Energy
Transitions
Commission

# Demand side flexibility

October 2024

# Agenda

- **Introduction: Power workstream context**

- **Section 1: Demand side flexibility: key concepts and current landscape**

- **Section 2: Understanding the potential for demand-side flexibility: deep dives**
  - Buildings
  - Industry
  - Transport

- **Conclusions**

# Workshops

Briefing note published in September 2024

| | |
|---|---|
| **Grid build challenge** | March 26th |
| **Key technologies to balance the system：** *dispatchable generation, energy storage, heat storage* | June 18th |
| **Key technologies to balance the system：** *demand side flexibility* | Oct 9th |
| **Sizing balancing needs across key regions & role of interconnectors** | Oct 24th |
| **Key enablers** | End 2024 |

# Introduction

# Power workstream context

# Two fundamental & interrelated key areas for power systems which the ETC is looking at this year

**ETC key areas this year:**

**The two key areas translate into the following focus domains of analysis:**

**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*

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

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

**Balancing the system via storage, flexibility & generation technologies**

# Demand side flexibility can help solve two sets of challenges

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

**Balancing the system via storage, flexibility & generation technologies**

**Building and optimising grids**

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

**Demand side flexibility**

Can shift demand in line to periods of high wind/solar generation, and/or away from low wind/solar generation, **reducing "peak" generation capacity** needed

*National*

Can **reduce "peak" grid capacity** needed, reducing local network & infrastructure capacity needed

*Local*

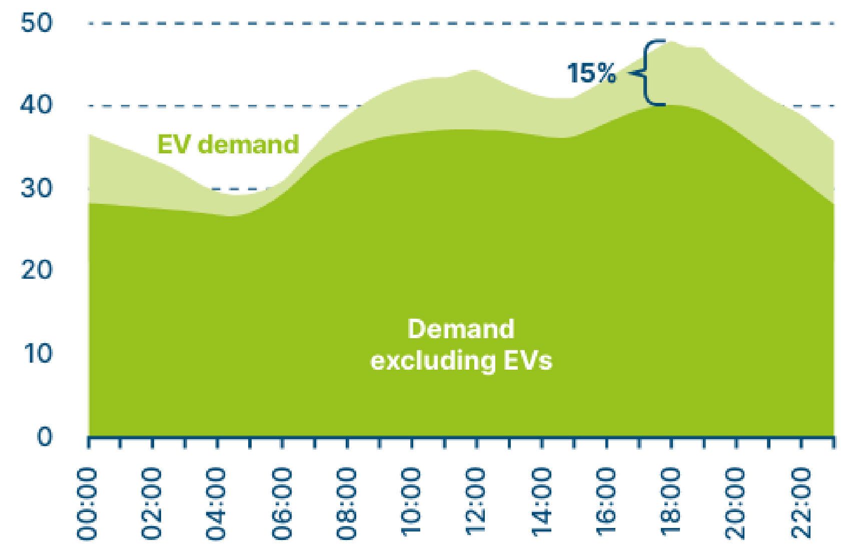
By offsetting new capacity needs **demand-side flexibility could avoid new investments & deliver system savings**

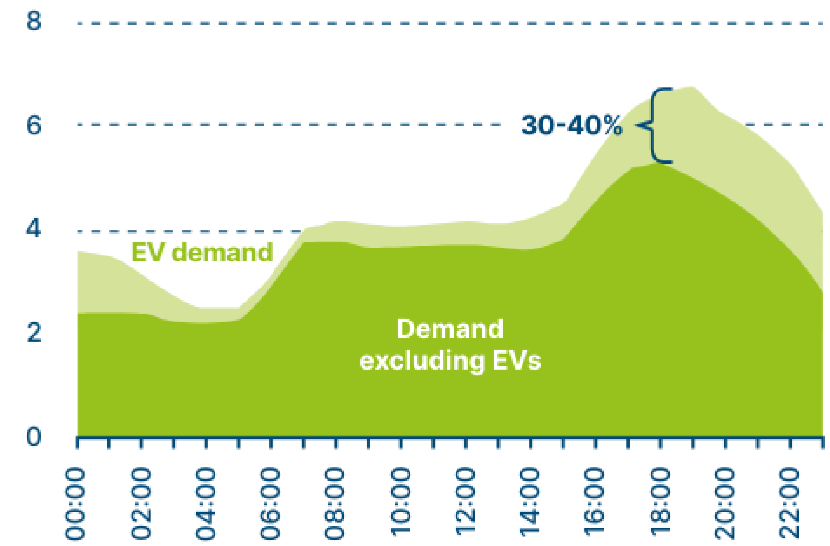
Dx – Spreading peak load to increase grid utilisation & balance the system

# Demand side flexibility can help to address local balancing challenges

## Peak demand at local level could be double that of national level, due to highly localised EV adoption

Illustrative examples


EV impact on U.K. national power demand at 50% EV adoption
GW


EV impact on typical 11kW feeder in the U.K., with 50% of houses owning an EV
GW

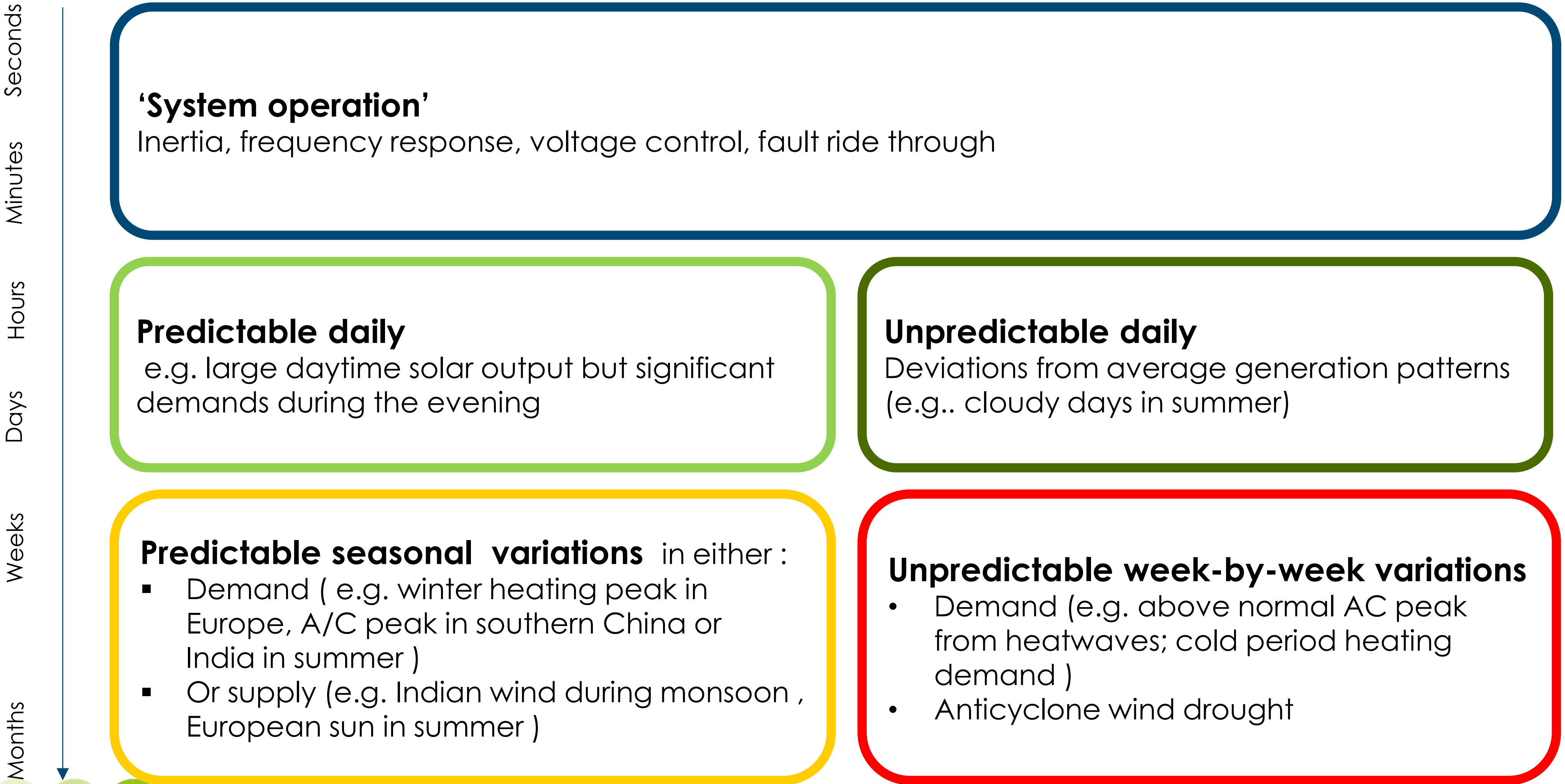
*Peaks will need to be mitigated through better power flow management solutions, including:*

- ***Demand-side flexibility**, to reduce the max grid capacity build required*
- ***More efficient grid flows**, e.g. via digitalisation to improve monitoring and reduce excess spare capacity*
- ***Greater energy storage**, to reduce the max grid capacity build required*

Notes: EV charging curve = combination of passenger and commercial EVs. Winter day. Assumes all EVs are BEVs charging at 7kW. Source: BNEF (2020), Sector Coupling in Europe: Powering Decarbonisation

# Reminder: different aspects of the 'balancing' challenge

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



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

**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

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

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

# Achieving balance: options to meet different challenges

| | | | | System operation | Predictable Daily | Unpredictable Daily | Seasonal | Unpredictable week by week |
|---|---|---|---|---|---|---|---|---|
| | **Dispatchable generation** | **Other zero carbon** | Hydro, nuclear[1] | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | **Fossil** | Fossil (or bioenergy) + CCS | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | | Fossil – low/very low utilisation | ✓ | ✓ | ✓ | ✓ | ✓ |
| | **Interconnection** | | 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. H2)[4] | ✓ | ✓ | ✓ | ✓ | ✓ |
| | **Heat storage** | | Heat battery | | ✓ | ✓ | | |
| ***Focus*** | **Demand side flexibility / Demand side response** | | EV (smart charging, V2G) | | ✓ | ✓ | | |
| | | | Heating load[5] | | ✓ | ✓ | | |
| | | | Industrial load[6] | | ✓ | ✓ | ✓ | |

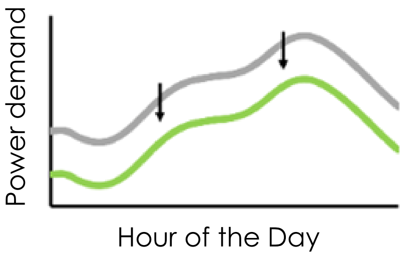
Notes: 1. Limited nuclear capacity for flexible ramping. 2. Li-ion storage is utility-scale and behind-the-meter. 3. Emerging tech night include gravitational storage and molten sands storage. 4. Examples of Power-to-X include the production of H2 from electrolysis and re-conversion of hydrogen in power 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*

# Section 1

# Demand side flexibility: key concepts and current landscape

# Several key demand side flexibility (DSF) strategies

## Efficiency



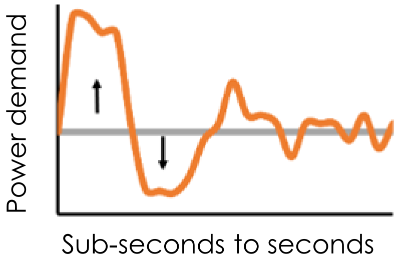
**Definition**

- The ongoing **reduction in energy use** while providing the same or improved level of function

**Use type**

- **Manual**: Replacing old appliances new models
- **Automatic**: Building management systems optimizing energy use

## Modulate



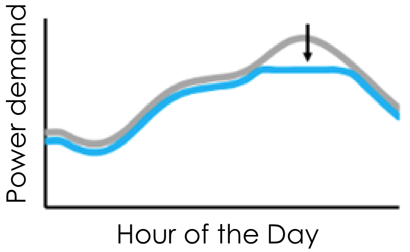
**Definition**

- 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

**Use type**

- **Manual**: Adjusting thermostat to reduce heating during peak
- **Automatic**: Fridges adjusting compressor cycles to off-peak

## Load shed



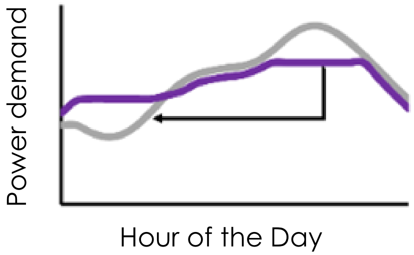
**Definition**

- 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

**Use type**

- **Manual**: Turning off lights during peak times
- **Automatic**: Smart plugs cutting power to non-essential devices

## Load shift



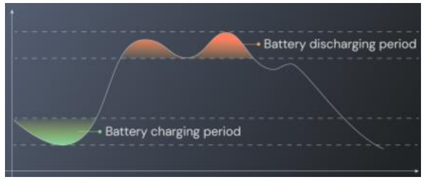
**Definition**

- 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

**Use type**

- **Manual**: Running washers at late night instead of during peak times
- **Automatic**: schedule EV to charge in off-peak

## Distributed storage



**Definition**

- 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

**Use type**

- Home batteries
- Thermal energy storage

***Changes to demand for grid electricity and to customer behaviour*** (Modulate, Load shed, Load shift)

***Change to demand for grid electricity but not to customer behaviour*** (Distributed storage)

**Covered in other ETC work (Buildings)** (Efficiency)

**Key focus of this work** (Modulate to Distributed storage)

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

# Examples of use cases

| | | Key category |
|---|---|---|
| **Buildings** | **Delaying or advancing the start of wet appliances** (dishwashers, washing machine, dryers) | *Load shifting* |
| | Via **thermal inertia/buffer**, using **pre-heating** to **draw from the grid at optimal times** | *Load shifting* |
| | **Home battery** to charge/discharge at optimal times | *Distributed storage* |
| **Industry** | **Running an electrolyser flexibly** at optimal times | *Load shifting* |
| | For industrial heat, using technology which **combines heat provision & electricity storage to draw from the grid at optimal times** | *Load shifting / distributed storage* |
| | **Modulating consumption of electricity for aluminium smelting** | *Load shifting* |
| **Transport** | **Smart charging** an EV at optimal times (e.g. at night) | *Load shifting* |
| | Using an **EV battery to supply electricity back to the grid** (e.g. at peak times) | *Load shifting / distributed storage* |

# Load shed & shift: scaling the opportunity requires automated route

## Manual

**Examples**

- Customer manually turns on appliance when electricity prices are lower(night) in locations when time-of-use tariffs
- Suppliers asking end users to turn up/down during grid stress events
- Contracts to industry end users for interruptible supply

***Can supply DSF, but at limited scale:***
*High human intervention*
*Savings likely to be more limited*

***Requires basic enabling capabilities*** *(e.g. some differentiated pricing structures)*

***Some behaviour change***

Manual and automated demand-side flexibility complement each other, maximizing flexibility potential when combined

