), this could more than offset the increase in demand

Note: IEA estimates of global cooling energy use in 2050 split into regions using IEA projections of AC stock in different countries in 2050.
Source: Systemiq analysis for the ETC; IEA (2023), World Energy Outlook 2023.

New buildings: Reducing locked in embodied carbon, lowering energy bills and improving living standards

Growth in global floor area, projections
Billion m^2

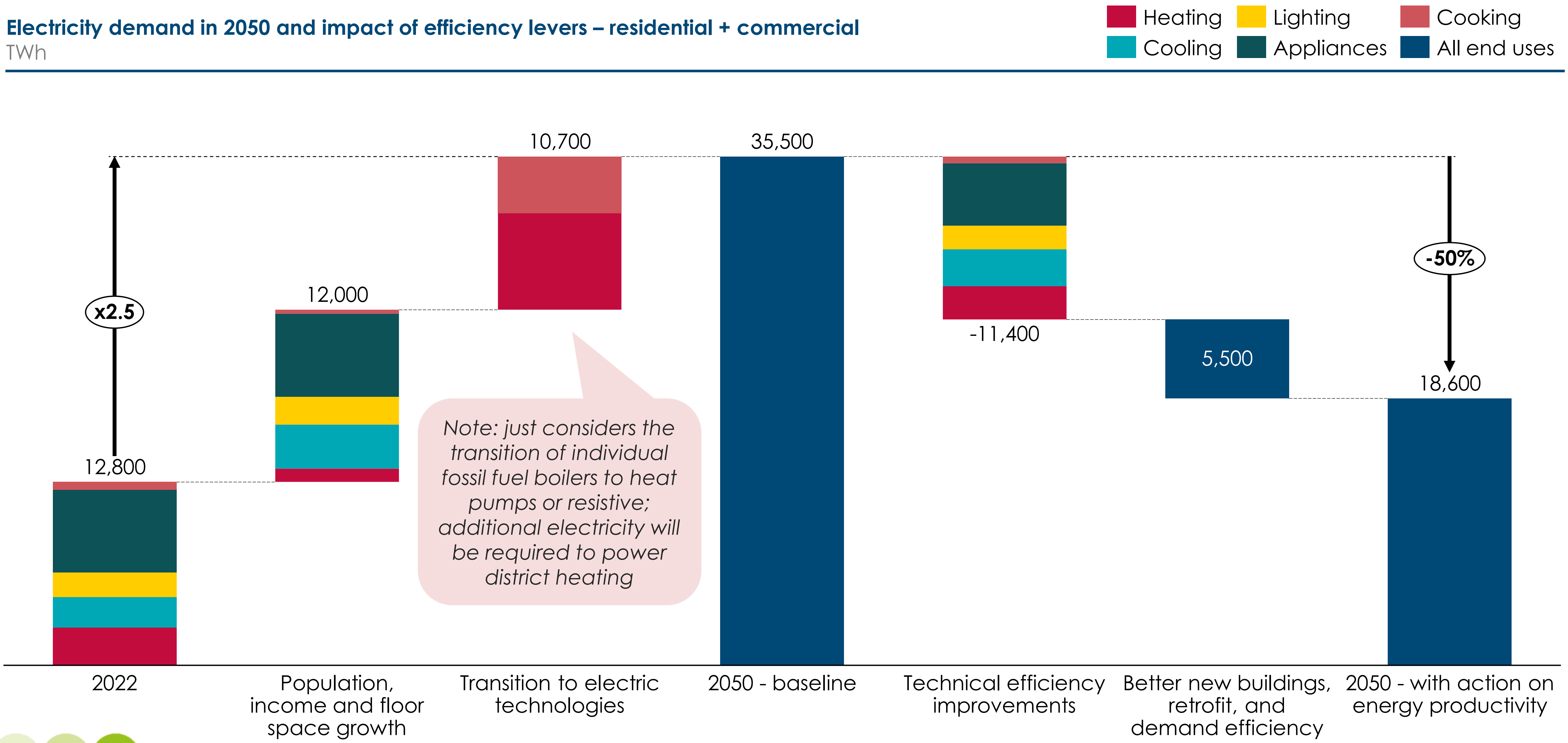


Note: Projections from the IEA's Net Zero scenario.
Source: IEA (2023), World Energy Outlook 2023.

- New construction could result in 75 $GtCO_2$, or 40% of the remaining carbon budget for 1.5C. There are, however, opportunities to reduce this to 30-40 $GtCO_2$
- The biggest opportunity is to decarbonise steel, cement and concrete production – but there are limits to how quickly low-carbon technologies can scale this decade
- Reducing emissions this decade requires material efficiency and substitution strategies, e.g., innovative building design strategies, using alternative materials such as timber, and better urban planning
- Regulation must:
  - Set embodied carbon limits for new developments
  - Move from a code compliance approach to setting ambitious energy intensity minimum standards

Global electricity demand could more than double by 2050 from 13,000 TWh to over 35,000 TWh – but strong action on energy efficiency could cut this in half to ~19,000 TWh

Electricity demand in 2050 and impact of efficiency levers – residential + commercial
TWh



Source: Systemiq analysis for the ETC; IEA (2023), World Energy Outlook 2023; IEA (2021), Net Zero by 2050.

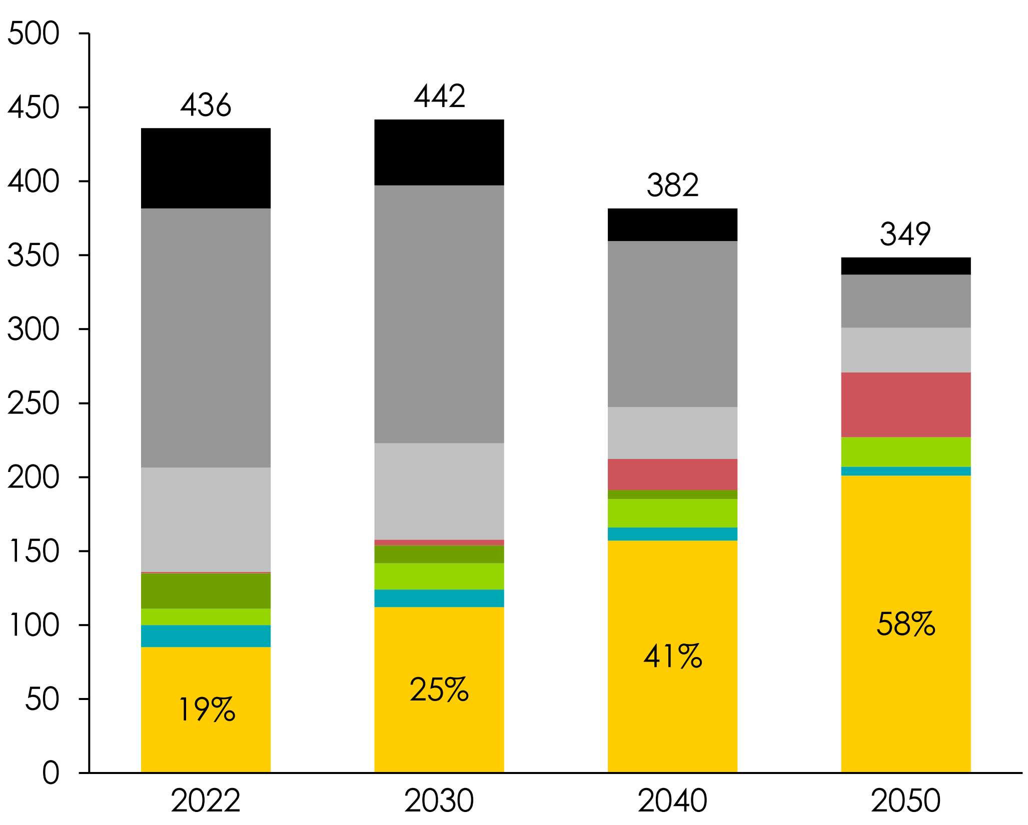
The balancing challenge

Electrification – on the cusp of taking off

Reminder: achieving net-zero emissions hinges on the successful transition to clean electrification, which ETC expects will rise to >60% by 2050