## Automated

**Examples**

- Customers allows supplier to turn devices (e.g. appliances, EV charging) on/off via permissions to automatically adjust consumption

***Could supply DSF at more extended scale***
*Low human intervention*
*Savings could be (marginally) higher*

***Requires a vaster set of enabling capabilities*** *to scale (e.g. some differentiated pricing structures, software & hardware)*

***Some behaviour change***

# Distributed storage: opportunity to scale flexibility given limited impact on behaviour change

**Distributed storage**

**Examples**

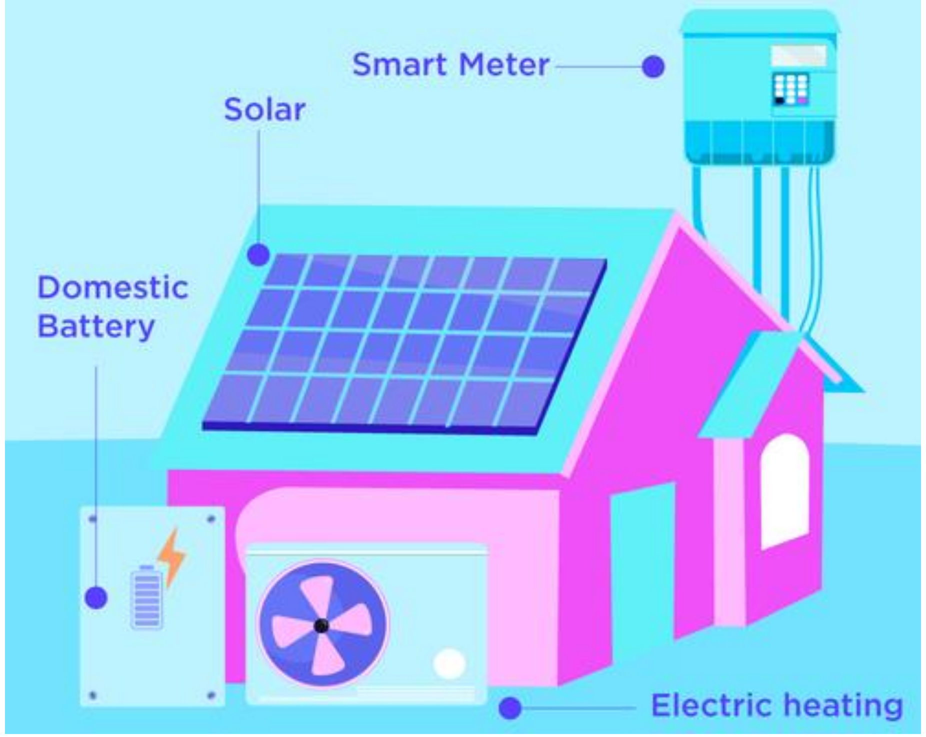
- Residential or industrial customers with a behind-the-meter battery can use that to charge/discharge at optimal times and provide low-cost power to avoid use at peak times

***Could supply DSF at more extended scale***
*Low human intervention*
*Savings could be substantial, but higher upfront Capex*

***Requires a vaster set of enabling capabilities*** *to scale (e.g. some differentiated pricing structures, typically software & hardware)*

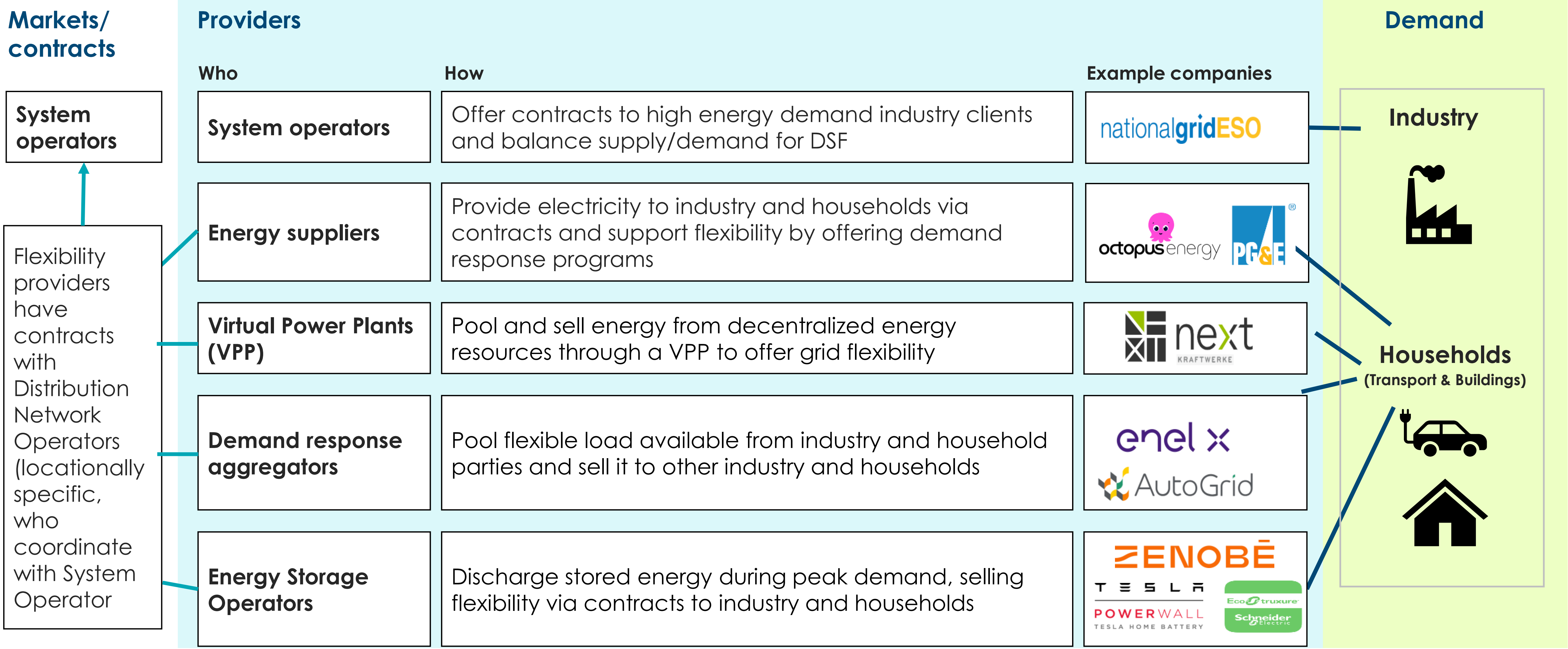
***No behaviour change***

**Household example with distributed storage and generation**



**Increasing opportunities driven by falling costs of solar and batteries**

# Several providers for demand side flexibility



**Markets/ contracts**

**System operators**

Flexibility providers have contracts with Distribution Network Operators (locationally specific, who coordinate with System Operator

**Providers**

| Who | How | Example companies |
|---|---|---|
| **System operators** | Offer contracts to high energy demand industry clients and balance supply/demand for DSF | nationalgridESO |
| **Energy suppliers** | Provide electricity to industry and households via contracts and support flexibility by offering demand response programs | octopus energy<br>PG&E |
| **Virtual Power Plants (VPP)** | Pool and sell energy from decentralized energy resources through a VPP to offer grid flexibility | next Kraftwerke |
| **Demand response aggregators** | Pool flexible load available from industry and household parties and sell it to other industry and households | enel x<br>AutoGrid |
| **Energy Storage Operators** | Discharge stored energy during peak demand, selling flexibility via contracts to industry and households | ZENOBĒ<br>TESLA POWERWALL TESLA HOME BATTERY<br>EcoStruxure Schneider Electric |

**Demand**

**Industry**

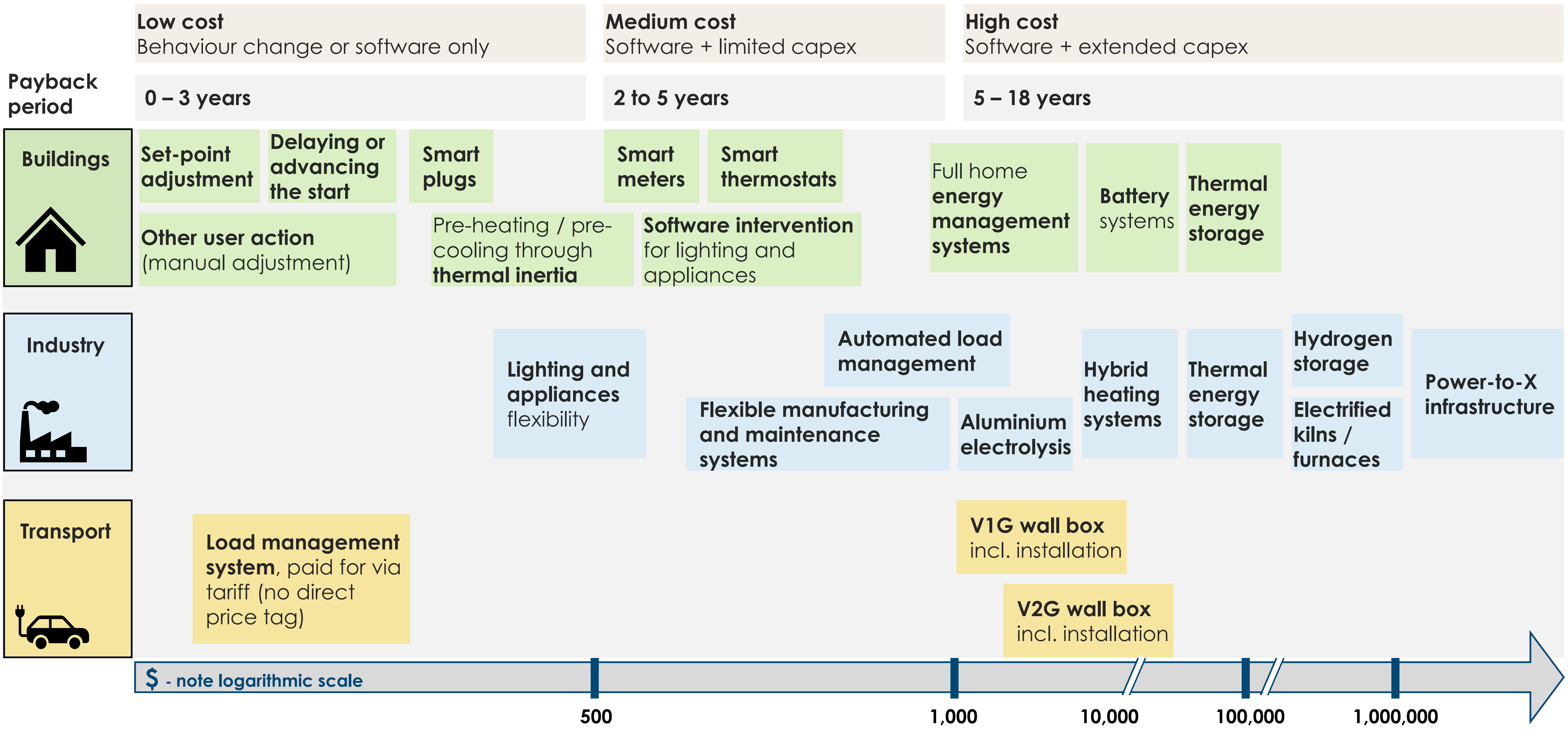
**Households**
**(Transport & Buildings)**

Source: Logos from respective company websites (2024)

# Key enabling capabilities required

| | |
|---|---|
| **Hardware and grid upgrades** | • **Smart meters** required to provide data on electricity flows/consumption levels (e.g. rollout of smart meters already regulated by EU law)<br>• **Dedicated asset metering** enabling accurate monitoring, control, and optimization of individual assets (e.g., EV, heat pumps, battery)<br>• **Specific hardware** is required to enable active management of electricity consumption, (e.g. via smart thermostats, smart plugs, smart substations distant-controlled, wall boxes for EV smart charging, energy storage including thermal energy storage and home battery)<br>• Significant electricity flows back into grid (e.g. from V2G, batteries) could require **physical grid upgrades** |
| **Software** | • **Grid communication and market software** enables interaction between grid operators and participants, managing price and bid signals for active market engagement; while **asset control software** for consumers/VPPs automates energy usage of assets (e.g., appliances, EVs) based on price signals and logic algorithms to optimize flexibility<br>• **Industrial EMS software**: tailored Energy Management Systems for automating factory processes, optimizing energy use, and leveraging flexibility based on dynamic pricing<br>• **AI and advanced modelling capabilities** enable real-time optimization, predictive analytics, and smarter decision-making |
| **Data exchange** | • Improved **data exchange and interoperability standards**, such as open access and common formats, ensure seamless communication between diverse energy assets and systems (e.g. EMS, dynamic operating envelopes), enabling efficient, scalable, & coordinated DSF |
| **Pricing structures** | • **Differentiated pricing structures** (time of use tariffs) are **important to provide incentives** for flexibility<br>• **Supplier exposure to granular wholesale prices** (to reflect what the system needs) |
| **Cost** | • **Financial considerations**; level of savings will vary; may be relatively small for consumers but larger for industry players; key enabler will be bundling with other benefits (e.g. efficiency); levels of upfront investments / paybacks will vary by use case<br>• **Clearly revealed value** to consumers through transparent billing, mobile apps, and personalized reports |
| **Market reform** | • **DSO reform** needed both in terms of expanding flexibility procurement on their part, as well as simplifying export licenses for V2G<br>• DSF players need to scale up **general administrative capabilities**, such as contract management, compliance with regulatory frameworks, and customer engagement |
| **Behaviour change** | • Load shifting and shedding will require some **adjustment to consumption patterns** (e.g. forgoing consumption at a given moment, temperature adjustments), while distributed storage / heat storage wouldn't affect this<br>• Increasing **trust** in supplier/flex provider to automate flexibility (e.g. data security concerns)and provide best tariff |

# Upfront costs range across use cases



**Low cost**
Behaviour change or software only

**Medium cost**
Software + limited capex

**High cost**
Software + extended capex

**Payback period**

**0 – 3 years**

**2 to 5 years**

**5 – 18 years**

**Buildings**

**Set-point adjustment**

**Delaying or advancing the start**

**Smart plugs**

**Other user action** (manual adjustment)

Pre-heating / pre-cooling through **thermal inertia**

**Smart meters**

**Smart thermostats**

**Software intervention** for lighting and appliances

Full home **energy management systems**

**Battery** systems

**Thermal energy storage**

**Industry**

**Lighting and appliances** flexibility

**Automated load management**

**Flexible manufacturing and maintenance systems**

**Aluminium electrolysis**

**Hybrid heating systems**

**Thermal energy storage**

**Hydrogen storage**

**Electrified kilns / furnaces**

**Power-to-X infrastructure**

**Transport**

**Load management system**, paid for via tariff (no direct price tag)

**V1G wall box** incl. installation

**V2G wall box** incl. installation

**$ - note logarithmic scale**

**500**

**1,000**

**10,000**

**100,000**

**1,000,000**

Source: UK DBEIS (2023), *Energy Security Bill factsheet: Smart metering*; EnergySage (2023), *Payback with a home battery: What to expect*; Hive Power (2021), *Everything You Need To Know About V1G, V2H, V2B, V2G, And V2X*

# Understanding the potential for demand side flexibility: how much of total 2050 electricity demand could be flexible?

**Total potential**

All electricity load (TWh) in 2050 across sectors

**Theoretical potential**

All electricity load (TWh) that can **theoretically** be time-shifted, e.g. without disruption to living comfort, disruption to mobility need and disruption to industrial process

*Assessment of barriers (based on enabling capabilities)*

**Technology barriers** to deployment, such as the lack of standardized practices for implementing thermal energy storage in industrial heat applications

**Financial barriers** to deployment, such as high upfront costs and insufficient return on investment

**Policy barriers** to deployment, such as insufficient dynamic pricing structures that fail to incentivize flexible energy use

**Behaviour barriers** to deployment, such as resistance to change and limited adoption of new technologies in residential settings

**Realistic potential**

All electricity load (TWh) that can **actually** be time-shifted, e.g. where it can be delivered overcoming the four barriers

*(% reduction of theoretical potential based on barriers assessment)*

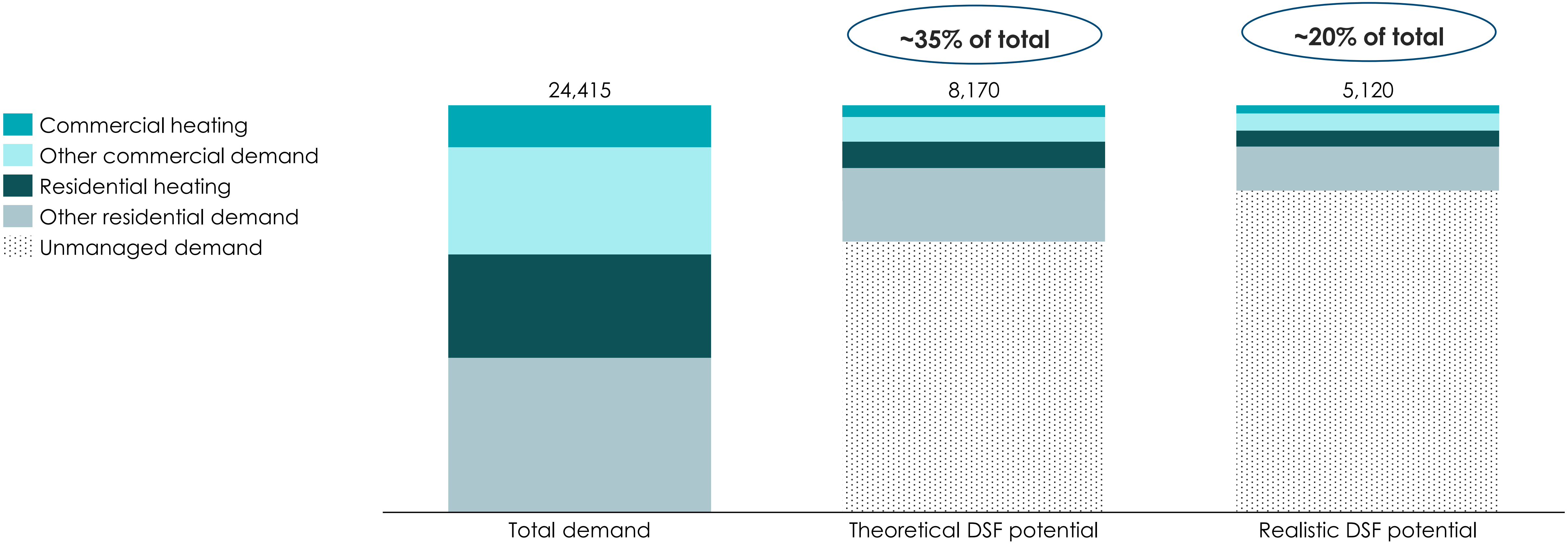
# Summary view: key potential for DSF in industry (industrial heat & hydrogen)

**Required** to scale and unlock full DSF potential

| | | **Buildings** | | **Industry** *Note: Level of electricity demand in 2050 more uncertain* | | | **Transport (passenger)** | |
|---|---|---|---|---|---|---|---|---|
| | | **Heating and cooling** | **Lighting and appliance** | **Electrified industrial heat (via heat storage)** | **Hydrogen** | **Other industry demand (e.g. mechanical)** | **Smart charging (V1G)** | **Smart charging (V2G)** |
| **Capabilities** | **Smart meter** | Required | | | | | | |
| | **Additional hardware** | Smart thermostats, thermal energy storage, batteries | Smart plugs or smart appliance | Thermal energy storage | Electrolysers; hydrogen storage | Dependent on specific processes | Wall box | |
| | **Software** | Required to connect user/supplier/grid operator | | | | | | |
| | **Grid upgrades** | Energy management systems required; Significant electricity flows back into grid (e.g. from V2G, batteries) may require physical upgrades | | | | | | |
| | **Pricing structures (e.g. time of use)** | Required | | | | | | |
| | **Cost** | Medium-low | Low | High | High-medium | Medium | Medium | |
| | **Behaviour change** | Adjustment to consumption patterns / temperature | Adjustment to consumption patterns | Limited, given storage route | Time shift electrolysis | Adjustment to consumption patterns | Adjustment to consumption patterns | |
| **Impact** | **Overall TWh in 2050** | 12,500 | 12,000 | 12,600 | 14,855 | 13,145 | 4,900 | |
| | **Overall realistic potential % share that can be flexible** | ◔ | ◔ | ◔ | ◕ | ◔ | ◑ | ◑ |
| | **Relevance of storage to provide enhanced flexibility (limited behaviour change)** | Medium (e.g. thermal and battery storage) | | High for electrified industrial heat (via heat storage) and hydrogen storage, otherwise none | | | High (vehicle battery provide flexibility) | |

Source: BloombergNEF (2024), New Energy Outlook 2024 NZS
Note: Grid enhancement upgrades physical infrastructure like cables, transformers, substations, and improves data exchange between supply and demand.

# Around 20% of building electricity demand can be flexible in 2050

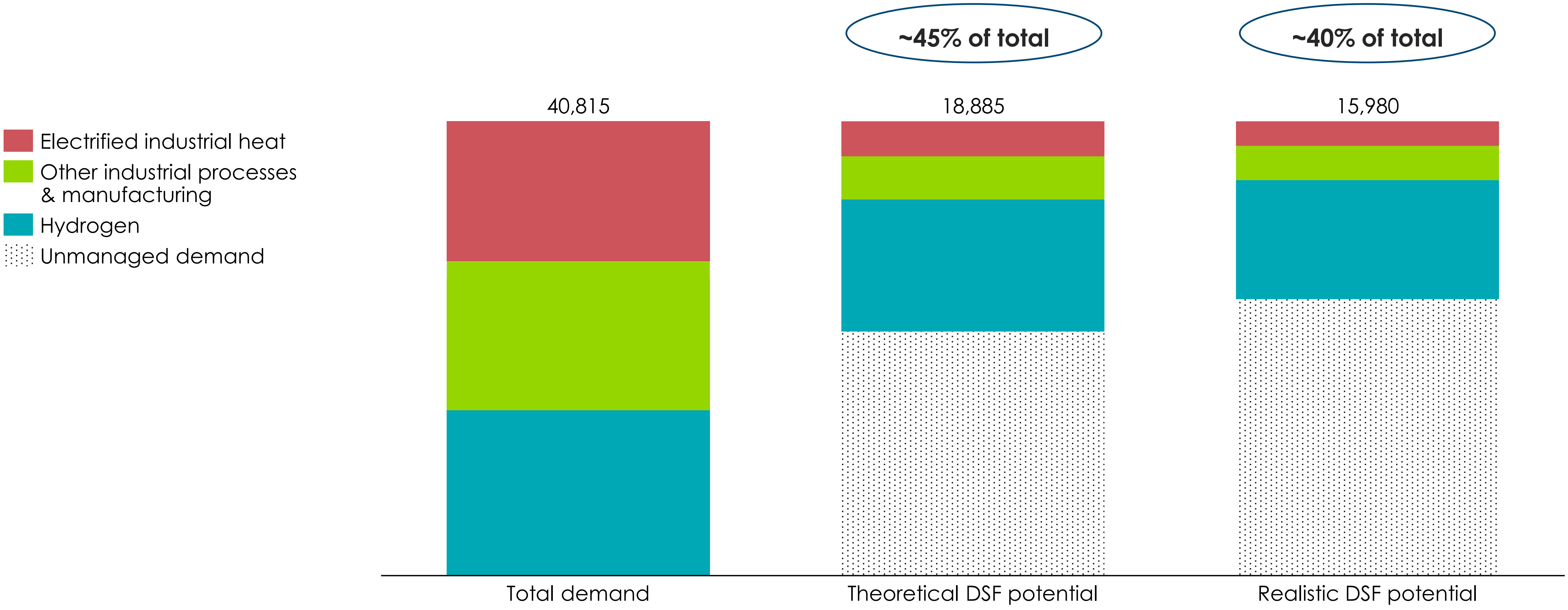


Source: Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Around 40% of industry electricity demand can be flexible in 2050

## Global electricity demand from industries and DSF potential, 2050

TWh

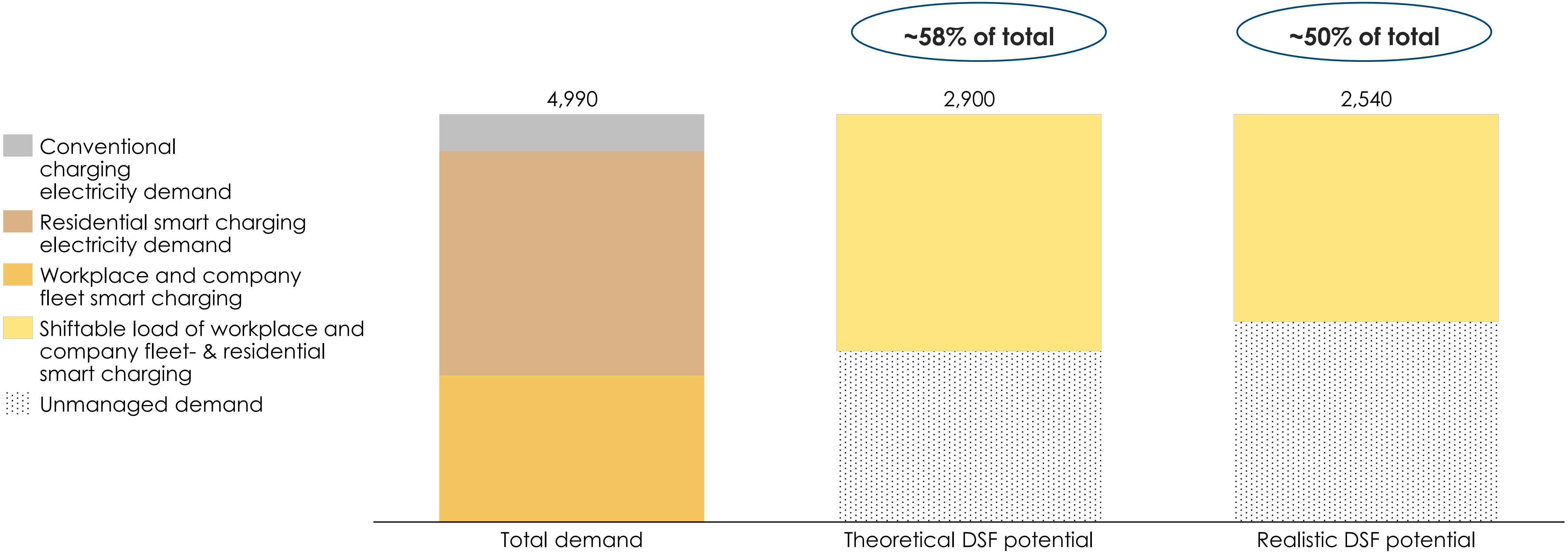


Source: Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# ~50% of passenger EV electricity demand (private and company passenger EV fleets) can be flexible in 2050

## Global electricity demand from passenger EV charging (private and company fleet EVs) and their DSF potential, 2050

TWh

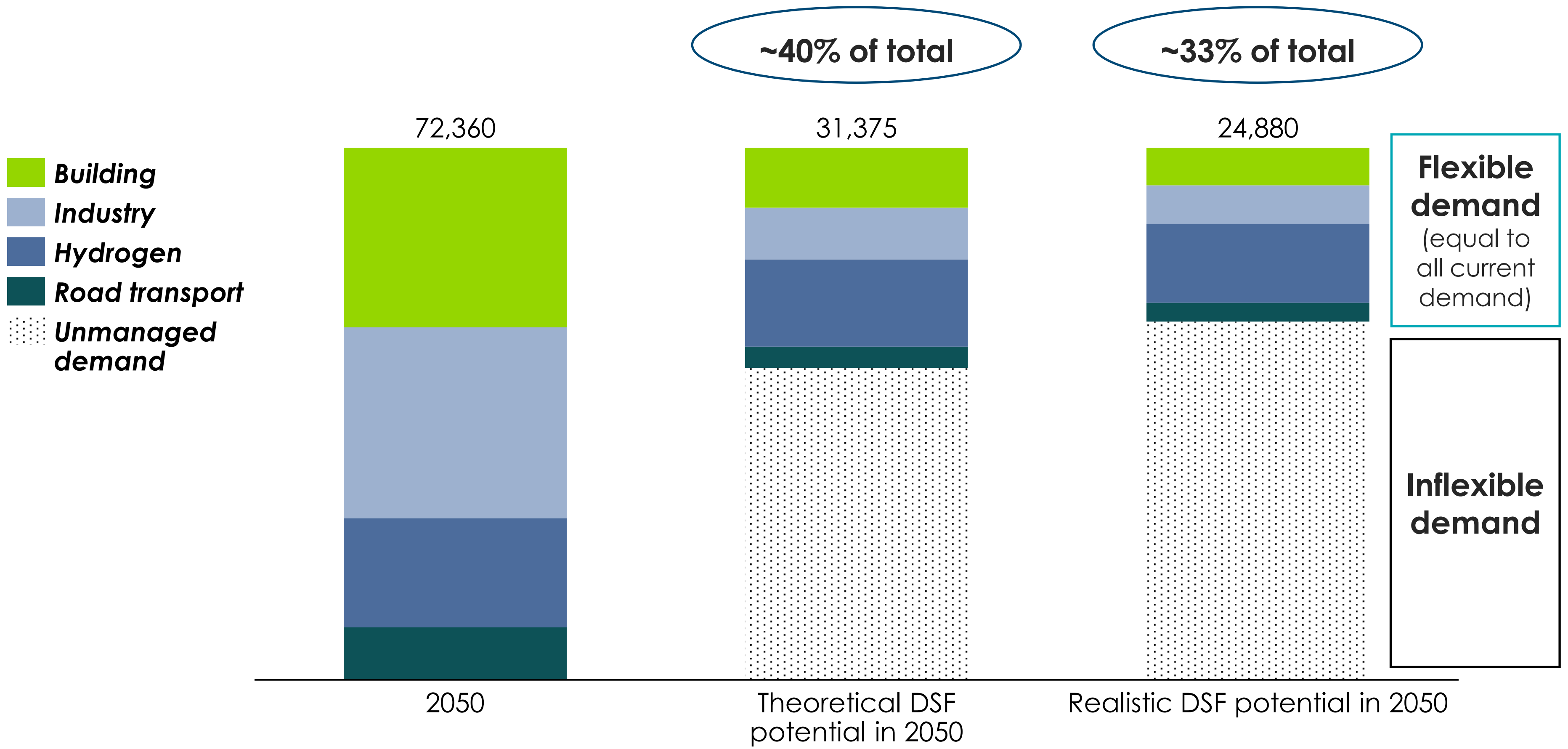


Source: Own analysis, based on data from BNEF (2024); *NEO*

# ~33% of total electricity demand in 2050 could be flexible on hourly basis

**Global electricity demand and DSF potential, 2050**

TWh



~40% of total

~33% of total

**Flexible demand** (equal to all current demand)

**Inflexible demand**

*Suggests that 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*

Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Storage provides several enhancements to overall flexibility

🟩 Examples

## Increase flexibility depth

- Decouples energy consumption from supply, **allowing load shifting** without immediate demand adjustments
- By storing energy during off-peak times, batteries **reduce the need for high-demand generation during peak periods**, lowering grid stress

Pre-heating homes with stored energy

## Avoid behaviour change

- Batteries enable **energy management without requiring changes** to user habits or comfort levels, and optimising charge/discharge based on grid signals.