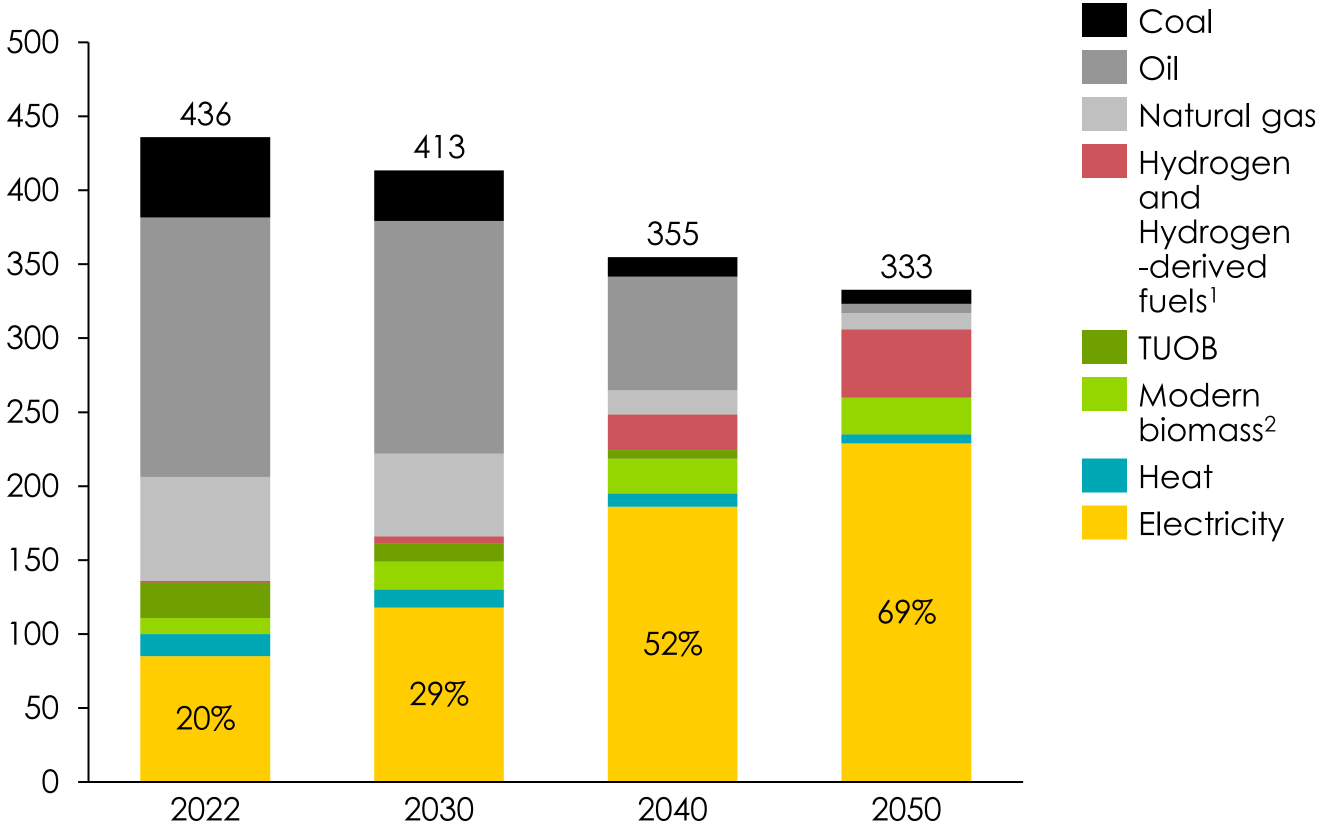
ACCELERATED BUT CLEARLY FEASIBLE

EJ/year



POSSIBLE BUT STRETCHING

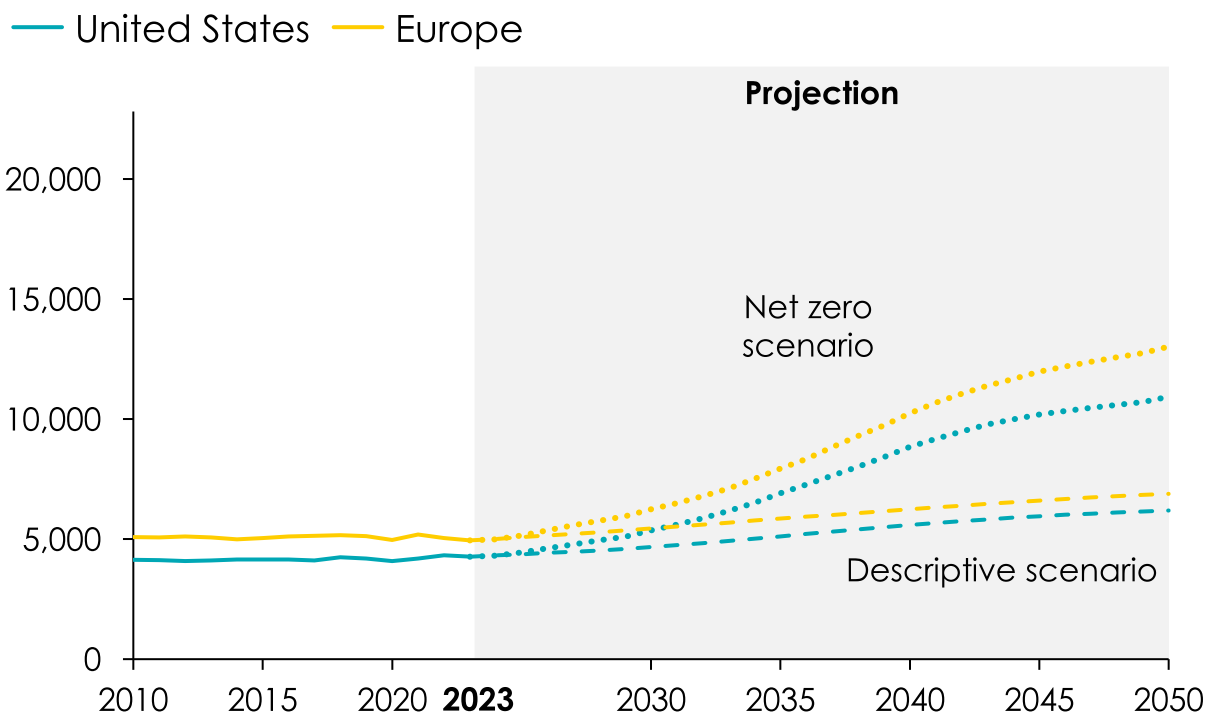
EJ/year



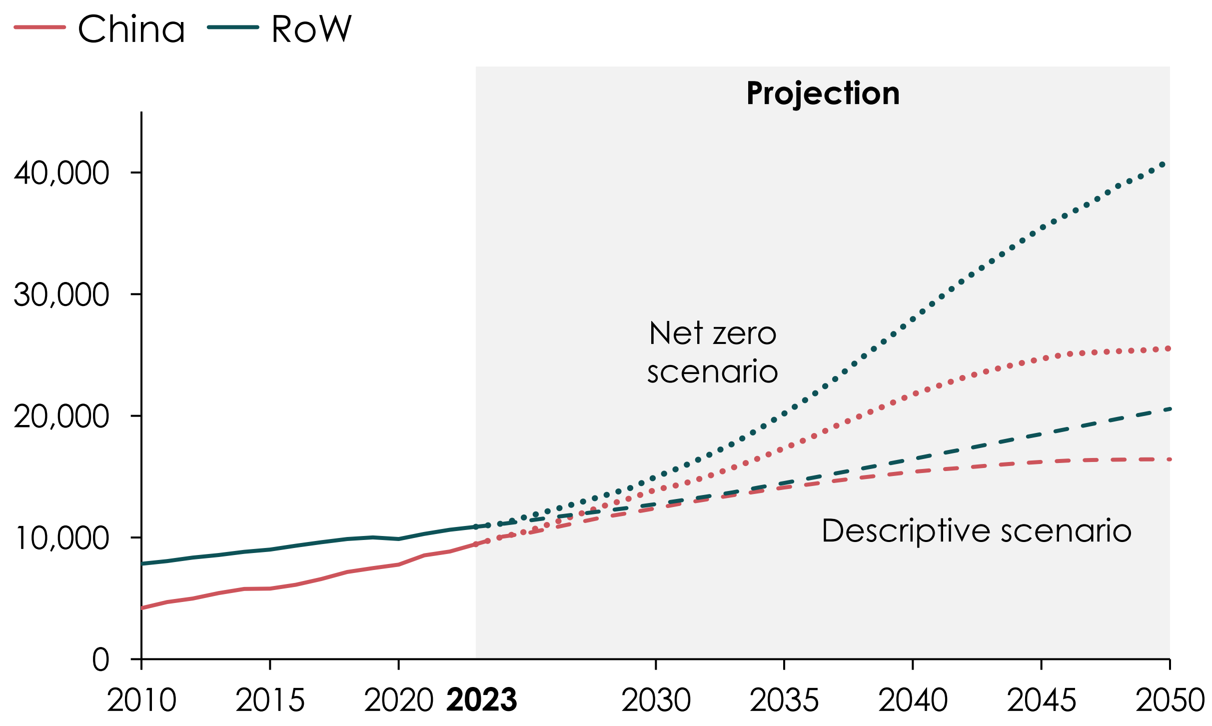
Note: [1]Mainly from green sources. [2]Final energy demand from Modern biomass to be finalized. Excludes wood products, pulp and paper.
Source: Systemiq analysis for the ETC (2023)

While electricity demand is not surging in all countries yet, growth is imminent

Electricity demand in Europe and the US, 2010–2050
TWh



Electricity demand in China and the RoW, 2010–2050
TWh

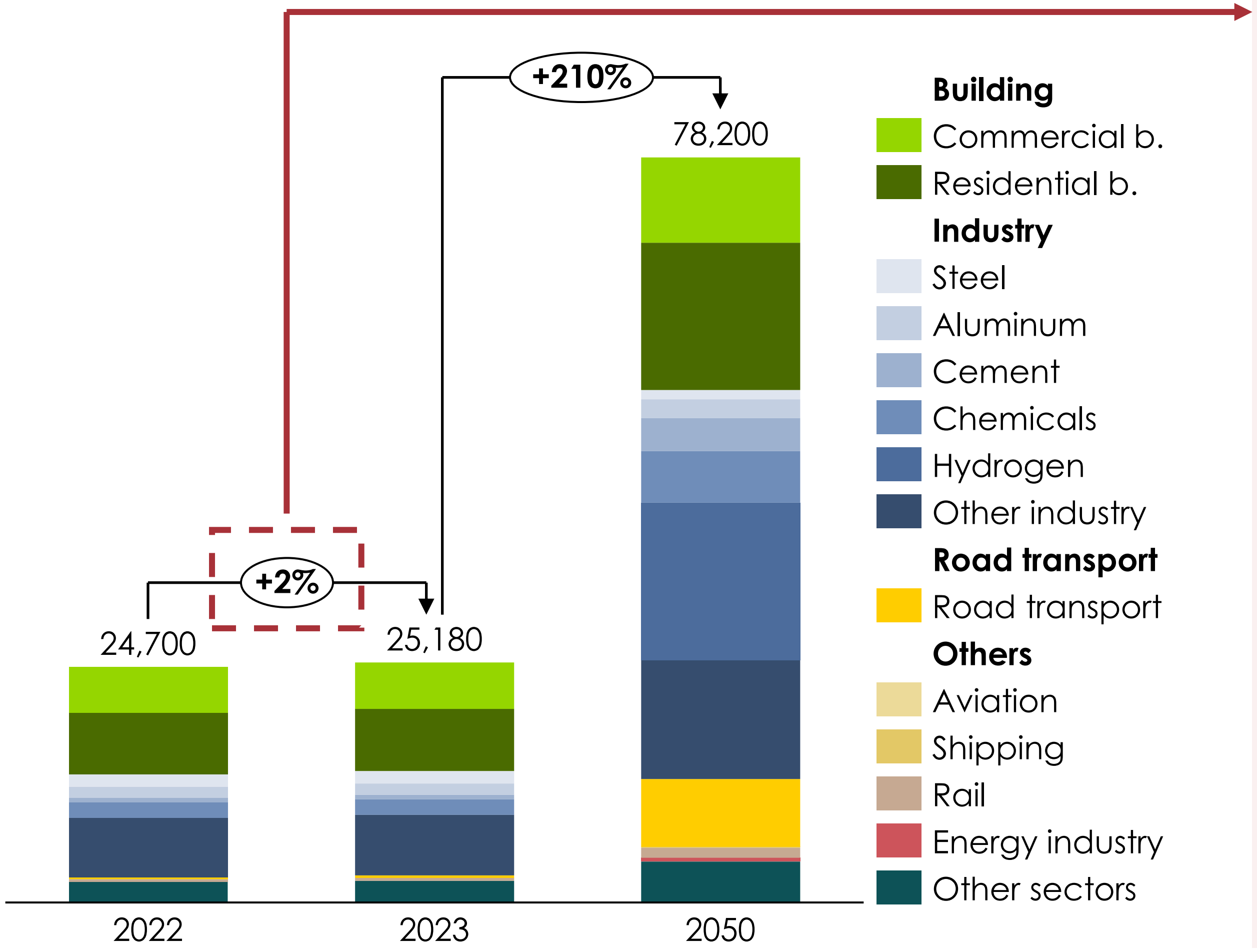


- Over the past decade, electricity **demand in the U.S. and Europe has remained relatively flat**
- **China and other developing regions have experienced a surge** in electricity demand
- Driven by **growth in EV, heat pumps, and data centres**, global electricity demand is entering an **era of stronger growth**

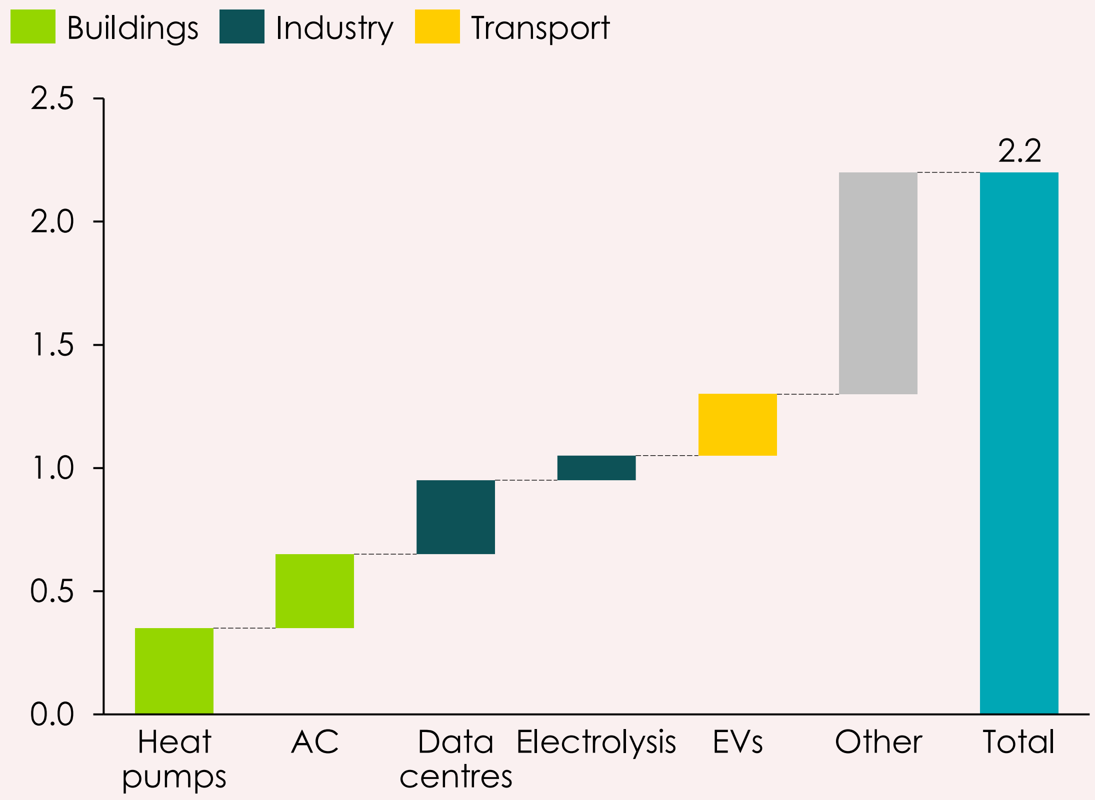
Source: Historical data from Ember (2024), Electricity data viewer; future projection based on the growth rates from BloombergNEF (2024) applying to Ember 2023 data, New Energy Outlook 2024 ETS.

Key sectors are already emerging as the main drivers for increasing demand

Global electricity demand by sector, 2023 & 2050
TWh



Share of global electricity demand growth attributed, 2023
Percentage points



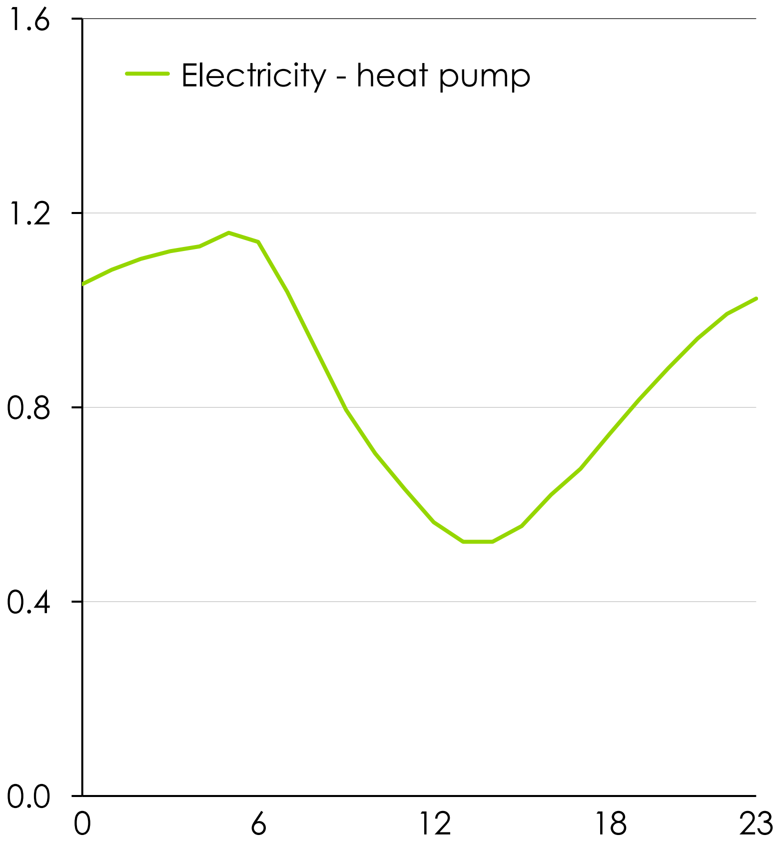
Notes: Other includes TVs, cooking and other appliances
Source: Ember (2024), Global Electricity market Review 2024; Ember (2024), Electricity data viewer; BloombergNEF (2024), New Energy Outlook 2024 NZS

Demand – new loads driving new patterns

New electricity loads have distinct peak profiles

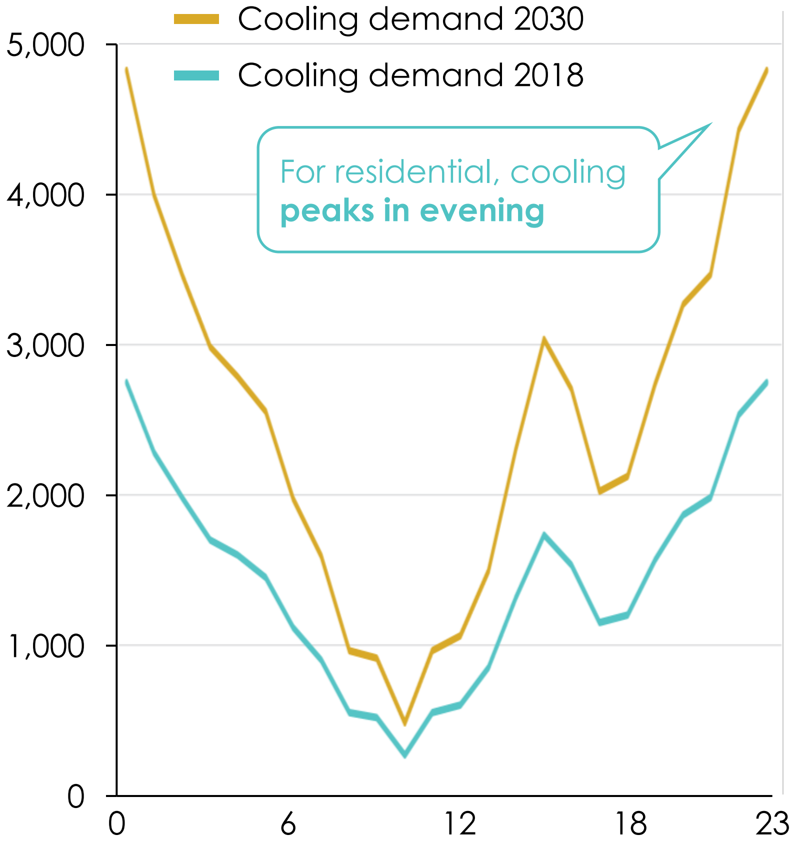
Heating

Hourly electricity use in a winter day in typical European house with a heat pump
KW



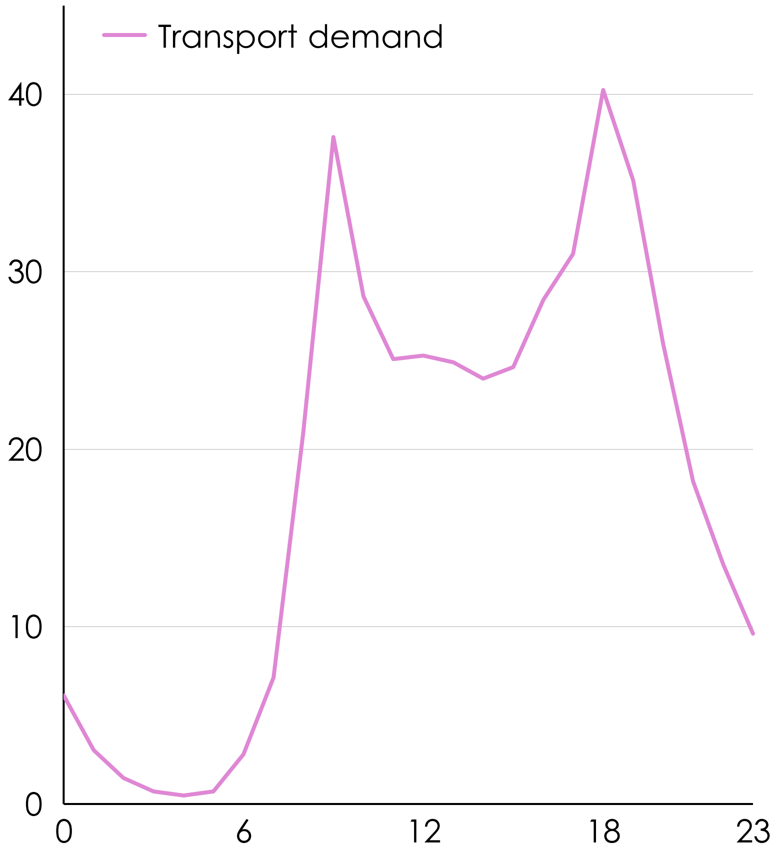
Cooling

Delhi's hourly domestic cooling demand in 2018 and in 2030 during a summer day
Electricity demand in MW



Transport

GB's projected hourly demand from transport in a winter day in 2050
GW demand

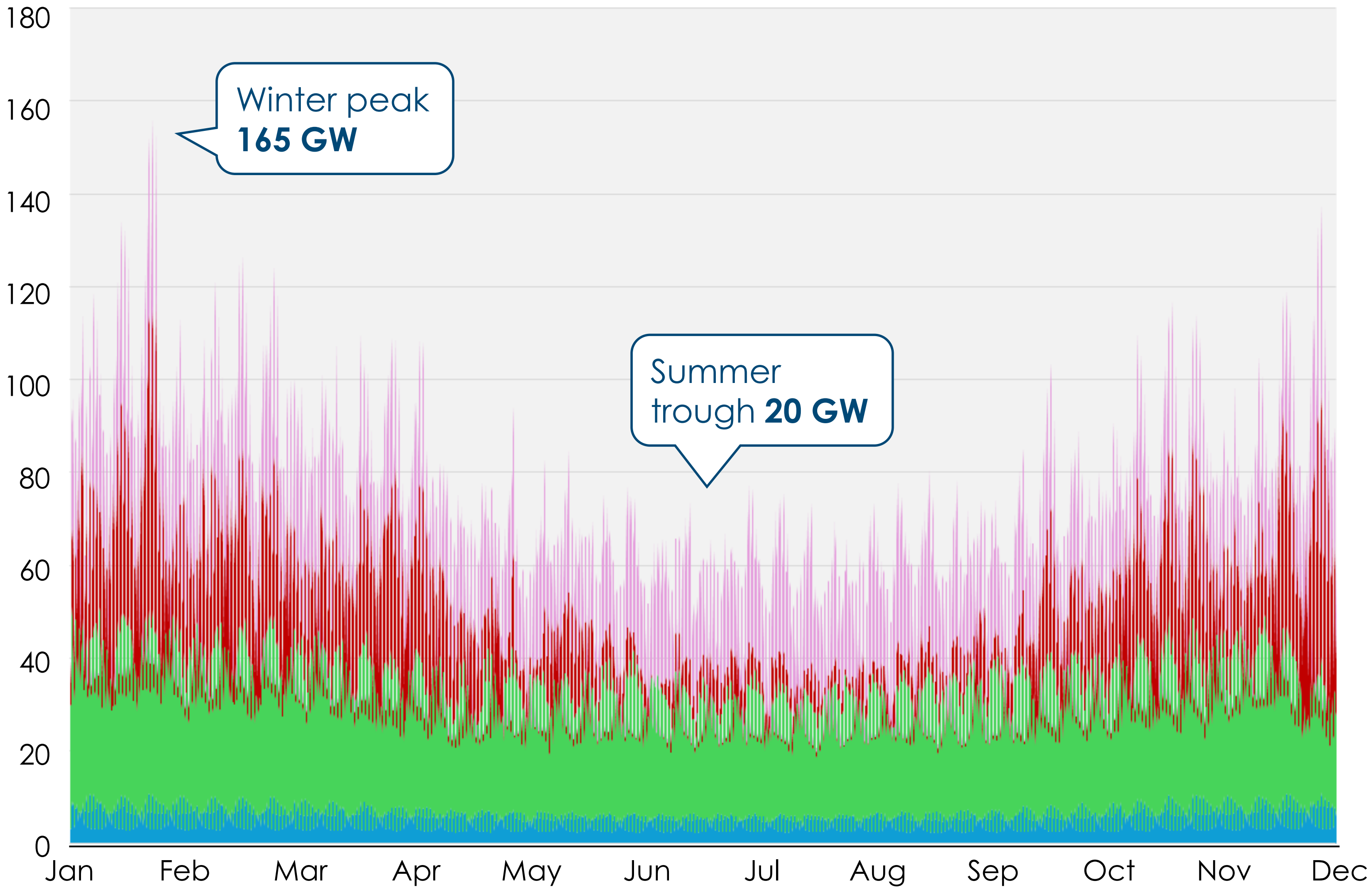


Note: Heating data based on a large residential house in France, scaled down to typical average household gas heating consumption
Source: Systemiq analysis for the ETC (2024) based on SE Sustainability Research Institute; RMI (2024), *Transforming Delhi's Power Grid;* NESO (2022) Future Energy Scenarios 2022