Behind the meter batteries in homes

## Save costs

- Storage systems can take advantage of price differences between peak and off-peak times, maximizing cost savings

Industrial facilities stores low-cost electricity during off-peak

## Enhance resilience

- Batteries provide **backup power** during outages, adding reliability

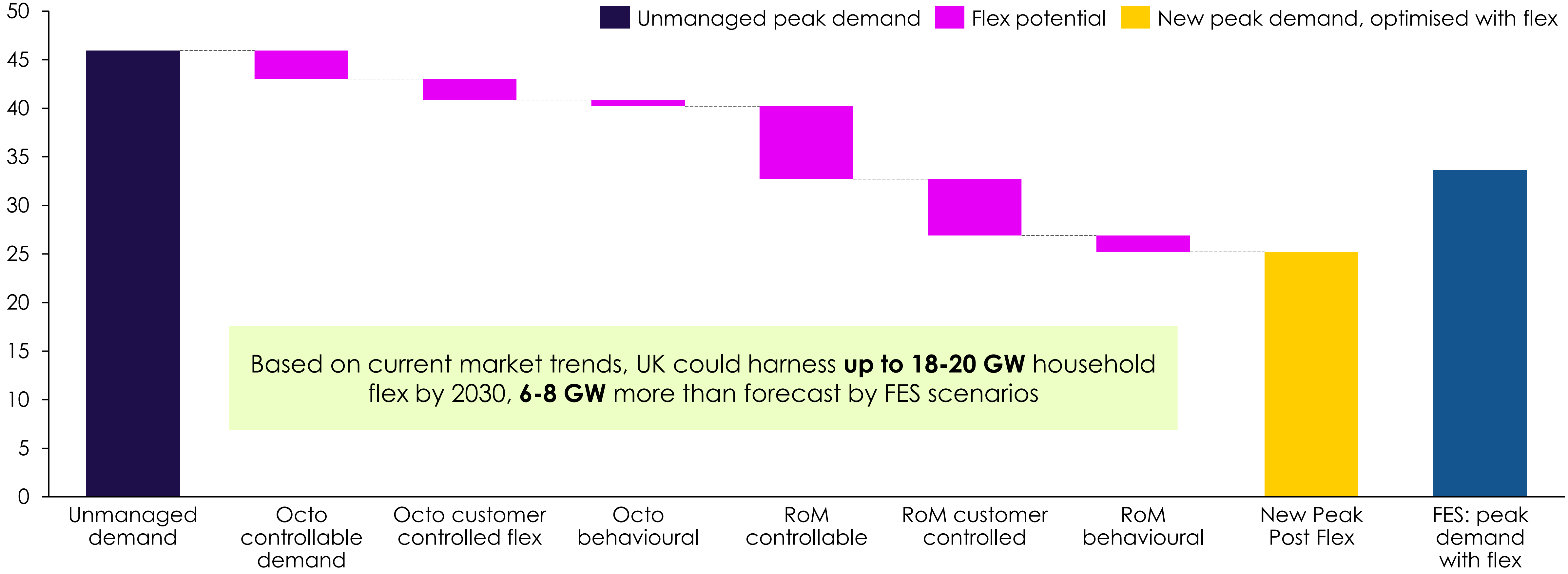
EVs can serve as backup generators during grid outages

# Octopus estimates for the UK show that ~45% of household demand could be flexible by 2030

octopus energy

## Household demand side flexibility potential, UK, 2030

GW at peak



Based on current market trends, UK could harness **up to 18-20 GW** household flex by 2030, **6-8 GW** more than forecast by FES scenarios

Unmanaged demand from FES 2023 leading the way scenario for 2030, with Octopus assumptions on what could be achieved if flexibility was properly incentivized across domestic demand and transport. £ Savings apply Cornwall Insight fex savings to Octopus scenario
Source: Octopus

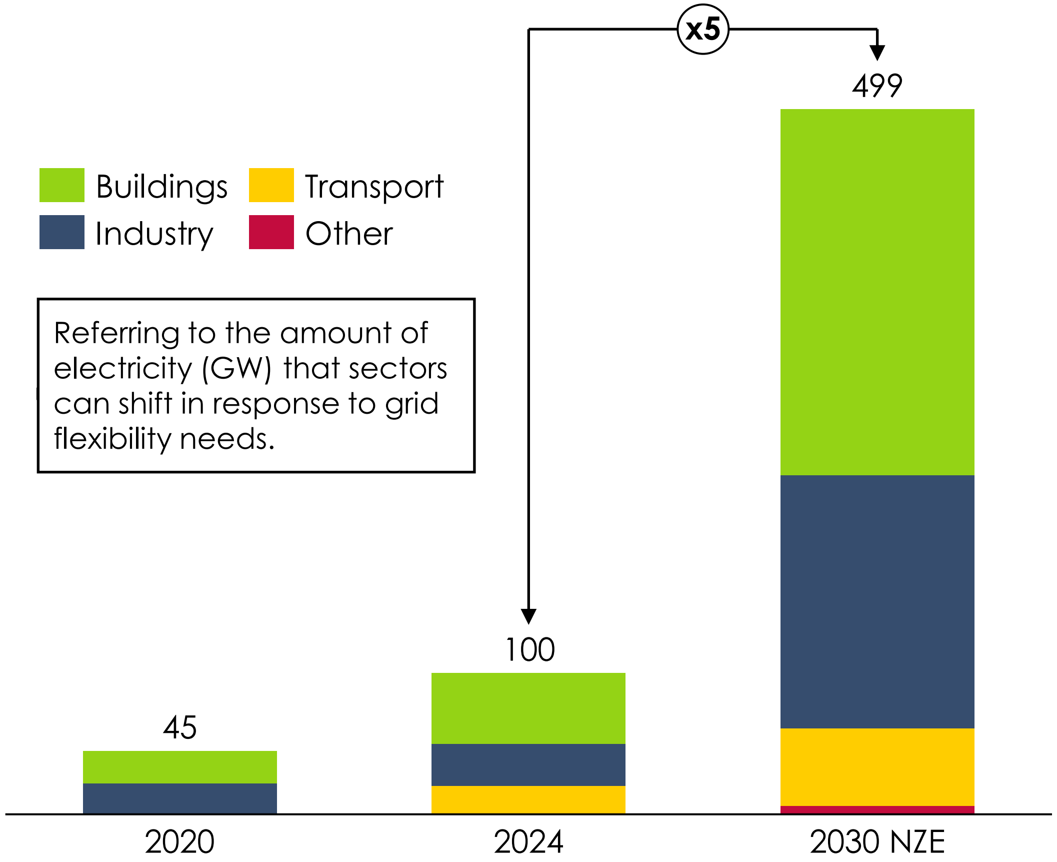
# Current landscape

# Where is DSF today? DSF capacity growth must increase significantly across sectors to meet 2030 flexibility targets

Global view

**DSF capacity in 2020 vs 2030 IEA NZE target**

GW, at times of greatest flexibility needs



Referring to the amount of electricity (GW) that sectors can shift in response to grid flexibility needs.

**To reach net-zero targets…**

**Buildings**

- Today: largest sector providing flexibility.
- Future: need 5x growth, remaining biggest sector contributor to DSF.

**Industry**

- Today: a significant flexibility contributor.
- Future: requires highest growth rate (x6) across sectors to reach flexibility target contribution.

**Transport**

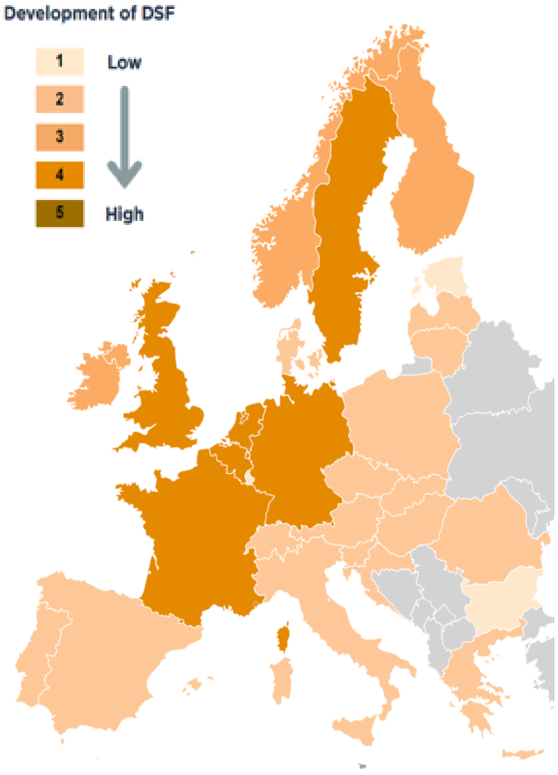
- Today: increasing significance to flexibility contribution.
- Future: steady growth required to fulfil expected DSF contribution.

Source: IEA (2023), *Demand Response;* IRENA (2023), *World Energy Transitions Outlook 2023;* Roland Berger (2023), *EV Charging Index Edition 4;* Smart Flags from Britannica (2024).
Note: 2020 and 2030 NZE data directly from IEA (2023), *Demand Response* data for 2024 from other sources. NZE is IEA Net Zero Scenario targets, 2020 base line.

# Where is DSF today? Recent flexibility progress varies, with successful countries leveraging a mix of policies, technology, pricing, and consumer incentives.

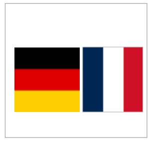
**European view**

## 1-5 Scoring of DSF expansion developments in Europe in 2023

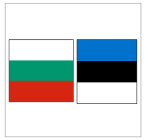



Rapid DSF growth is expected in Sweden and the Netherlands due to recent grid electricity tariff reform policies


The UK is leading in innovative pricing models and consumer awareness of DSF.


Germany and France's high recent investments in smart grid infrastructure and real-time information exchange expected to drive rapid DSF.


Spain and Greece ended pilot projects with no plans for continuation.


Regulatory barriers and low investments block DSF adoption in Bulgaria and Estonia.

## DSF implementation drivers

### ① Regulatory alignment and market access

Harmonized regulations, along with greater access for independent DSF service providers, for DSF across different regions.

### ② Integration of smart systems and advanced grid management

Rollout of smart meters, smart load management systems and flexible assets such as EVs, smart appliances, etc.

### ③ Tariffs and economic incentives

Further increase of electricity time-of-use tariffs and dynamic tariffs.

### ④ Consumer awareness

Increasing consumer awareness of cost savings and sustainability.

Source: LCP Delta & Smart Energy Europe (2024), *2023 Market Monitor for Demand Side Flexibility;* BNEF (2024), *Europe's Local Flexibility Markets: Aiding a Strained Grid.* Flags from Britannica (2024).

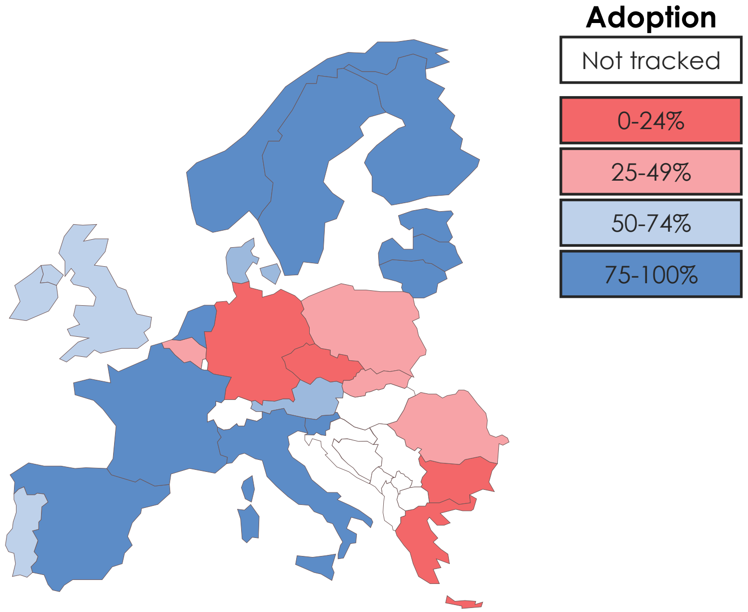
# Enabling technology: Smart meter rollout forms the basis for smart grids and are on good track in most regions of Europe, others need to speed up

**European view**

**Hardware**

## Smart meters market share

**Smart meters are essential for dynamic tariffs, providing real-time data on end user electricity consumption.**



**50-60% of metering points in Europe are smart** (residential, commercial and industry)

**Smart meters measure real-time energy usage,** allowing utilities and consumers to monitor and adjust consumption for unlocking instant flexibility.