2050 GB demand fluctuates on a seasonal basis, driven by heating loads

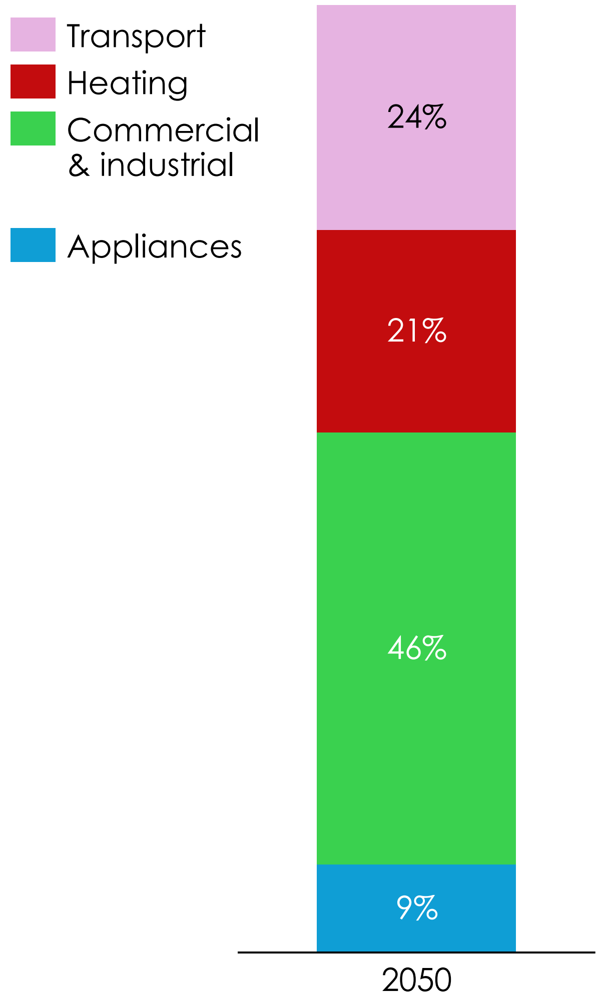
GB hourly demand load, 2050, highly electrified scenario

GW demand for each hour of the year



Demand by use case

Proportion of total, %

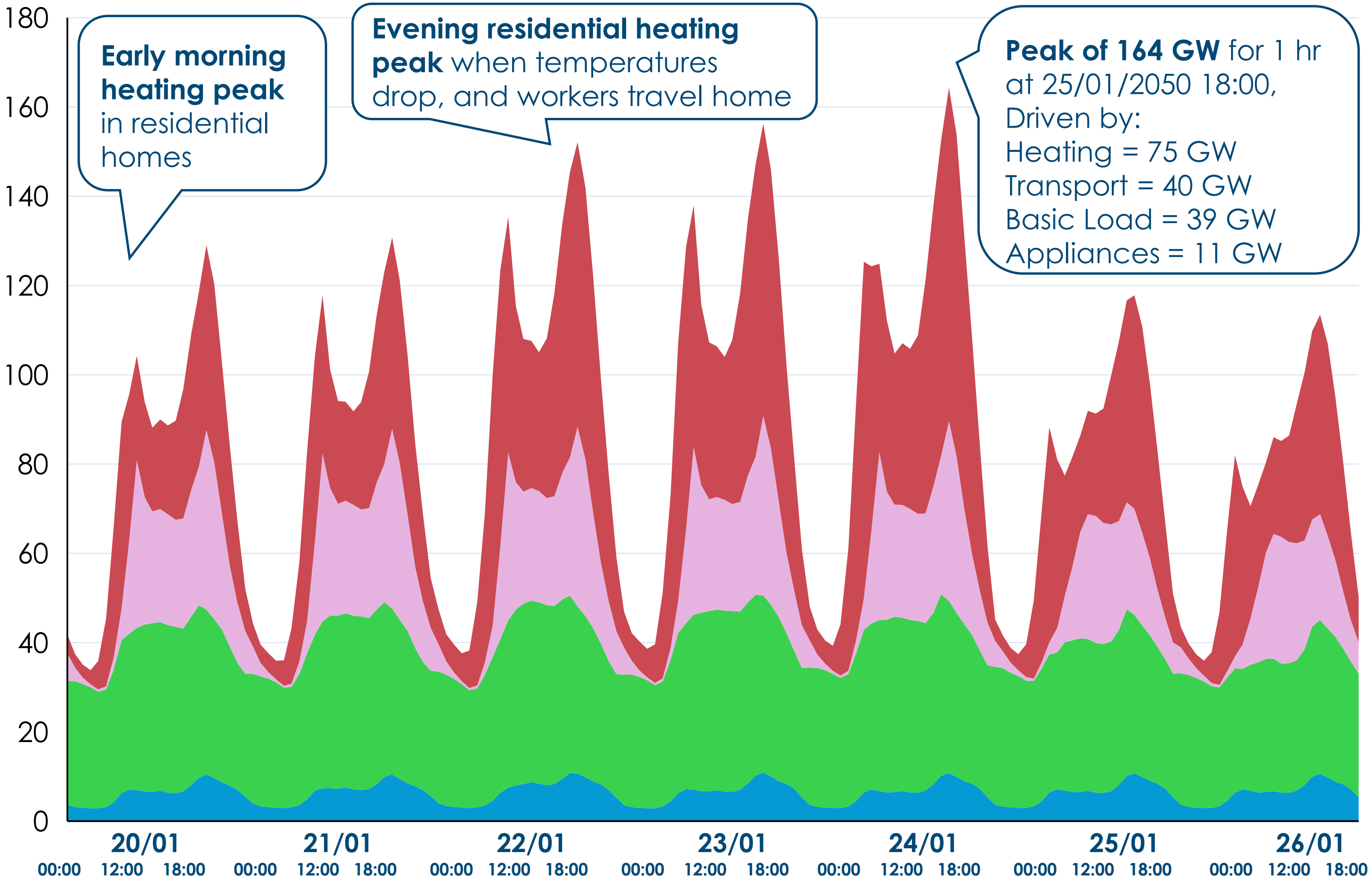


Archetype: Northern latitude (GB)

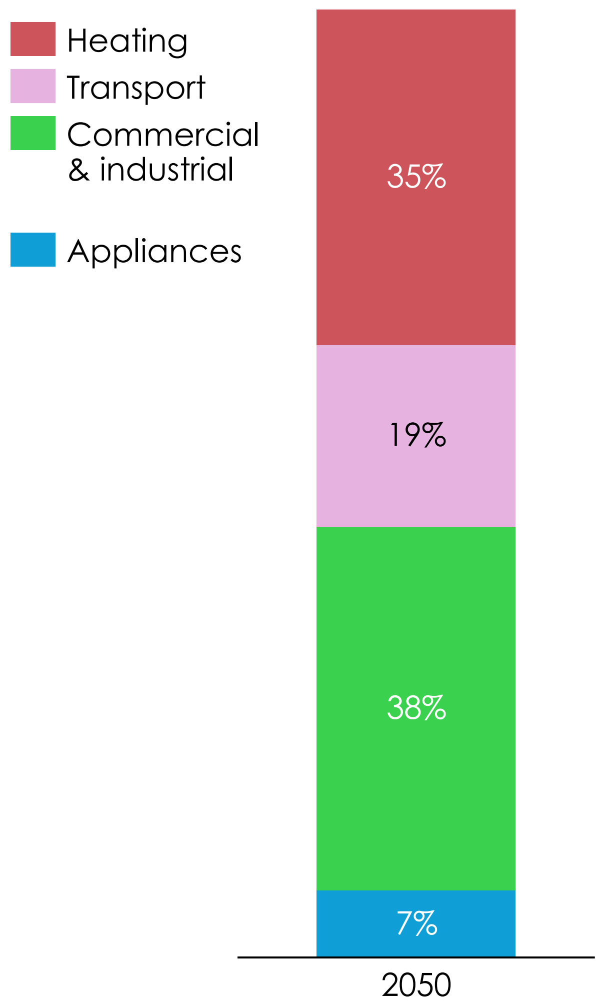
Source: Systemiq analysis for the ETC; NESO (2022) Future Energy Scenarios 2022

In cold months, daily fluctuations are driven by heating needs

GB hourly demand load, January 20-26, 2050, highly electrified scenario
GW demand for each hour week



Demand by use case
Proportion of peak weekly demand, %



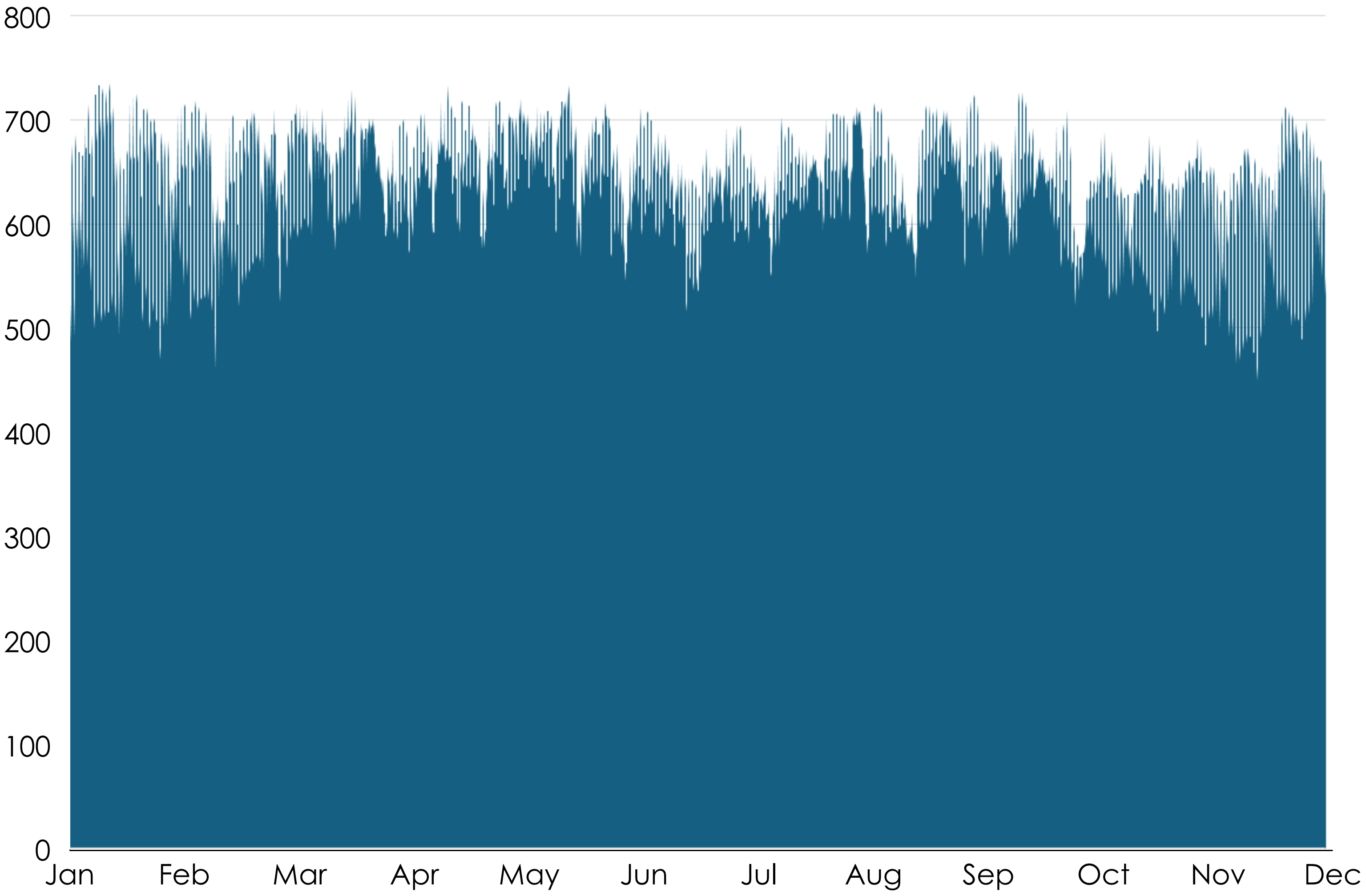
Archetype: Northern latitude (GB)