**Driven by EU directives and national targets, many European countries, have recently achieved high smart meter adoption rates.**

**Increasing number of utility companies aim at reaching 100% smart meter deployment by 2030.**

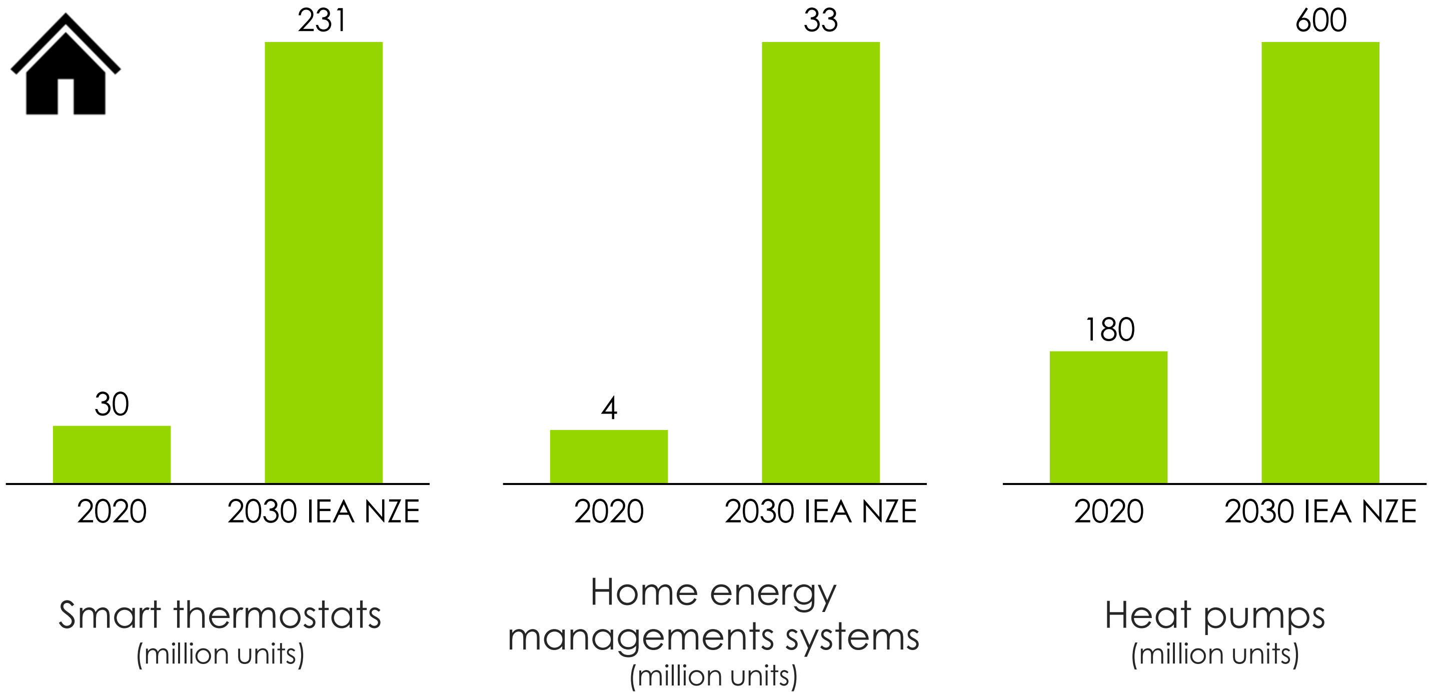
Source: IoT Analytics (2024), *Smart electricity meter market 2024: Global adoption landscape;* LCP Delta (2024), *Dynamic Tariffs An essential component of future electricity markets?* using data from NEMBS Tariff Database

# Enabling technology: deployment speed of key behind-the-meter technologies to unlock flexibility varies across buildings and transport

**Global view**

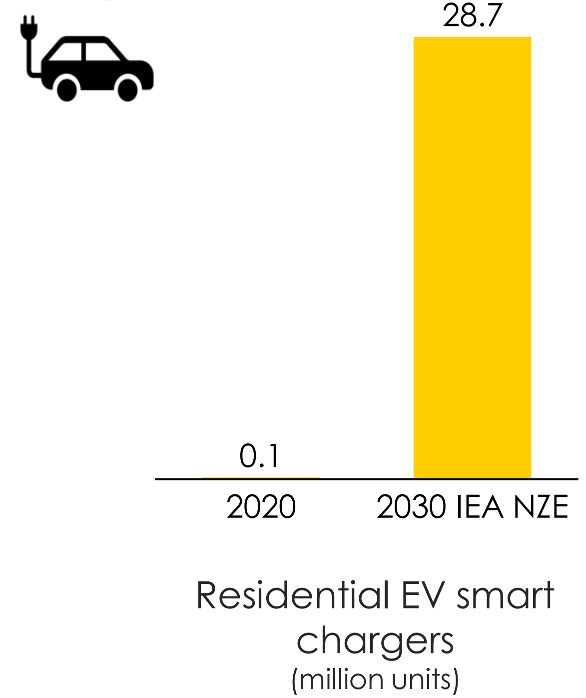
**Hardware**

**Buildings**



**Deployment of technology must grow significantly to reach 2030 targets.**

**Transport**



**Deployment of technology is behind 2030 targets.**

**These technologies serve as key indicators for understanding DSF deployment**

- Optimizing energy consumption
- Enabling load shifting
- Enhancing grid flexibility by allowing users to automatically adjust their electricity usage based on real-time demand

Source: IEA (2023), *Demand Response;* Flags from Britannica (2024).
Note: NZE is IEA Net Zero Scenario targets.

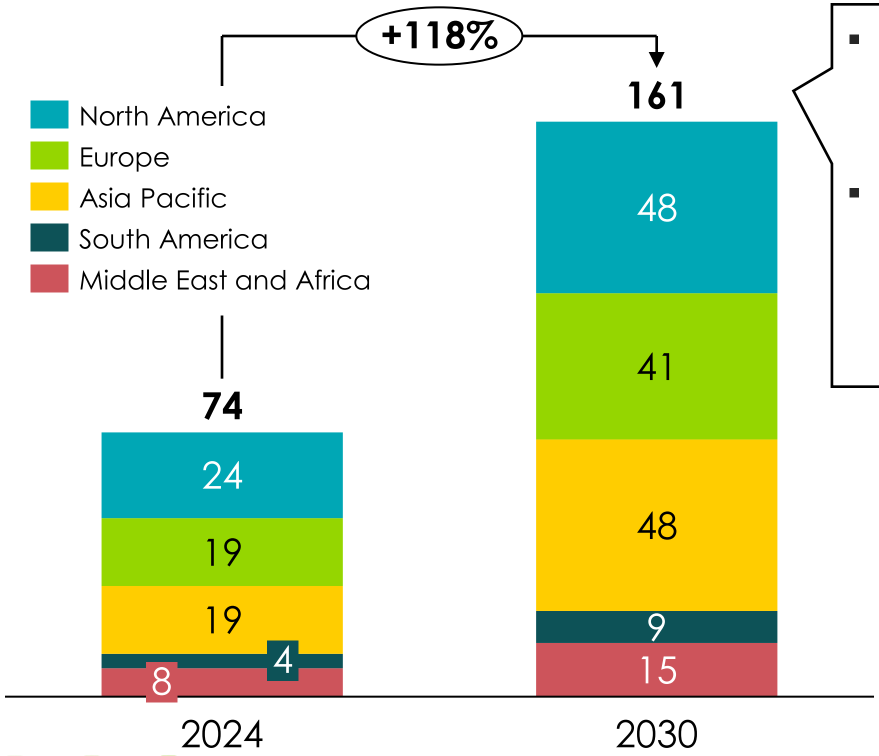
# Enabling technology: smart grids are a backbone of DSF, but unlocking their full flexibility potential requires substantial global investment in enabling technology

**Smart Grids:**

**Smart grids, through real-time data exchange, enable demand-side flexibility by allowing automated and dynamic adjustments** in consumption, optimizing energy use, and supporting grid stability during peak demand or supply fluctuations.

## Expected investments in smart grids in world regions

$ bn



- **$ 74 bn and 161 bn ≈ 20%** of total grid investments
- **IEA calls for *significant increase* of this share** for sufficient smart grid investments.

## Focus areas of smart grid investments and key smart grid technologies

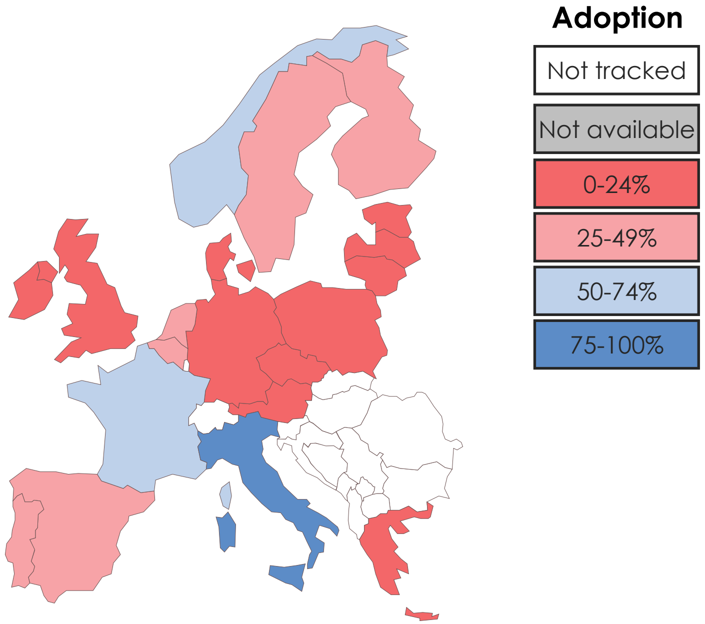
| | |
|---|---|
| **Grid automation** | Including deployment of Smart Energy Management Systems by grid operators, Dynamic Operating Envelopes |
| **Distributed Energy Sources integration** | Increasing role for Virtual Power Plants/aggregator functions |
| **Metering** | Faster rollout of Advanced Metering Infrastructure via Smart Meters |

Sources: Data from IMARC (2024), *Smart Grid Market Report by Component (Software, Hardware, Services)*; PowersystemsTechnology (2024), *Investing in Tomorrow's Power: Smart Grids Lead the Charge for a Sustainable Future*

# Time-varying pricing: time-of-use tariffs are unevenly implemented across Europe, and dynamic tariffs need even a faster rollout.

## Time-of-Use (TOU) tariffs

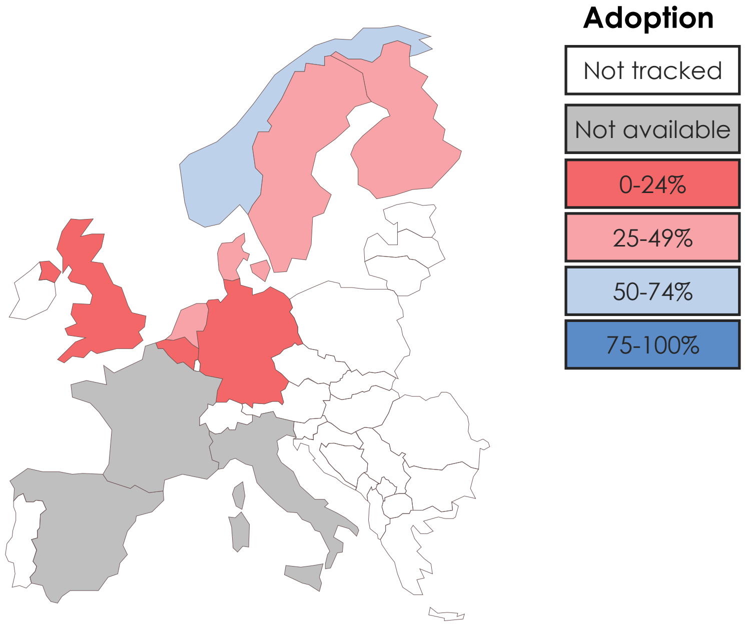
**Provide flexibility by offering different electricity rates during pre-determined off-peak and peak demand periods.**



**20-30% of tariffs in Europe are TOU**
(residential and commercial)

## Dynamic tariffs

**Provide further flexibility by offering electricity rates that adjust in real-time pricing based on supply and demand fluctuations during the day.**



**17% of tariffs in Europe are dynamic**
(residential and commercial)

**Time-varying tariffs incentivise private and industry electricity consumers** to use energy when it is cheaper.

**Dynamic tariffs are even more effective for DSF**, unlocking instant consumer reaction to shift electricity consumption from real-time supply/demand fluctuation.

**Between predetermined time-of-use and dynamic tariff rates, Critical Peak Pricing is growing from a niche model,** e.g. in France, notifying consumers a day ahead of increasing rates the following day.

**Key barriers for TOU and dynamic tariffs are insufficient regulatory pressure** on utilities to offer them to consumers and the **low consumer awareness** of their cost saving potential.

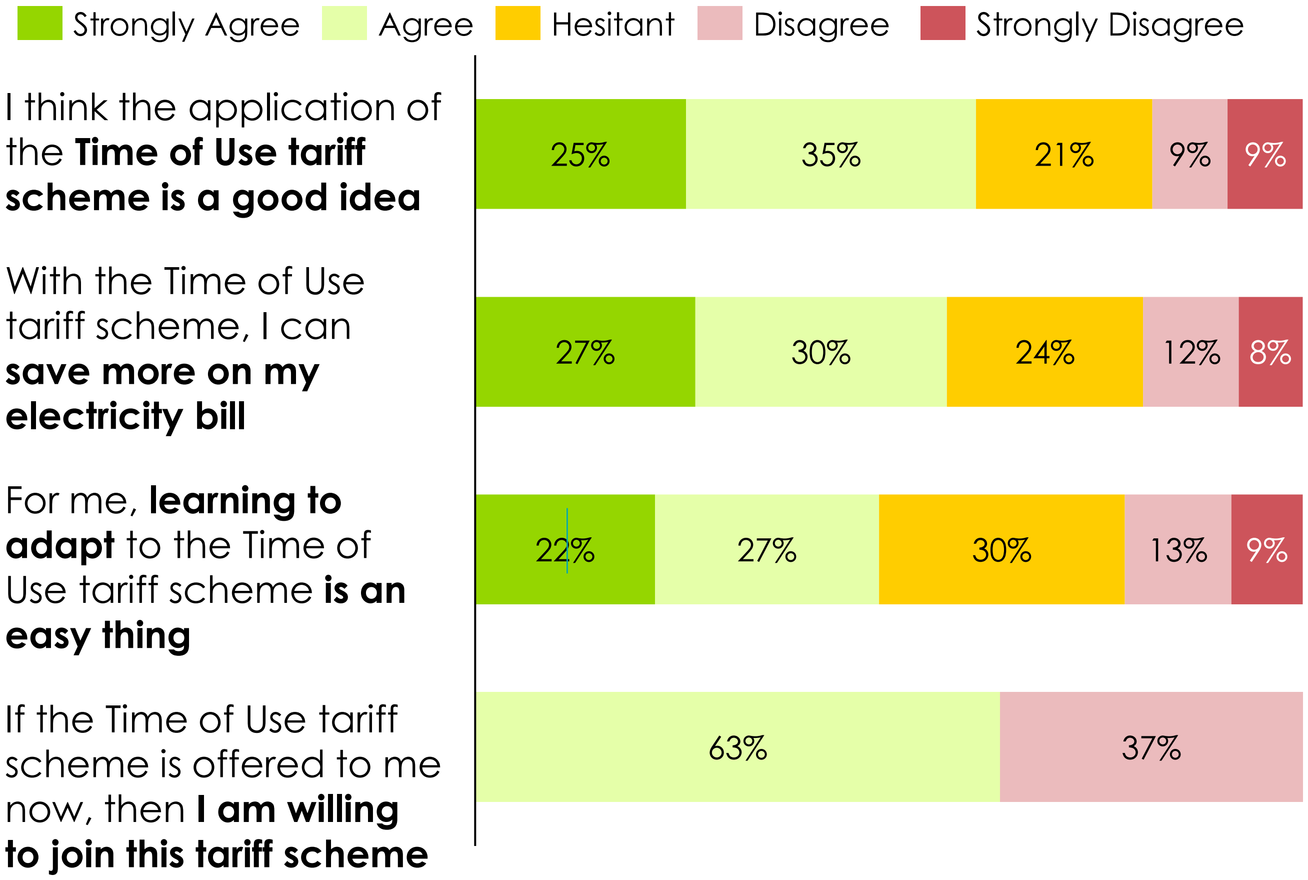
Sources: Enefirst (2024), *Using Time-of-Use Tariffs to engage customers and benefit the power system*; LCP Delta (2024), *Dynamic Tariffs – An essential component of future electricity markets.*