Notes: 20/02/2050 is the first day of the week.
Source: Systemiq analysis for the ETC; NESO (2022) Future Energy Scenarios 2022

India demand has limited seasonal variation, driven by somewhat constant cooling load

Indian hourly demand load, 2050, highly electrified scenario

GW demand for each hour of the year



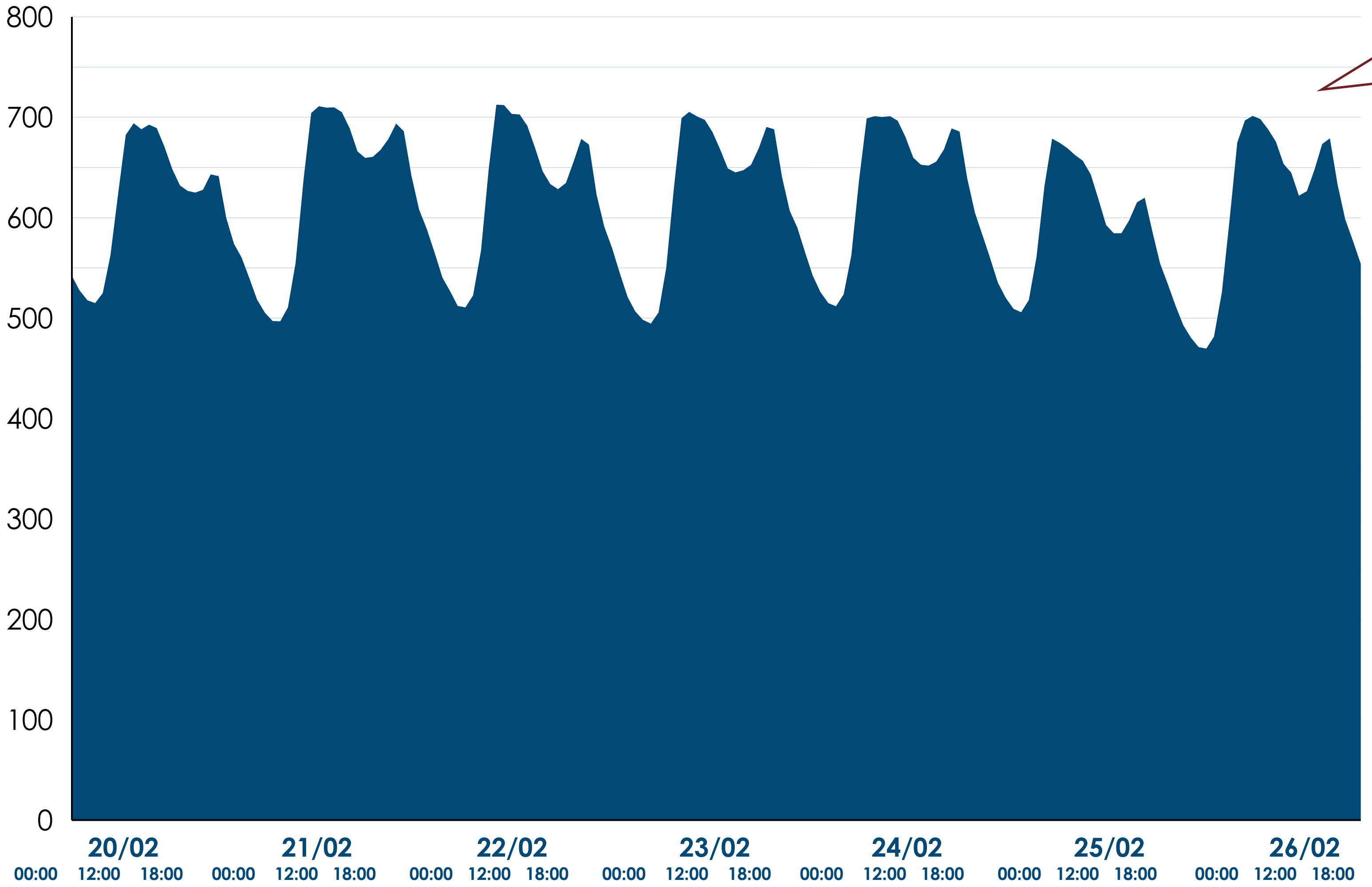
- **Somewhat constant cooling** demand throughout the year, which lessens in some areas in winter months
- Given the sheer size of India (over 15* bigger than GB), some geographical areas will experience **both heating and cooling needs**

Archetype: Low latitude / tropical (In)

Source: Systemiq analysis for the ETC; TERI (2024) India's Electricity Transition Pathways to 2050: Scenarios and Insights

India's daily variation is driven by midday and evening peaks

India hourly demand load, February 20-26, 2050, highly electrified scenario
GW demand for each hour week



Midday peaks increase ~200GW from midnight troughs, as overall load higher during the day

Archetype: Low latitude / tropical (In)

- Indian air conditioning units forecast to increase from **0.08 billion units in 2023** to **1.14 billion units in 2050**, a key driver of increased demand
- Big uptake in EVs which charge during the day to align with solar patterns

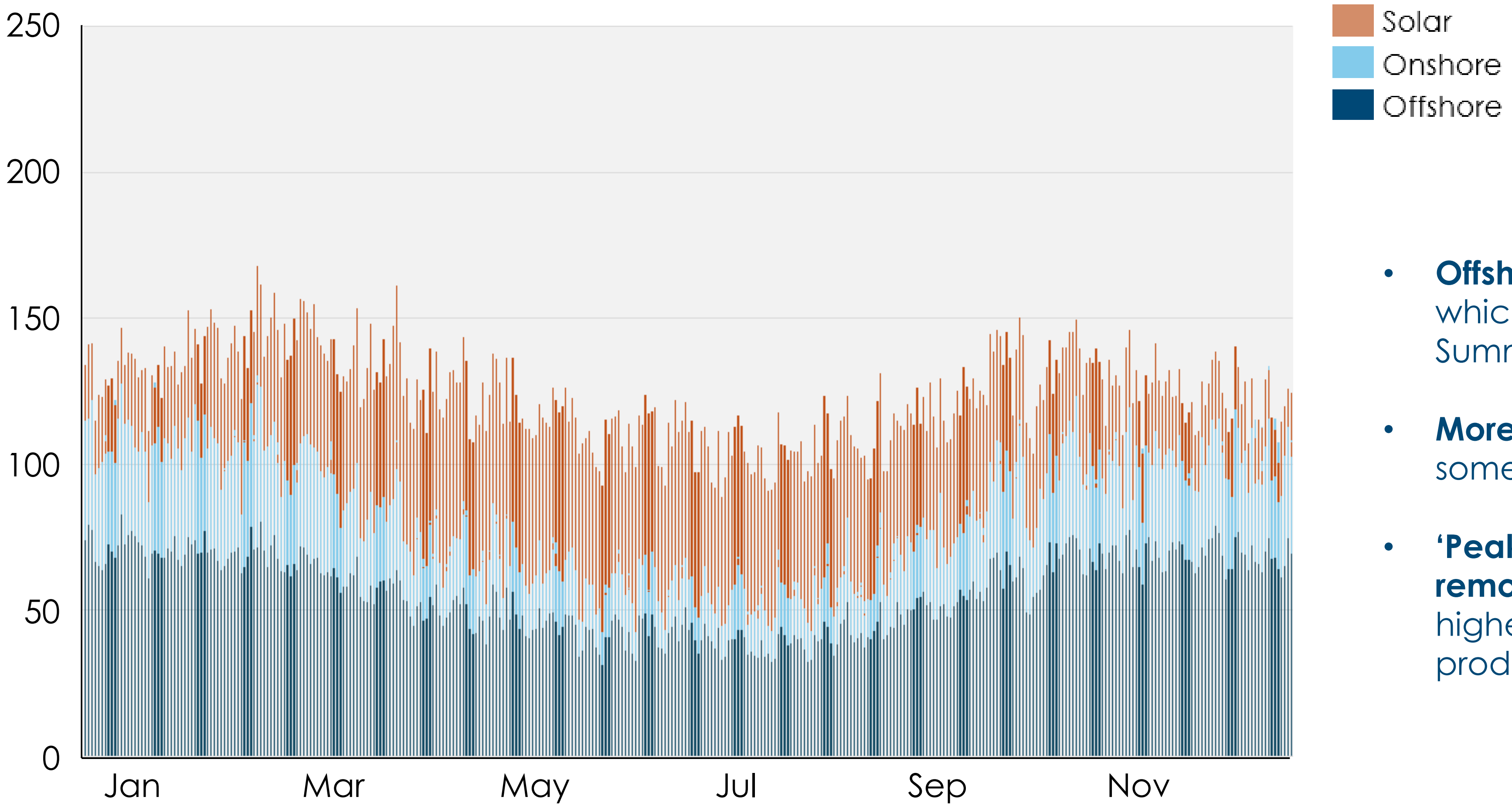
Notes: 20/02/2050 is the first day of the week.
Source: Systemiq analysis for the ETC; TERI (2024) *India's Electricity Transition Pathways to 2050: Scenarios and Insights*; IEA (2024) *Growth in global air conditioner stock, 1990-2050*

Supply patterns in a high wind/solar system

Wind generation in the UK is highest in the winter

Archetype: Northern latitude (GB)

GB 2050 median hourly generation across 1994-2023
GW, Hourly generation



- **Offshore wind dominates UK supply,** which provides more energy outside of Summer
- **More solar available in Summer** which somewhat offsets lower wind production
- **'Peakiness' seen in-year weather data is removed**, but min/max years show higher peaks/troughs of wind production

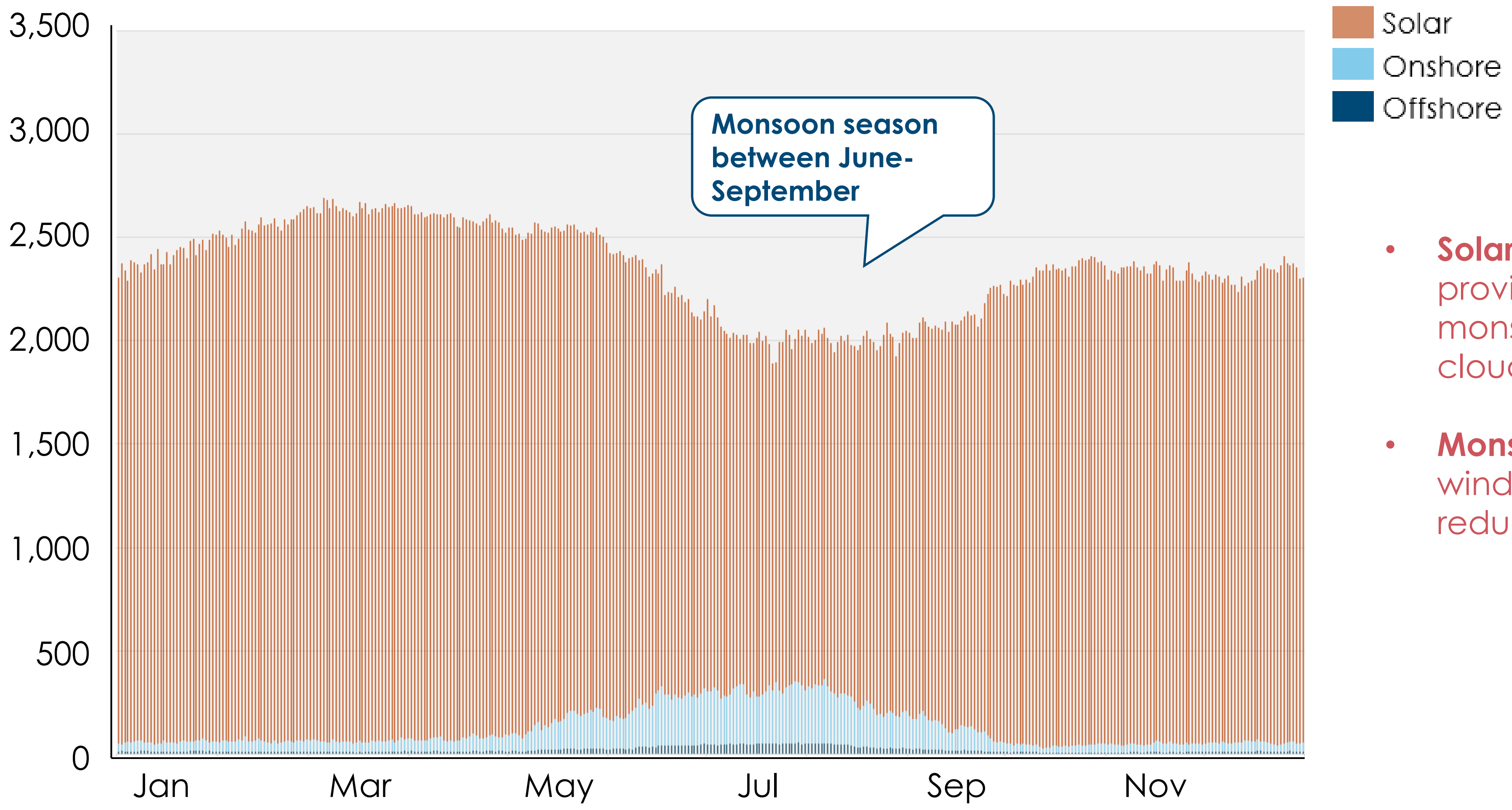
Source: ECMWF (2024) ERA 5 modelling; Systemiq analysis for the ETC