# Behavioural changes, domestic: customers are gaining awareness of the benefits of providing flexibility; participation is growing

Behaviour change

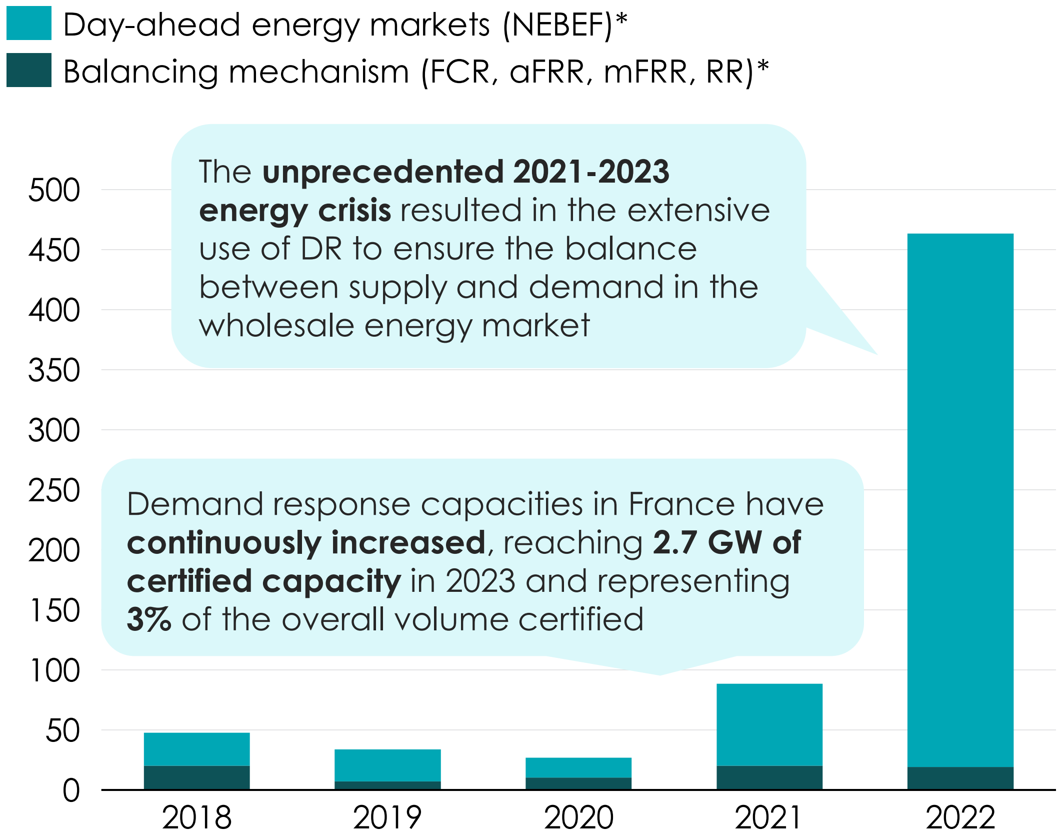
## Customer's attitude and response to dynamic pricing in Indonesia, 2024

% Share



## Historical French incentive-based demand-side participation (industrial & residential), 2015–2022

GWh



The **unprecedented 2021-2023 energy crisis** resulted in the extensive use of DR to ensure the balance between supply and demand in the wholesale energy market

Demand response capacities in France have **continuously increased**, reaching **2.7 GW of certified capacity** in 2023 and representing **3%** of the overall volume certified

*Note: Frequency Containment Reserve (FCR), automatic/manual Frequency Restoration Reserve (aFRR/mFRR), Replacement Reserve (RR)

Source; Yuniarto et al. (2024), *Customer's response to dynamic pricing in utility energy Tariff quality and reliability with the time of use: An Empirical case study of household electricity customers in Indonesia*; Cabot (2023), *Economic considerations on the demand-side of electricity markets in a context of energy transition*

# In France, explicit market integration of demand-side resources has been progressively implemented since the end of the 2010s

Behaviour change

| | NEBEF (The Block Exchange Notification of Demand Response) | FCR (Frequency Containment Reserve) | aFRR (automatic Frequency Restoration Reserve) | mFRR-RR (manual Frequency Restoration Reserve -Replacement Reserve) |
|---|---|---|---|---|
| Market | Energy | Balancing | Balancing | Balancing |
| Availability | Signal from the clearing operator | Automatic, frequency deviation | Continuous activation based on the N level | Signal from the TSO |
| Settlement | Market (day-ahead) or contractual basis | Annual and daily call for tenders | Daily call for tenders in D-1 | Daily prescription to obliged players or participation via secondary market |
| Remuneration | Marginal price | Marginal price | Marginal price | Marginal price 19 €/MWh, offer price |
| Note | Payment due to suppliers of curtailed demand | | | |

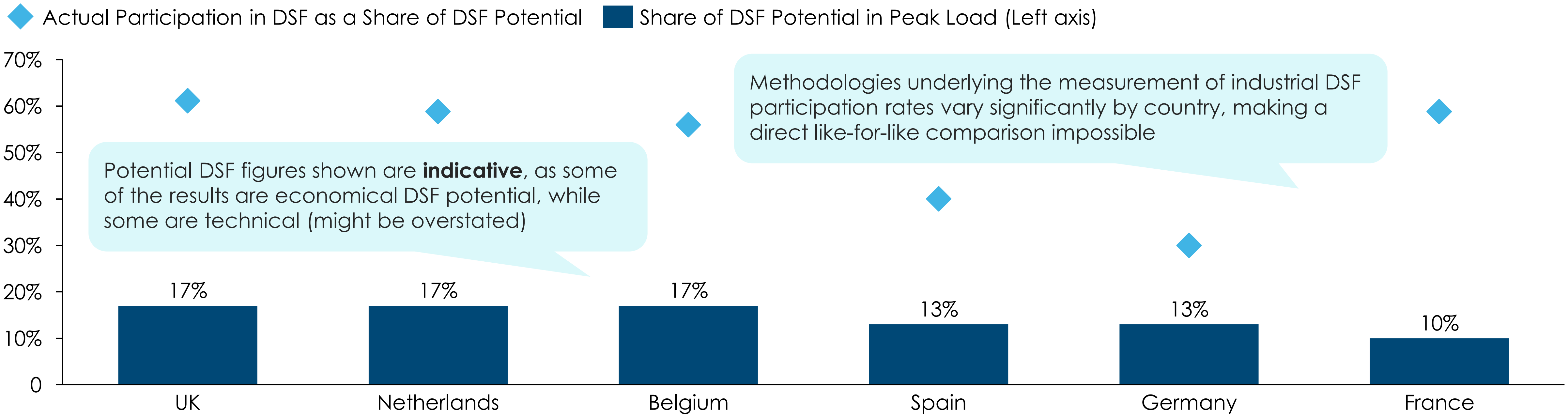
Source: Cabot (2023), Economic considerations on the demand-side of electricity markets in a context of energy transition

# Behavioural changes, industry: some participation in DSF based on ability to switch off demand at stress moments

Behaviour change

## Theoretical potential and actual participation level of DSF in 6 countries, 2020

% Share



Potential DSF figures shown are **indicative**, as some of the results are economical DSF potential, while some are technical (might be overstated)

Methodologies underlying the measurement of industrial DSF participation rates vary significantly by country, making a direct like-for-like comparison impossible

| | | | | | | |
|---|---|---|---|---|---|---|
| **Methodology** | Participation rates not measured, but estimated based on a **bottom-up model with assumptions on DSF participation by source** over time | Based on **day-ahead wholesale market data** for available capacity, excluding DSF in balancing market | Based on **day-ahead wholesale market data** and **adding up tendered DSF capacity** in the balancing market | Taking the sum of the **capacity tenders for the interruptible load** programs in a given year | Taking the sum of **prequalified DSF capacity in the balancing market** in a given year | Underlying methodology remains unclear, however it states that both explicit and implicit DSF is taking into account |

Source: TenneT & Strategy& (2021), Unlocking Industrial Demand Side Response

# Key enablers

# The key enablers for driving DSF adoption is through the integration of incentives, financing, and behavioural change

| Capabilities | High-potential policy enablers | Examples |
|---|---|---|
| **Hardware** | • Accelerate adoption of **smart meters** and **asset metering devices** through regulation and financing | • Rollout of smart meters is already regulated by EU law |
| **Data exchange** | • Establish clear rules on **data exchange** and **interoperability standards** | • EU Smart Grids Task Force serves as guidance on data protection and privacy for data controllers and investors in smart grids |
| **Pricing structures** | • Implement **time-of-use tariffs**, **real-time pricing**<br>• Wholesale **price signals** for supplier half hourly settlement | • California Public Utilities Commission (CPUC) requires utilities to **ToU rates** for V1G and V2G<br>• The EU Clean Energy for All Europeans package promotes **dynamic tariffs** by setting frameworks for energy suppliers |
| **Cost** | • **Reduce barriers to entry** via financing through **financial institutions and government-backed grants**<br>  • Upskilling **retail banks** to understand and appreciate DSF<br>  • **Development banks** are crucial for reducing risk of projects<br>  • Blended finance<br>  • ESCOs – Energy Service Companies | • Energy Service Companies (ESCOs) operate in many countries around the world, using **performance-based contracts to guarantee energy savings**<br>  • Guaranteed savings model: U.S., Germany<br>  • Shared savings model: China, Chile |
| **Market reform** | • Enable DSOs to expand their flexibility procurement capabilities and streamline the export licensing process for V2G tech | |
| **Behaviour change** | • Clearly reveal the value of DSF to consumers through transparent billing, mobile apps, and personalized reports, including for those without all electrified loads | • Hong Kong consumers are incentivised to lower load during events by **earning reward points**. They can redeem these points for supermarket coupons, food coupons, smart appliances, and more |
| **Other** | • Leverage other policy as incentives, such as building codes, EPCs | |

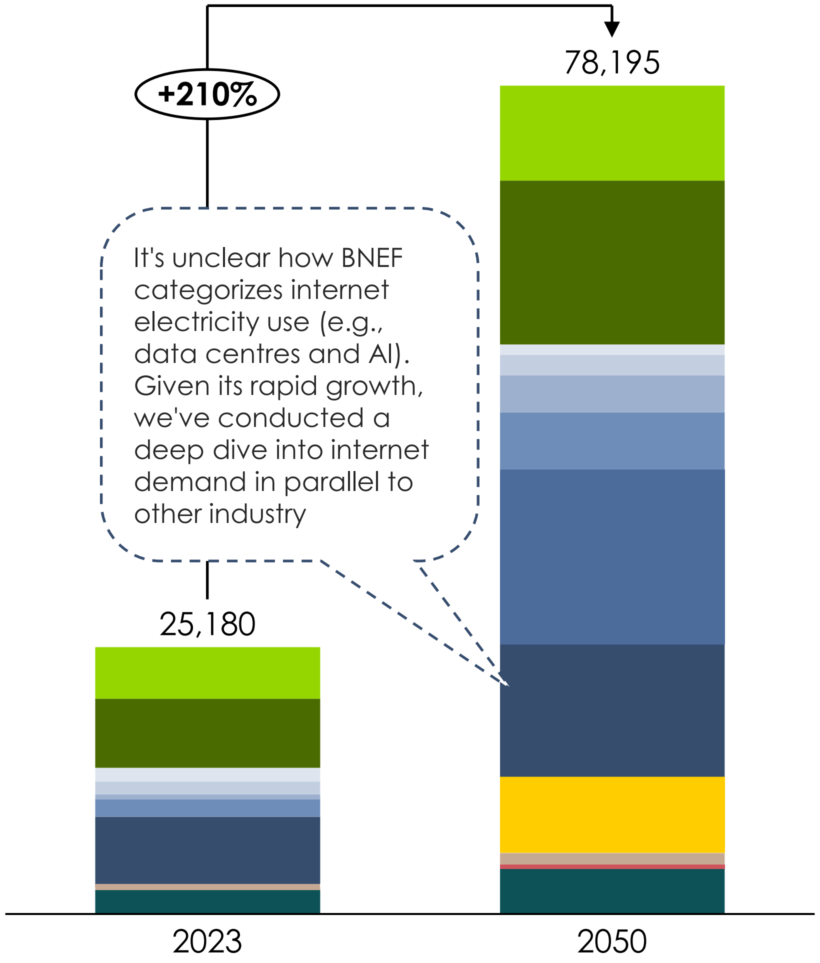
# Section 2

# Understanding the potential for demand-side flexibility: deep dives

# ETC assessment of DSF potential will look at key use cases

## Global electricity demand by industry, 2023 & 2050

TWh



It's unclear how BNEF categorizes internet electricity use (e.g., data centres and AI). Given its rapid growth, we've conducted a deep dive into internet demand in parallel to other industry

**Total demand**

**Buildings: 24,415 TWh**

🟩 Commercial b.
🟩 Residential b.

- Heating
- Cooling
- Lighting & Appliances

**Industry: 40,815 TWh**

🟦 Steel (direct electricity use)
🟦 Aluminium
🟦 Cement
🟦 Chemicals
🟦 Hydrogen (incl. hydrogen for steel production)
🟦 Other industry

- Electrified industrial heat
- Aluminium
- Other industry demand (e.g. mechanical)
- Hydrogen electrolysers

**Road transport: 7,130 TWh**

- EVs (incl. dynamic charging + V2G)

**Others: 5,835 TWh** 🟨 Aviation 🟨 Shipping 🟫 Rail 🟥 Energy industry 🟩 Other sectors

Source: Own analysis, data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Methodology: 3 step assessment towards ‘realistic potential’

**Total potential**

All electricity load (TWh) in 2050 across sectors

**Theoretical potential**

All electricity load (TWh) that can **theoretically** be time-shifted, e.g. without disruption to living comfort, disruption to mobility need and disruption to industrial process

*Assessment of barriers*

**Technology barriers** to deployment, such as the lack of standardized practices for implementing thermal energy storage in industrial heat applications

**Financial barriers** to deployment, such as high upfront costs and insufficient return on investment

**Policy barriers** to deployment, such as insufficient dynamic pricing structures that fail to incentivize flexible energy use

**Behaviour barriers** to deployment, such as resistance to change and limited adoption of new technologies in residential settings

**Realistic potential**

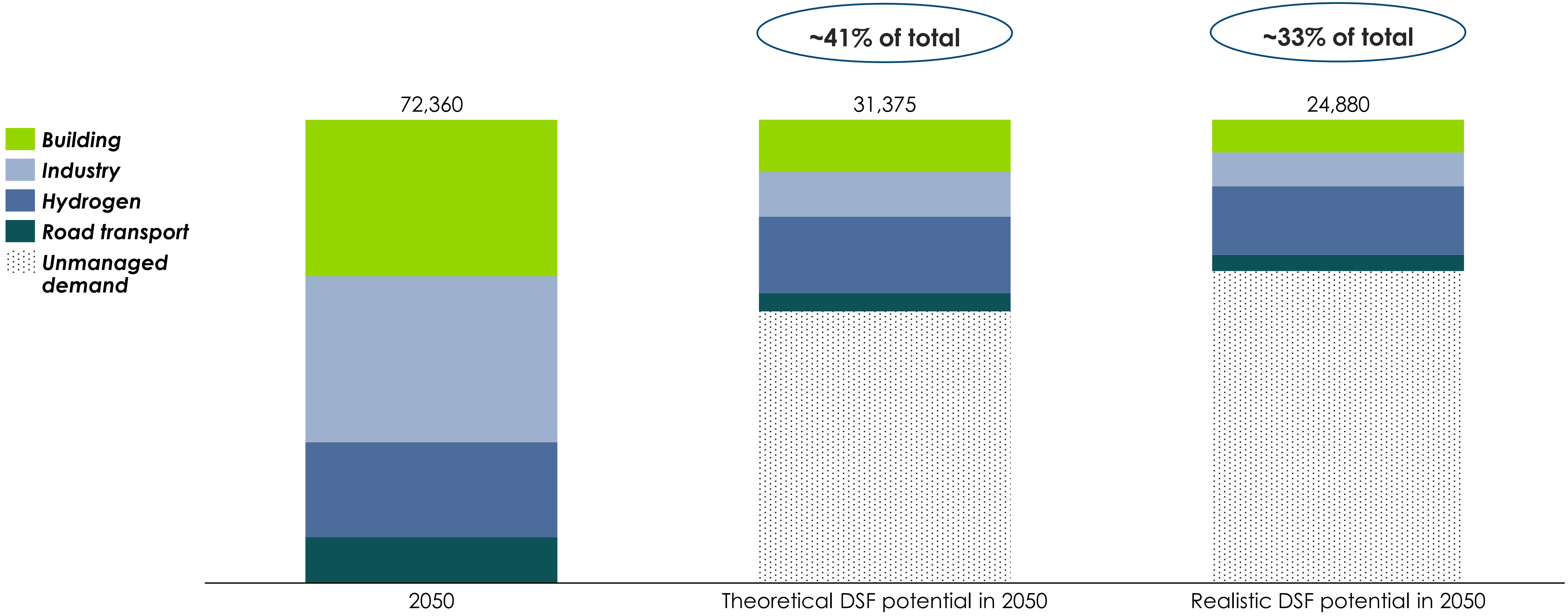
All electricity load (TWh) that can **actually** be time-shifted, e.g. where it can be delivered overcoming the four barriers

*(% reduction of theoretical potential based on barriers assessment)*

# ~35% of total electricity demand in 2050 could be flexible on an hourly/daily basis, after accounting for adoption barriers

## Global electricity demand and DSF potential, 2050

TWh



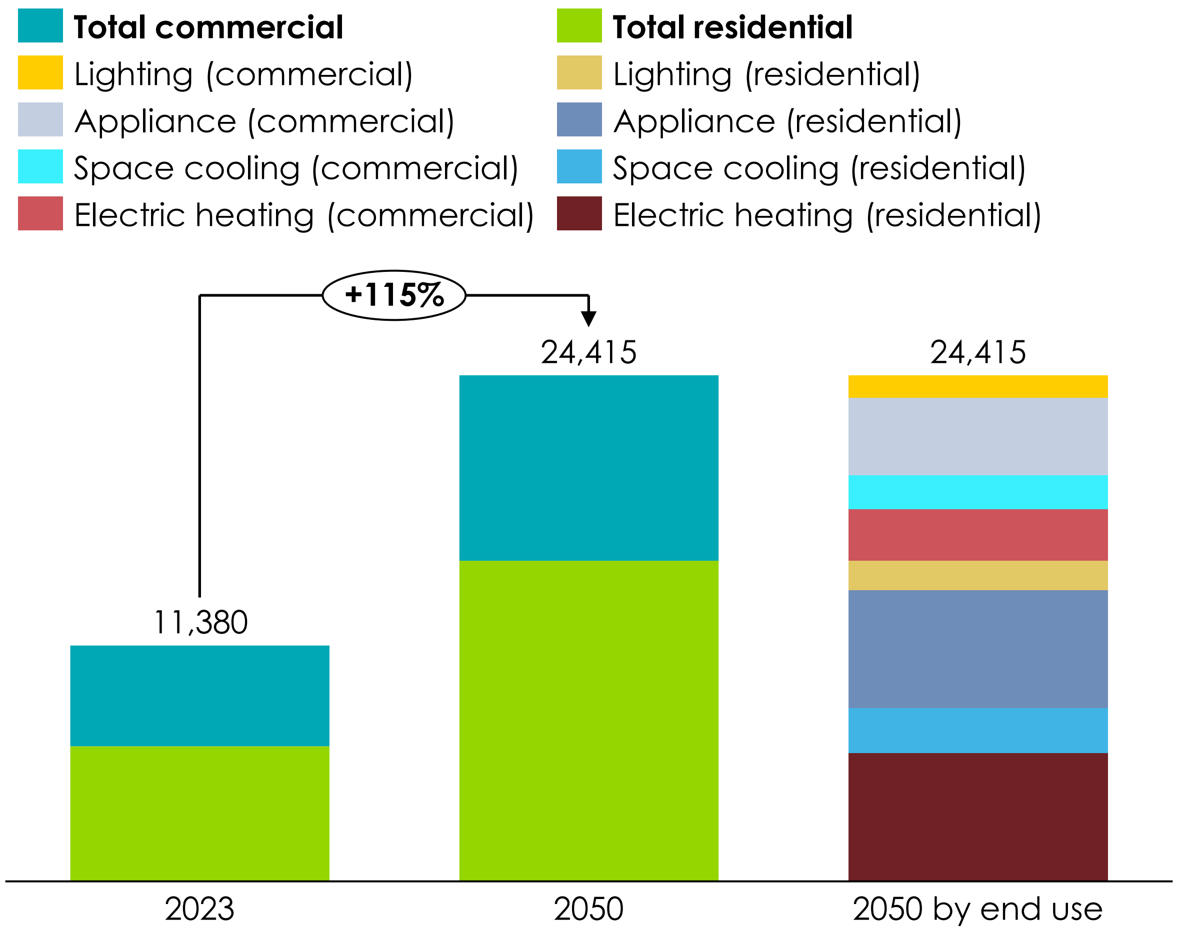
Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Buildings

# Assessing DSF potential across several buildings areas

## Global electricity demand from buildings, 2023 & 2050

TWh



**Residential**

- Heating
- Cooling
- Lighting & Appliances

**Commercial**

- Heating & Cooling
- Other, including Lighting & Appliances

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Overall, several demand-side flexibility pathways exist for buildings for hourly/daily shifting

| | | Response duration | Load shedding | Load shifting | BDR vs ADR* |
|---|---|---|---|---|---|
| Direct response mechanisms | **Pre-heating / pre-cooling through thermal inertia**<br>• Cooling/heating capacity can be **stored in a building's thermal mass** discharged during the peak demand period | 0.5 – 3.00 hr | ✓ | ✓ | • BDR<br>• ADR |
| | **HVAC system set-point adjustment**<br>• <2 min response time and 5 – 30 min ramping time<br>• For example, by increasing the room temperature set-point, the AC load can be shed during summer peak time | 0.5 – 4.00 hr | ✓ | | • BDR<br>• ADR |
| | **Thermal energy storage (TES) / thermal buffer**<br>• For example, an **electric storage water heater** heat the water inside a container and then store it for later usage | Up to 10 hr | ✓ | ✓ | • ADR |
| | **Controlled lighting**<br>• Run continuously during evenings / insufficient outdoor light<br>• When there is sufficient daylight, artificial lighting can be **turned down** | Unshiftable demand | ✓ | | • BDR<br>• ADR |
| | **Refrigerators and freezers**<br>• Run Intermittently but used all day, <30 s response time and 15 min ramping time<br>• Set-point adjustment<br>• Low-power-mode continuous operation | 1 hr | ✓ | ✓ | • ADR |
| | **Delaying or advancing the start of wet appliances** (dishwashers, washing machine, dryers)<br>• Finite cycle with sequential processing<br>• Usage frequency depending on occupants | No time restraint | | ✓ | • BDR |
| Enabling | **Smart thermostats and smart systems**<br>• Optimise heating/cooling consumption according to need<br>• Incentivise household behaviour change | | | | • ADR |

*Note: BDR: Behavioural demand response; ADR: Automated demand response

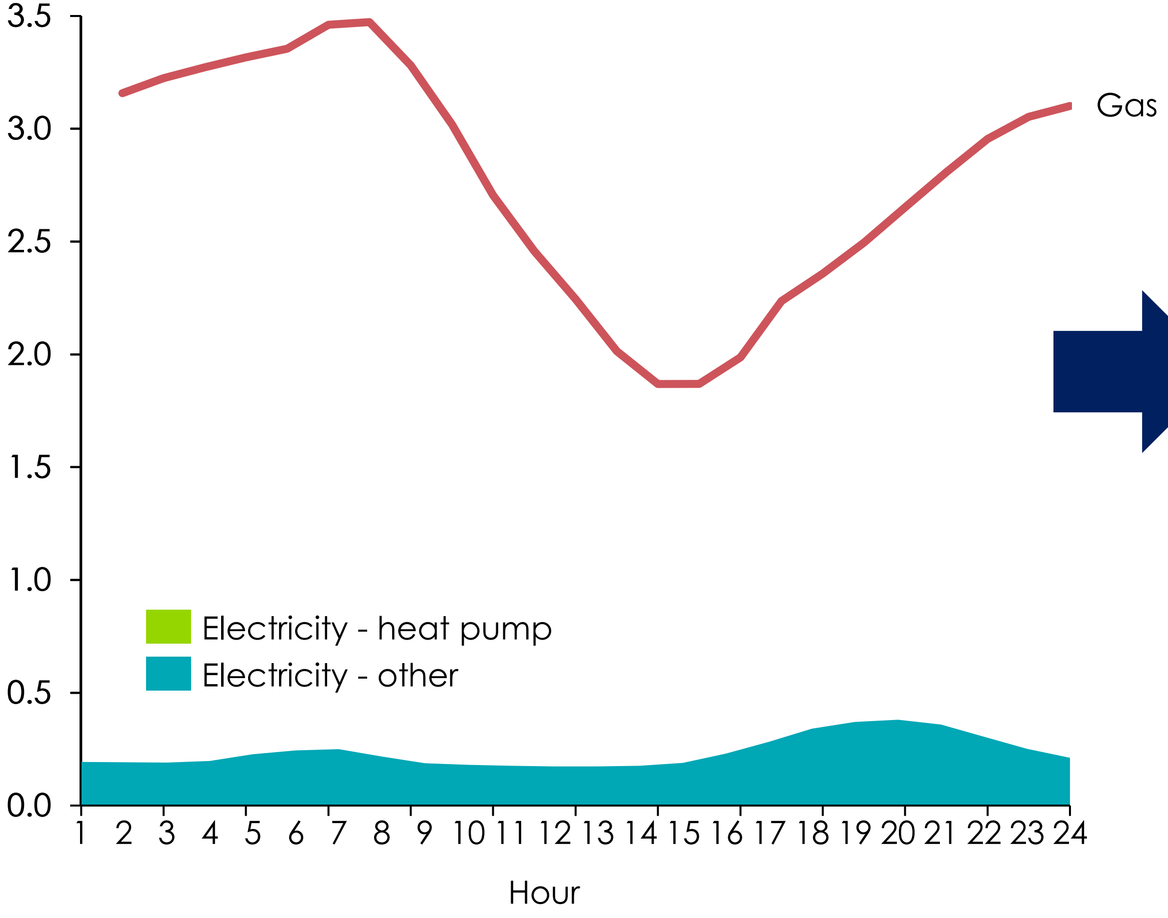
Source: Luo et al. (2022), *Demand Flexibility of Residential Buildings: Definitions, Flexible Loads, and Quantification Methods*

# Heating in the winter months, along with other electricity use for lighting and appliances, creates demand peaks in the morning and evening

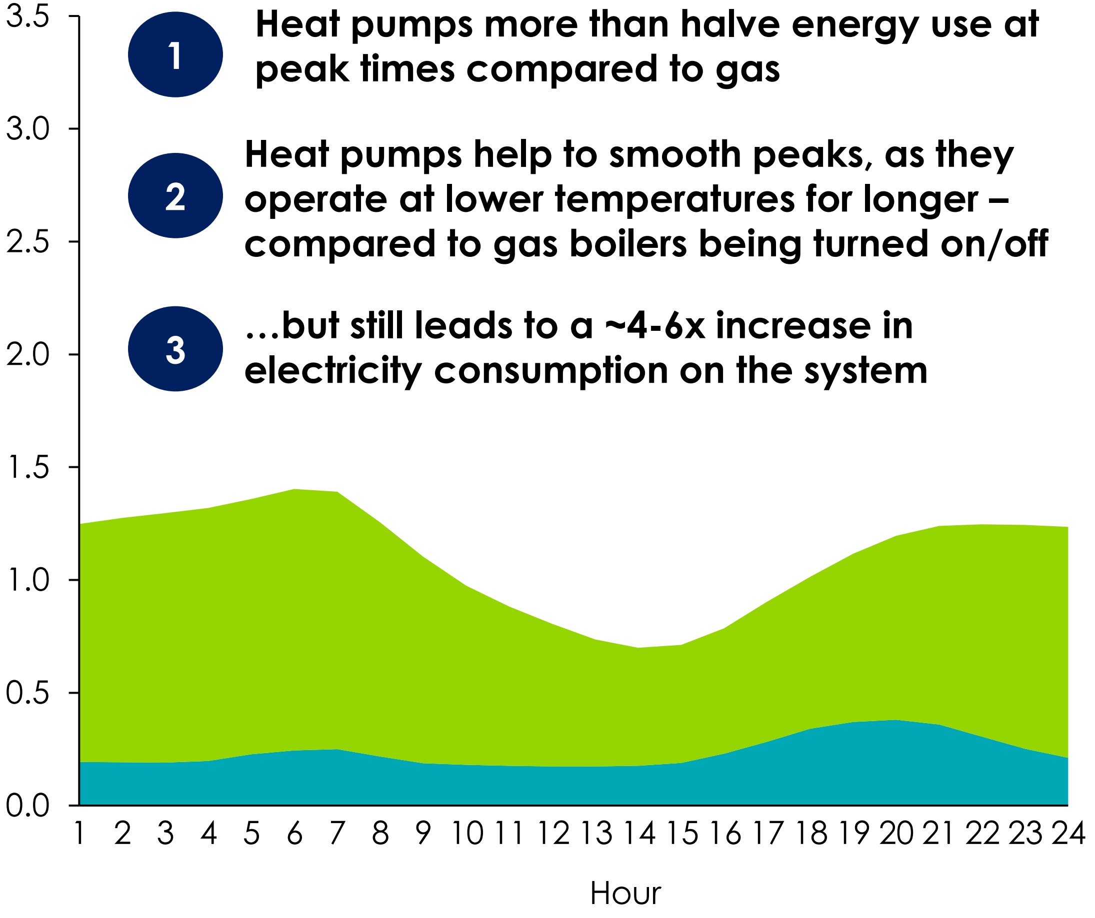
**Hourly electricity and gas use, typical European house**

kWh

**Energy consumption with a gas boiler**



**Energy consumption with a heat pump**



1. **Heat pumps more than halve energy use at peak times compared to gas**
2. **Heat pumps help to smooth peaks, as they operate at lower temperatures for longer – compared to gas boilers being turned on/off**
3. **…but still leads to a ~4-6x increase in electricity consumption on the system**