Consistent solar generation in India besides monsoon season

Archetype: Low latitude / tropical (In)

Indian 2050 median hourly generation across 1994-2023

GW, Hourly generation



- **Solar dominates Indian supply,** which provides consistently outside of monsoon season (heavy rainfall and cloud cover)
- **Monsoons increase wind speed** and wind generation picks up to cover some reduction in solar

Source: ECMWF (2024) ERA 5 modelling; Systemiq analysis for the ETC

The balancing challenge

Context for the "balancing challenge"

- **The balancing challenge is a "late stage" challenge for power sector decarbonisation:** until ~50% penetration of wind/solar, balancing can be met by running existing fossil more flexibly, and many countries can and must deploy more wind and solar imminently without need to address balancing

- **Balancing challenge is not homogenous across the world; important to understand variation of balancing needs by archetype – not always a hard challenge**:

  - For many geographies ("Tropical", with fast-growing electricity demand), challenge is primarily day/night variation required short-duration, lower-cost balancing only

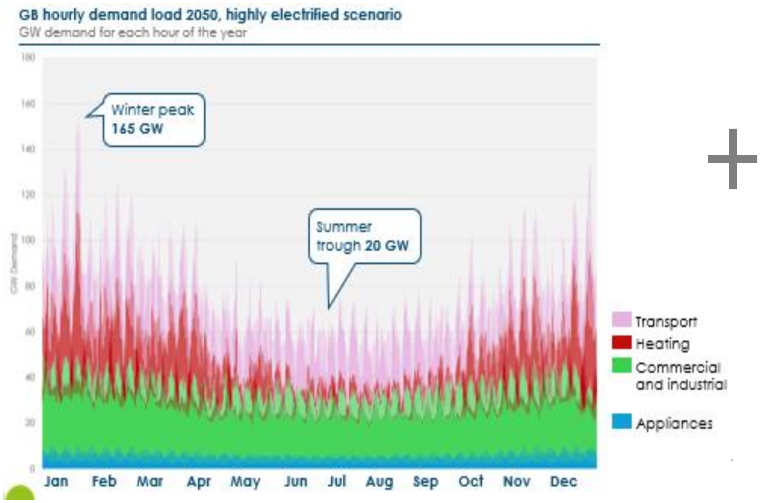
  - In some geographies ("Northern latitude", ~15% of electricity demand today), challenge will require longer duration balancing routes, which are more expensive

- **Overall, understanding the balancing challenge is critical to provide certainty of route to zero or near zero-carbon power systems, as countries approach 2030 & 2035 decarbonisation targets**

Approach to sizing the balancing challenge analysis

For each archetype (e.g. Northern Latitude, Tropical)

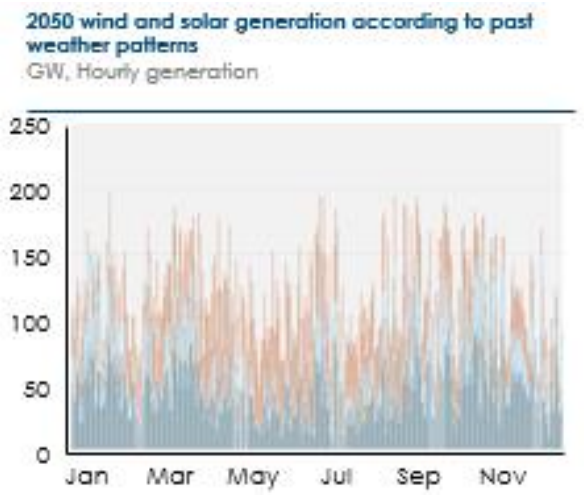
Demand



Detailed 2050 hourly load profiles obtained from expert forecasters which are reflective of high electrification and specific peak profiles (i.e. UK ESO, TERI in India)

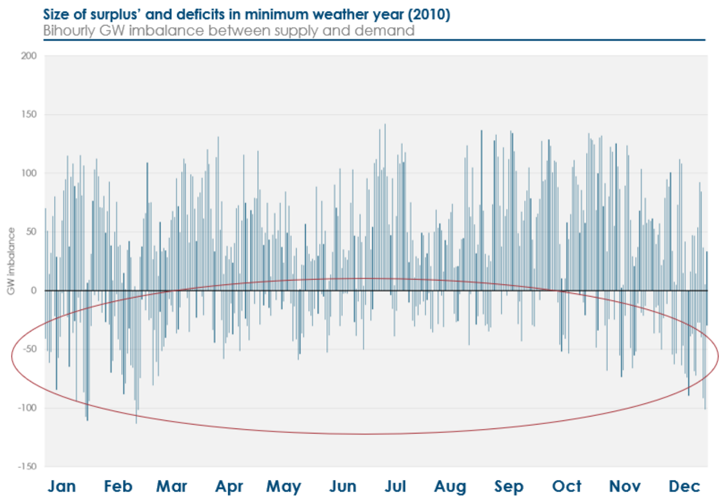
+

Supply (wind + solar)



Bihourly weather data obtained for past 30 years (1994-2023); assumed wind and solar deployment for each country*; weather patterns applied to renewables to provide generation across low-high scenarios)

Balancing

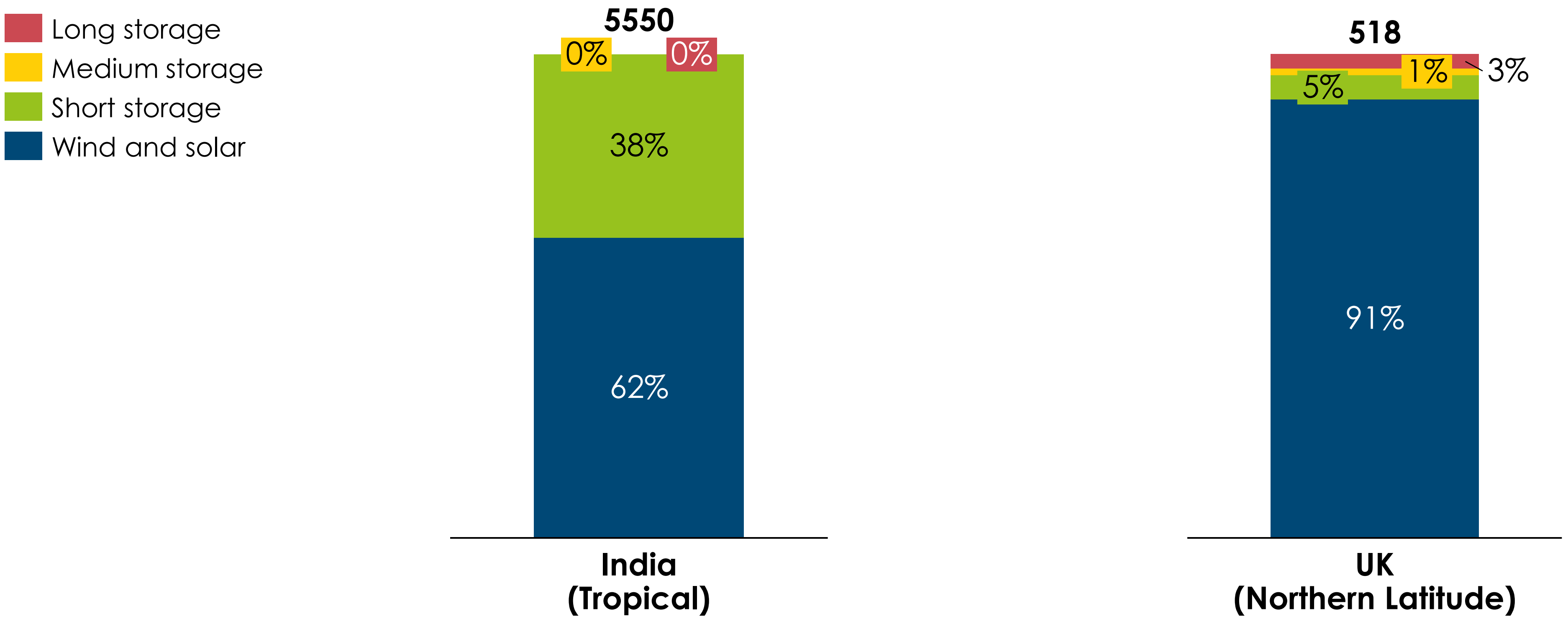


Matching at bi-hourly level across demand and supply to assess periods of wind & solar generation excess/shortfall relative to demand

Balancing challenge varies for Tropical and Northern Latitude archetypes

Balancing variability for India and UK in a 100% wind and solar system

% of TWh of annual demand provided by specified generation/storage



Primarily a diurnal challenge

Balancing required across short, medium and long durations

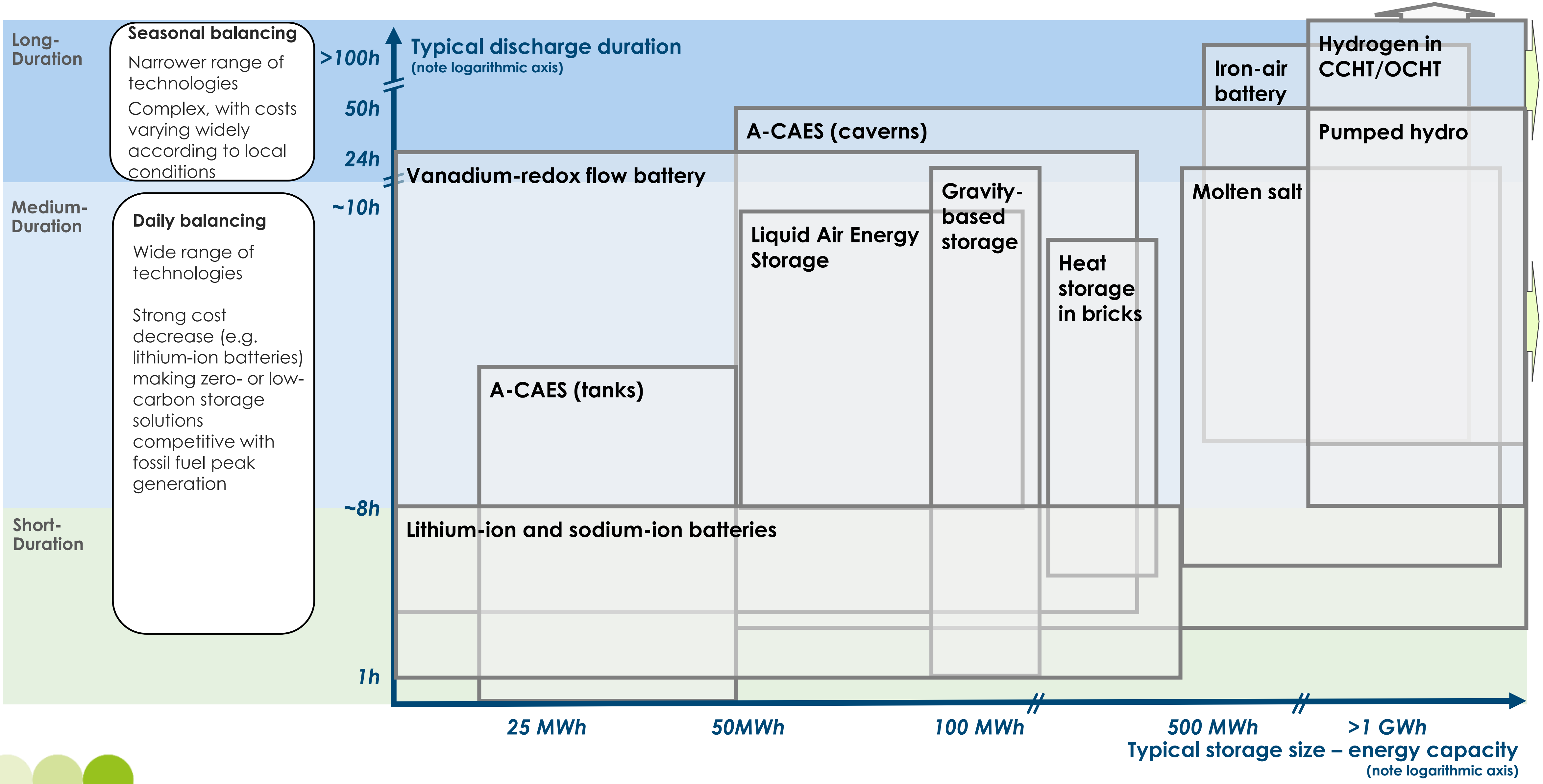
Source: Systemiq analysis for the ETC (2024)

Different routes to meet balancing challenge

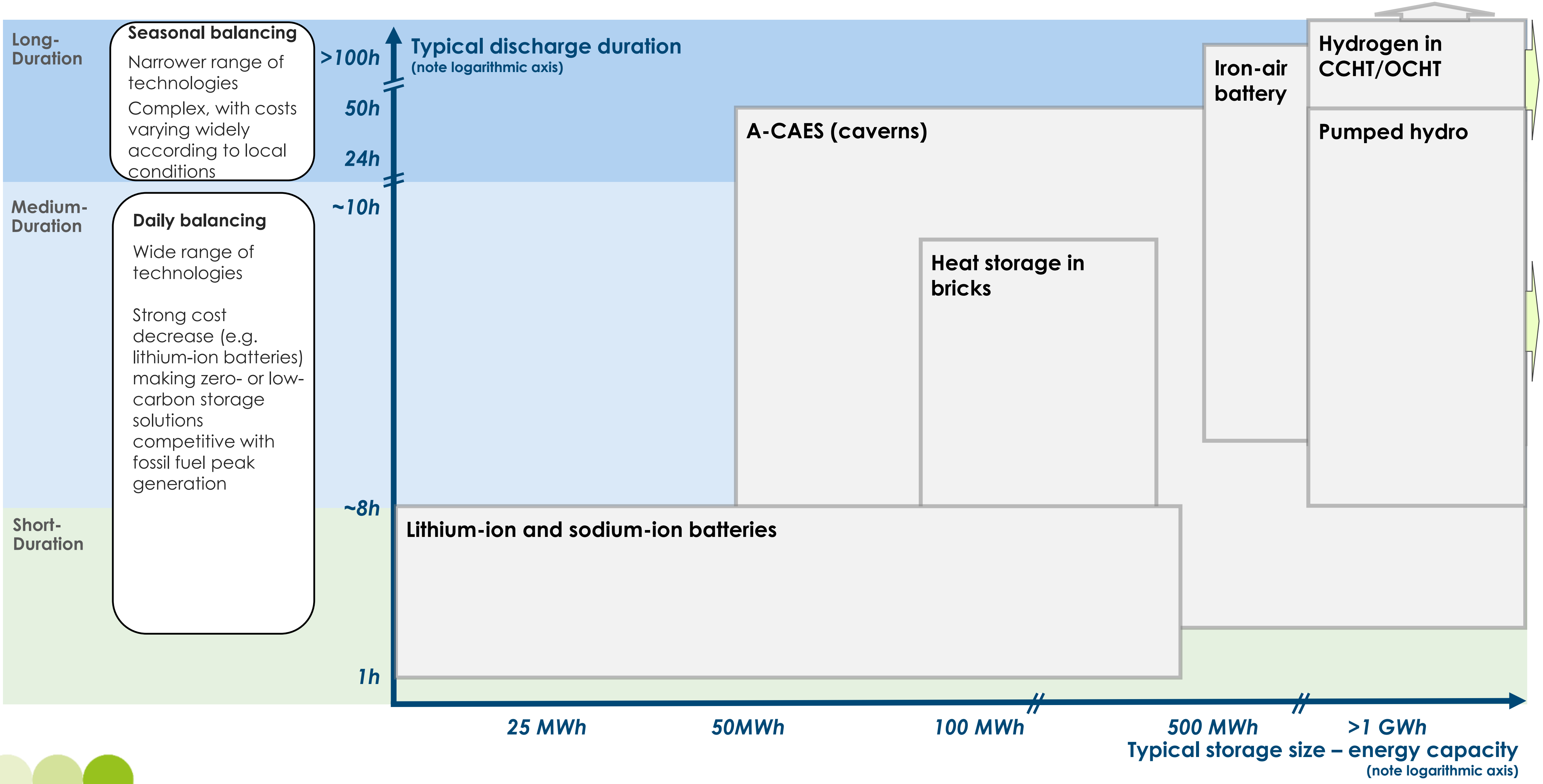
			System operation	Predictable Daily	Unpredictable Daily	Medium duration	Long duration
Dispatchable generation	Other zero carbon	Hydro, nuclear[1]	✓	✓	✓	✓	✓ (yellow)
Dispatchable generation	Fossil	Fossil (or bioenergy) + CCS	✓	✓	✓	✓	✓
Dispatchable generation	Fossil	Fossil – low/very low utilisation	✓	✓	✓	✓	✓
Interconnection		Accessing complementary weather patterns and time shifting generation		✓	✓	✓	
Energy storage		Pumped hydro	✓	✓	✓	✓	✓ (yellow)
Energy storage		Lithium ion battery[2]	✓	✓	✓	✓ (yellow)	
Energy storage		Other technology (i.e. CAES, liquid air, etc.)[3]	✓	✓	✓	✓	✓ (yellow)
Energy storage		Power-to-X (i.e. H2)[4]	✓	✓	✓	✓	✓
Heat storage		Heat battery	✓	✓	✓		
Demand side flexibility		EV (smart charging, V2G)		✓	✓		
Demand side flexibility		Heating load[5]		✓	✓		
Demand side flexibility		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 night 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 needs6. 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*

Earlier this year, we assessed a range of storage technology



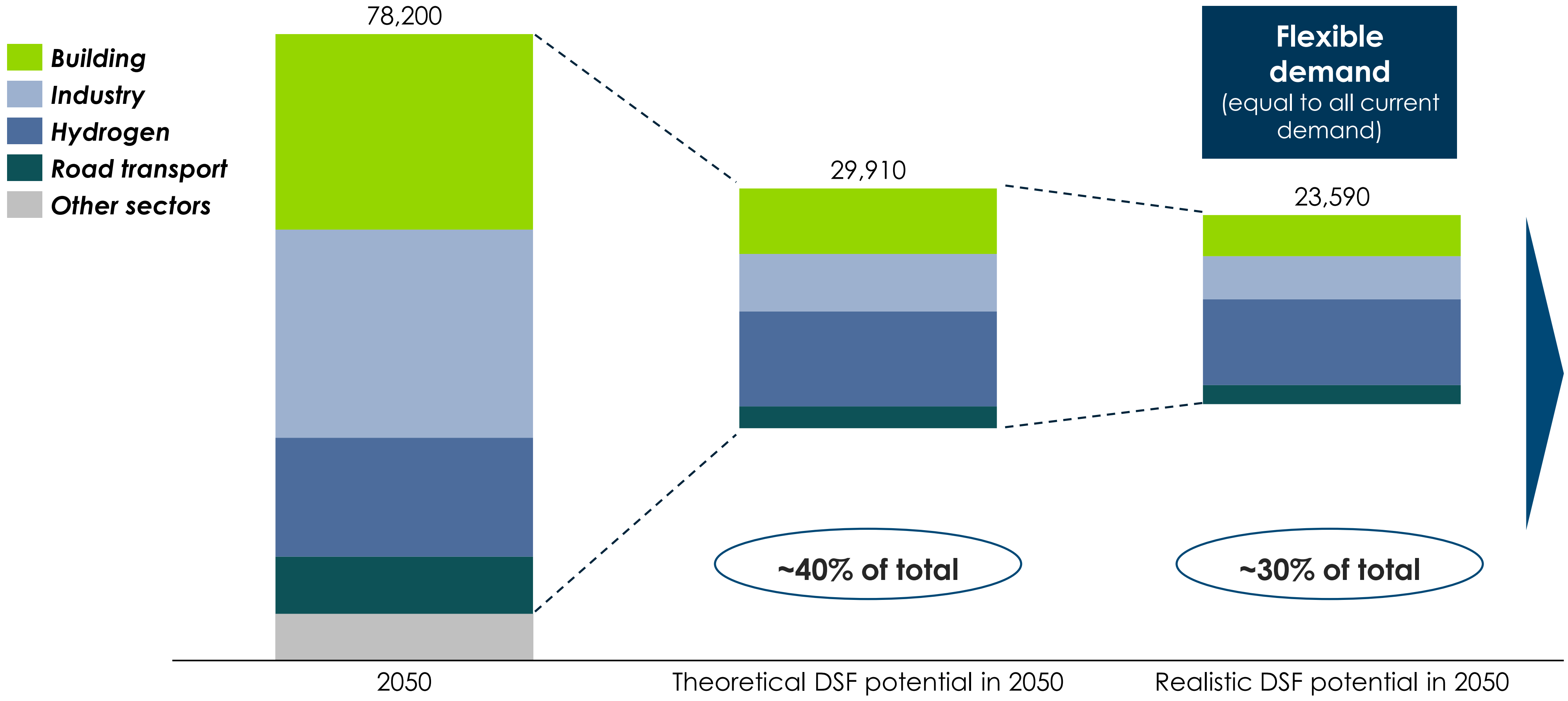
ETC assessment points to key techs at given durations/sizes



A third of overall electricity demand in 2050 could be flexible, hinging on the adoption of storage, smart charging, green H2 and behaviour change

Global electricity demand and DSF potential, 2050

TWh



Demand side flexibility ***has potential to meet important share of daily balancing challenge in a highly electrified system****; however, relies on significant barriers being overcome*

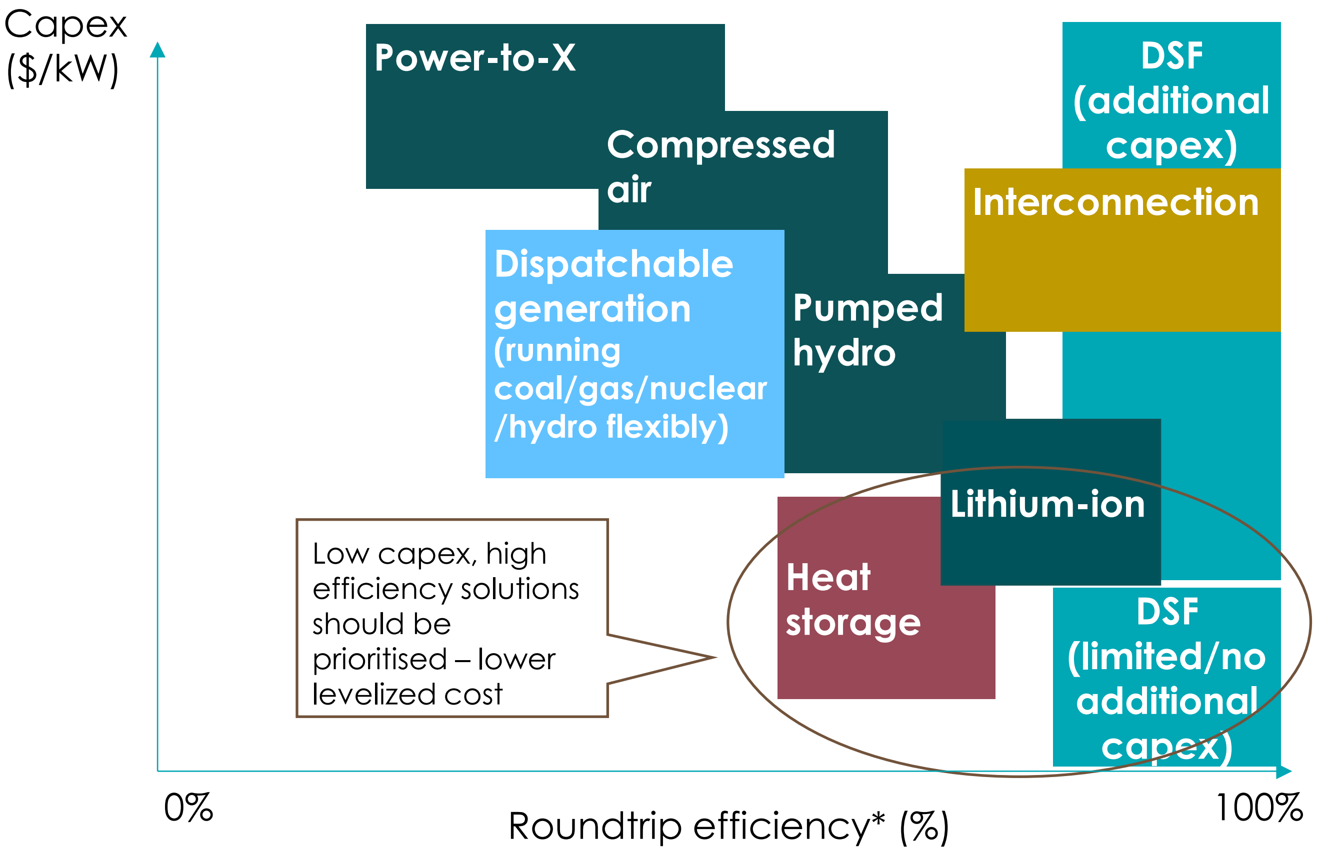
Demand side flexibility options range from no/low additional capex, to higher capex

	Solutions	Details	Capex considerations
Demand side flexibility (limited/no additional capex)	**Pre-heating / pre-cooling**	Cooling/heating capacity can **be stored in a building's thermal mass,** discharged during the peak demand period	**No additional capex** required – simply involves turning on heating/cooling earlier
	Smart appliances	Appliances like washing machines or dishwashers that automatically operate at optimal times	Most modern smart appliances **come equipped** with shifting capabilities
	EV smart charging	**Shifting charging load** to optimal times	**Smart wall box** is often provided with the vehicle or charging system
	Shifting data centre demand geographically	**Moving computing tasks** across data centres to optimal times	**Software-based** solutions
Demand side flexibility (additional capex)	**Water tanks in homes**	**Storing heated** water during off-peak hours to be used during peak times	**Moderate investment** for installation of thermal storage systems
	Industrial load management (e.g. for aluminium electrolysis)	Automatically **controlling industrial processes** based on grid signals	**Requires high investment** in automated control systems and infrastructure

Increasing capex ↓

Daily balancing: given option set available, low capex, high efficiency solutions should be prioritised

Illustrative view of selected balancing routes



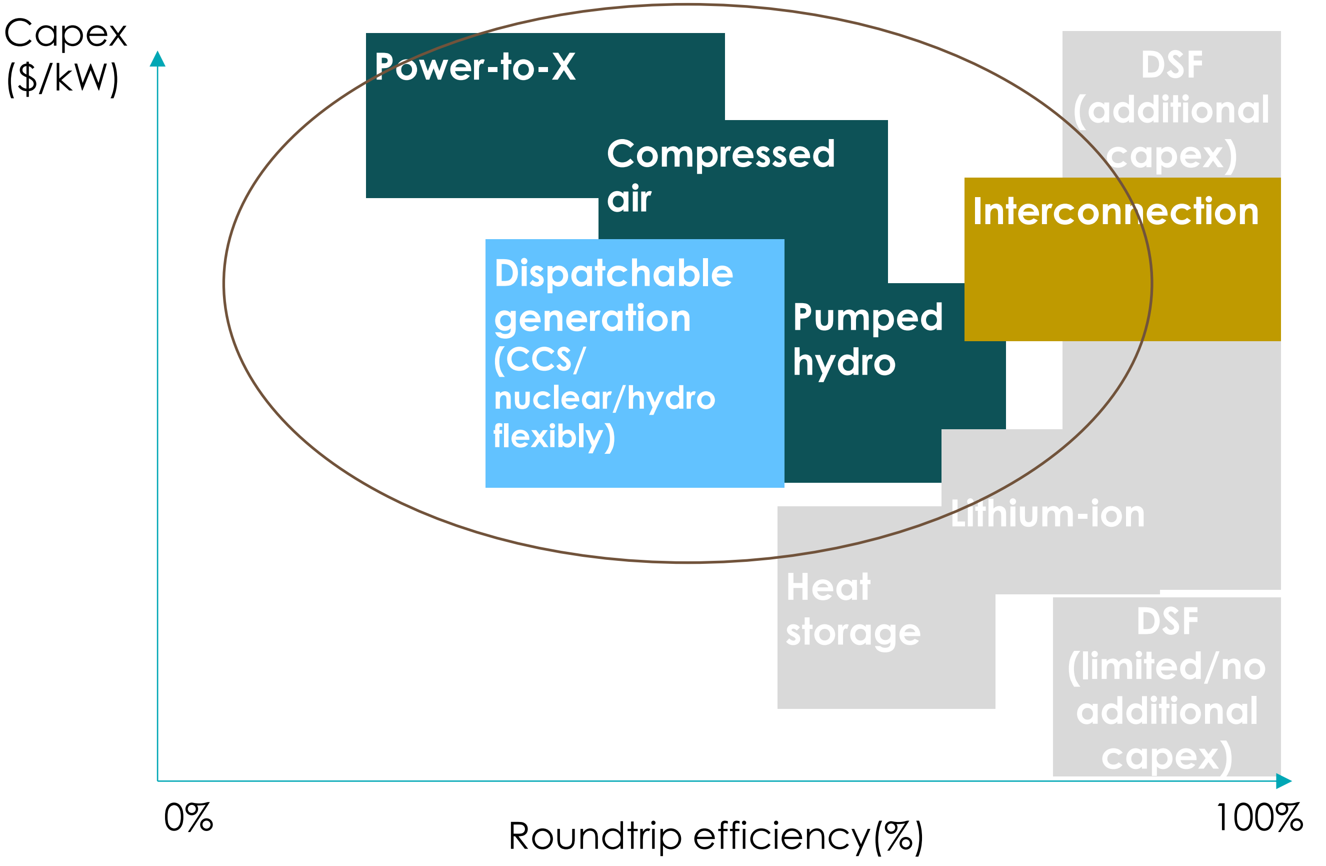
Capex & efficiency key determinants for 'levelised cost'

- **Storage and demand-side flexibility** should both play a role in meeting daily balancing
- While some demand-side flex is lowest cost, **some required level of behaviour change could pose a barrier** to maximise deployment

Note: Efficiency is irrelevant for DSF

Medium, long duration balancing: reduced option set to meet these needs

Illustrative view of selected balancing routes



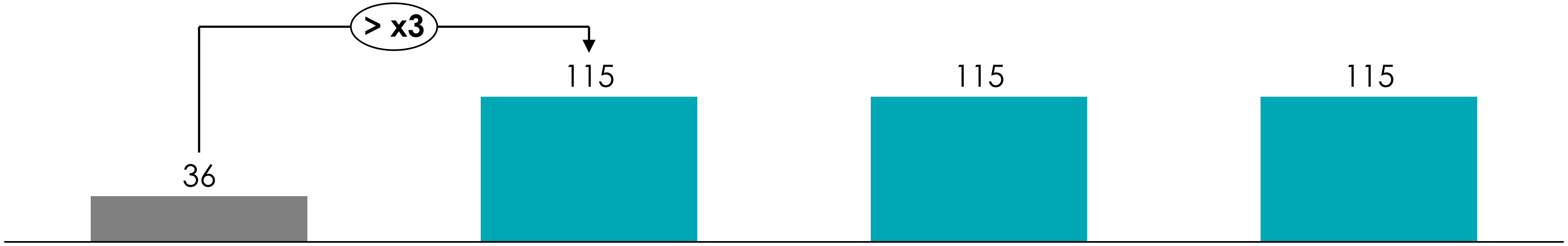
Capex & efficiency key determinants for 'levelised cost'

- **Significant technology development and innovation around medium-duration storage** which will determine cost pathways
- **For long-duration storage** (e.g. to meet security of supply needs), **only Power-to-X with storage** (e.g. H2 stored and then burned in CCGTs**) or dispatchable generation** will be able to meet duration needs

In 2050 in the UK, meeting long duration balancing peak will require ultra-low utilization assets; portfolio of options likely required

Capacity today vs capacity required in to fully meet max peak of long-duration balancing

GW



	Gas capacity in UK in 2024	H2-ready CCGTs	Gas CCGTs with CCS	Unabated gas CCGTs
Annual TWH of generation	101	15	15	15
Annual hours running	2,800	136	136	136

Cost vs emissions trade off for "last mile" decarbonization

Additional annual cost for UK households (on typical household bill of $2000/year)	n/a	~ $ 95	~ $ 120	~ $ 40
Annual emissions ($MtCO_2e$)	~19 $MtCO_2e$	~ 0 $MtCO_2e$	~ 0 $MtCO_2e$	3 $MtCO_2e$

* New build cost is lower due to higher utilization factor. Note: Annual capacity factors based on assumption that total TWh annually generated from CCGTs is 26 TWh. Emissions intensity of unabated gas assumed to be 0.1829 kg CO_2e per kWh. LCOEs assume $3/kg cost of hydrogen and 1000 $/kw cost of plant, 20 years lifetime. Household costs based on 26 TWh of generation and 30 million households. Systemiq analysis for the ETC (2024).

Summary conclusions

- **New electricity loads have peak consumption patterns through days and seasons** which impact balancing. Taken together with **wind and solar generation profiles,** this highlights the need to **manage the balancing challenge as we progress to zero (or near zero) carbon power systems.**

- The **system balancing challenge which varies by geography.** Tropical countries have primarily a diurnal balancing challenge, while Northern Latitude countries require longer duration balancing routes.

- For short duration balancing, **key options include lithium-ion batteries, demand-side flexibility, and storage via electrified heat provision** (where applicable). **Batteries and demand-side flexibility**, which can be free and 100% efficient**, also critically important in lowering system costs in all archetypes. A key consideration will be reliability of demand-side action.**

- **To meet long duration balancing where needed, could require building more new gas turbine capacity than exists today, though at much lower utilisation.** Meeting this challenge requires a portfolio of options (e.g. CCS, H2, likely marginal role for unabated gas – if properly ringfenced to ultra-low utilisation).

Key enablers required to deploy solutions for balancing the system

Strategic vision, with clear deployment targets

Market design

- Need **to incentivise energy storage / capacity / kWh at specific hours** of need; market and contract mechanisms missing, including for low-utilisation long duration storage options where required
- **Evolution of electricity price mechanisms** – both at wholesale level (e.g. to provide locational signals and time granularity to help optimise power flows) and at consumer level (e.g. time-of-use to incentivise demand response
- **Need to incentivise procurement of flexibility** from network operators, via flexibility markets

Grid regulation

- **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** – some action required to fully maximise opportunities in demand side flexibility