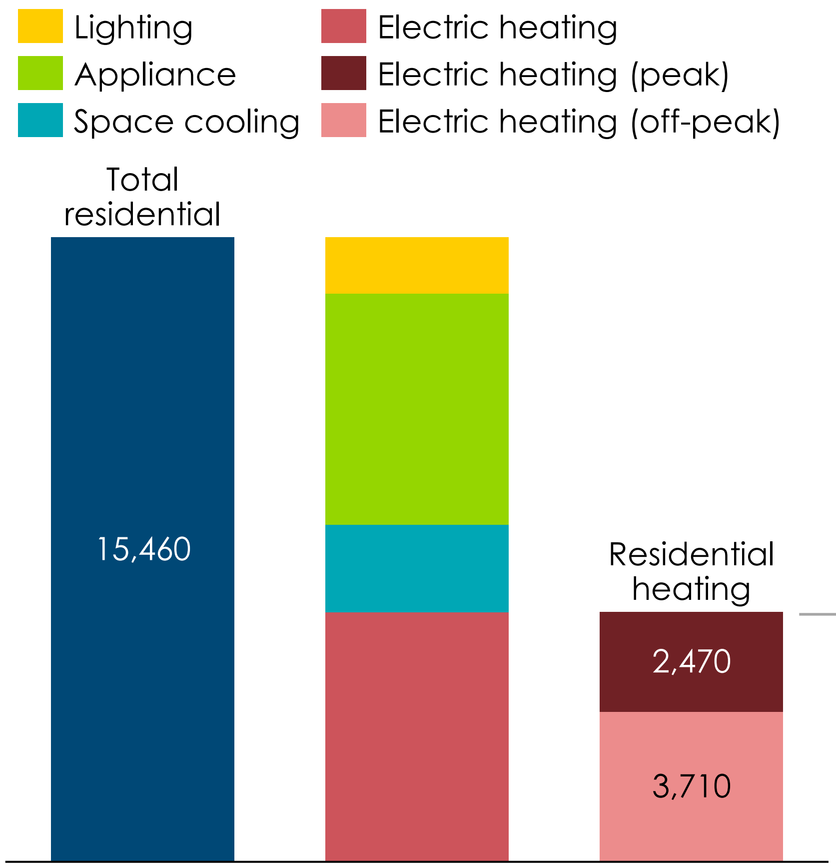
Note: data based on a large residential house in France, scaled down to typical average household gas heating consumption

Source: Systemiq analysis for the ETC (2024) of Schneider Electric Sustainability Research Institute

# Residential heating loads can provide 50-60% flexibility of peak demand through thermal inertia, thermal energy storage, and set point adjustments

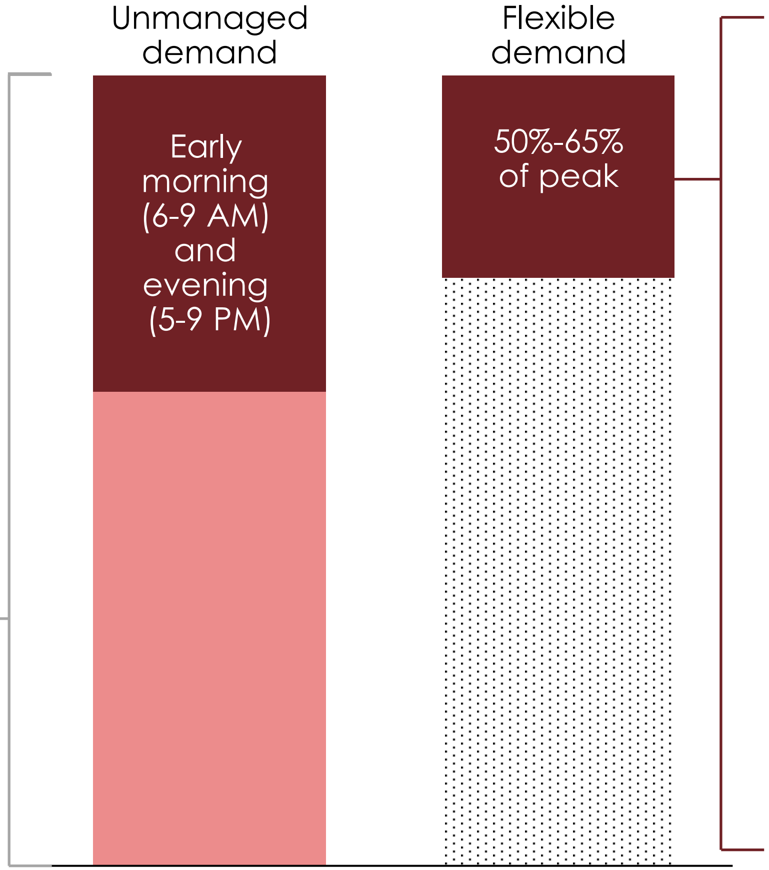
## Global residential electricity demand, 2050

TWh



## Global residential electrical heating theoretical DSF potential*, 2050

TWh



**Load shift**

**3% to 14%** of the space heating load can be shifted from peak demand period by using thermal inertia in a single, well-insulated building

The electricity peak loads can be **reduced by 25%** by shifting heating loads to off-peak hours using TES

**Load shed**

**5%** of the space heating load can be shed through better thermal inertia

**20%** of the space heating load can be shed by lowering the room temperature set-point

*Note: Energy consumption in buildings follows more predictable patterns, such as higher heating demand during mornings and evenings. This approach allows us to shift energy use from peak to off-peak times, directly reducing stress on the grid during high-demand periods. Since building energy consumption patterns are closely aligned with overall grid peaks, optimizing building flexibility has a significant impact on mitigating grid congestion and enhancing overall grid stability

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; Masy et al. (2015), Smart grid energy flexible buildings through the use of heat pumps and building thermal mass as energy storage in the Belgian context; Erdemir & Dincer (2020), Potential use of thermal energy storage for shifting cooling and heating load to off-peak load: A case study for residential building in Canada

# Actual flexibility potential constrained by insufficient policy support and resistance to change

| | Criteria | Details |
|---|---|---|
| **Tech** | Underlying electrification technology | • Most heat pumps sold today **already allow to connect a control device** to the unit |
| | Enabling technology | • **Smart thermostats** and meters ensure that heating systems can respond dynamically<br>• It is expected that the required smart meter infrastructure will be in place **by 2030 in the UK** |
| **Financial** | Cost and payback period | • The payback period for heat pump is around **25** years, adding insulation is around **4-9** years, adding smart system is another **7** years, for water cylinder and power battery is **5-20** years<br>• Storage solutions requires additional cost and space in the house – National Grid ESO predicts that only **40%** of homes with heat pumps will have thermal storage by 2050 |
| | Investment attention | • The financial proposition for smart system today is too **weak** to attract much attention |
| **Policy** | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022, Denmark, Estonia, Finland, Norway, Spain, Sweden, The Netherlands and The United Kingdom |
| | Interoperability standards | • Crucial for seamless integration of different devices and systems |
| | Cybersecurity regulations | • Includes regulations on data collection, storage, sharing, and usage |
| | Labelling schemes | • **Over 110 countries** employ mandatory energy efficiency labels for new appliances |
| | Building energy codes | • Implemented over 80 countries, and a further 31 are actively developing them |
| **Behaviour** | Lack of awareness | • Consumers are **not fully aware** of what DSF are, how they work, or the benefits they offer |
| | Concerns and scepticism | • **Uncomfortable with automated changes** to appliance operation based on external signals |
| | Inertia/resistance to change | • Reluctant to time-shift heating or lower thermostats if it **compromises their comfort** |

Source: Carbon Trust & Imperial College London (2021), Flexibility in Great Britain; IEA (2022), The Future of Heat Pumps; Systemiq analysis for the ETC (2024), Mascherbauer et al. (2022), Impact of variable electricity price on heat pump operated buildings

# Water and space heating use can be time-shifted away from peak times using water or heat storage solutions

## Water storage

- Heating hot water when electricity is cheap/ abundant and storing it in a well-insulated tank
- Typically used for domestic hot water heating today
- It could also be used to heat water in hydronic heating systems for space heating → but households would need a separate, creating large additional space requirements

Average cost for a 2-4 bedroom house is €500 - 1,500

## Power storage

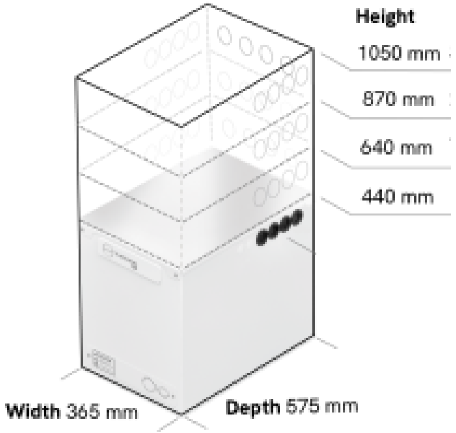
W: 0.5 - 1.5m
H: 1 – 2m
D: 0.2-0.5m

- Store electricity generated from solar panels in a battery
- Enables excess solar generation to be stored for later use
- Or charge from grid at off-peak times
- Enables households to avoid peak energy consumption from the grid
- Can be used for electric space or water heating

Average cost for a 5 kWh battery ~€3,000

This reflects current retail prices; however, the cost of producing batteries is significantly lower and falling fast → retail prices are expected to fall too with mass adoption

## Heat storage



- Thermal energy storage
- Charge up the battery to heat a phase change material at off-peak times
- Battery heats up water when needed
  - Currently used for water heating
  - Could also be used for space heating
- Around half the size of water cylinders

*Consumer costs currently unclear – we are working on developing assumptions*

# The economic viability of storage, like hot water cylinders and batteries, directly enhances DSF potential by enabling cost-effective load shifting

## Water cylinder

| Annual water heating needs, kWh | How much could be stored? kWh | How much could be heated at off-peak times? kWh | Annual savings from off-peak heating compared to peak heating |
|---|---|---|---|
| 2,300 | 1,265 (~55%) | 950 (~75%) | **€175** |

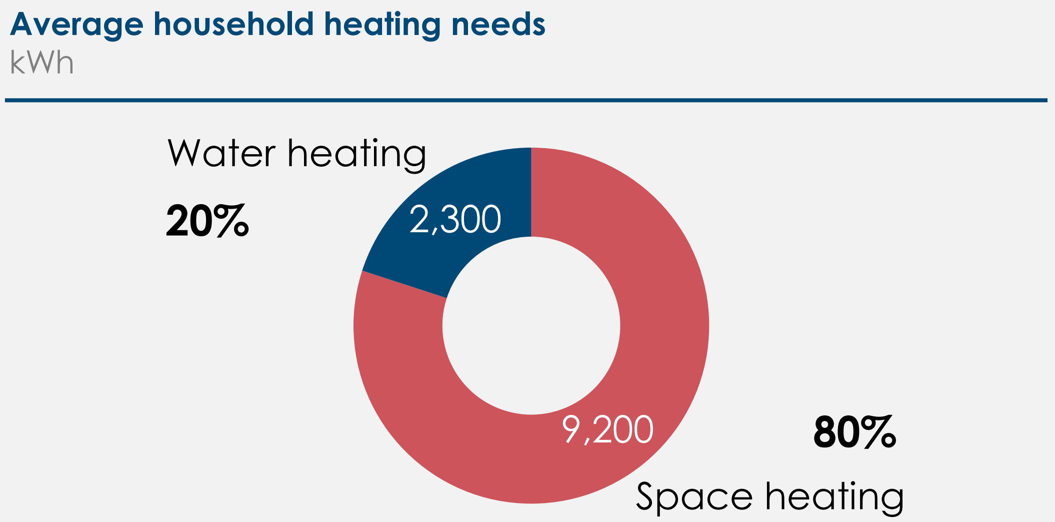
| | Capex cost | Payback | IRR |
|---|---|---|---|
| Water cylinder | €1,000 | 5 years | 21% |
| Power battery | €3,000 | 19 years | 3% |
| | *If fell to €1,500* | *9 years* | *11%* |

## Battery storage

| How much could be stored? kWh | Assuming all of this is used at peak times - annual savings from off-peak compared to peak tariffs |
|---|---|
| 5 kWh battery * 365 days = 1,800 | **€150** |

*Savings could be ~€300-500 if combined with solar*

**Key assumptions:**
€0.29/kWh European electricity price
€0.2/kWh – off-peak electricity price


**Average household heating needs**
kWh

Source: Systemiq analysis for the ETC (2023); Eurostat (2023), Energy use in households up 6% in 2021.

# Stronger time of day pricing creates even stronger paybacks to storage solutions

**Off peak tariffs are 1/3 lower**

| | Capex cost | Payback | IRR |
|---|---|---|---|
| Water cylinder | €1,000 | 5 years | 21% |
| Power battery | €3,000 | 19 years | 3% |
| | *If fell to €1,500* | *9 years* | *11%* |

**Key assumptions:**
€0.29/kWh European electricity price
€0.2/kWh – off-peak electricity price

**Off peak tariffs are 2/3 lower**

| | Capex cost | Payback | IRR |
|---|---|---|---|
| Water cylinder | €1,000 | 3 years | > 25% |
| Power battery | €3,000 | 8 years | 12% |
| | *If fell to €1,500* | *4 years* | *29%* |

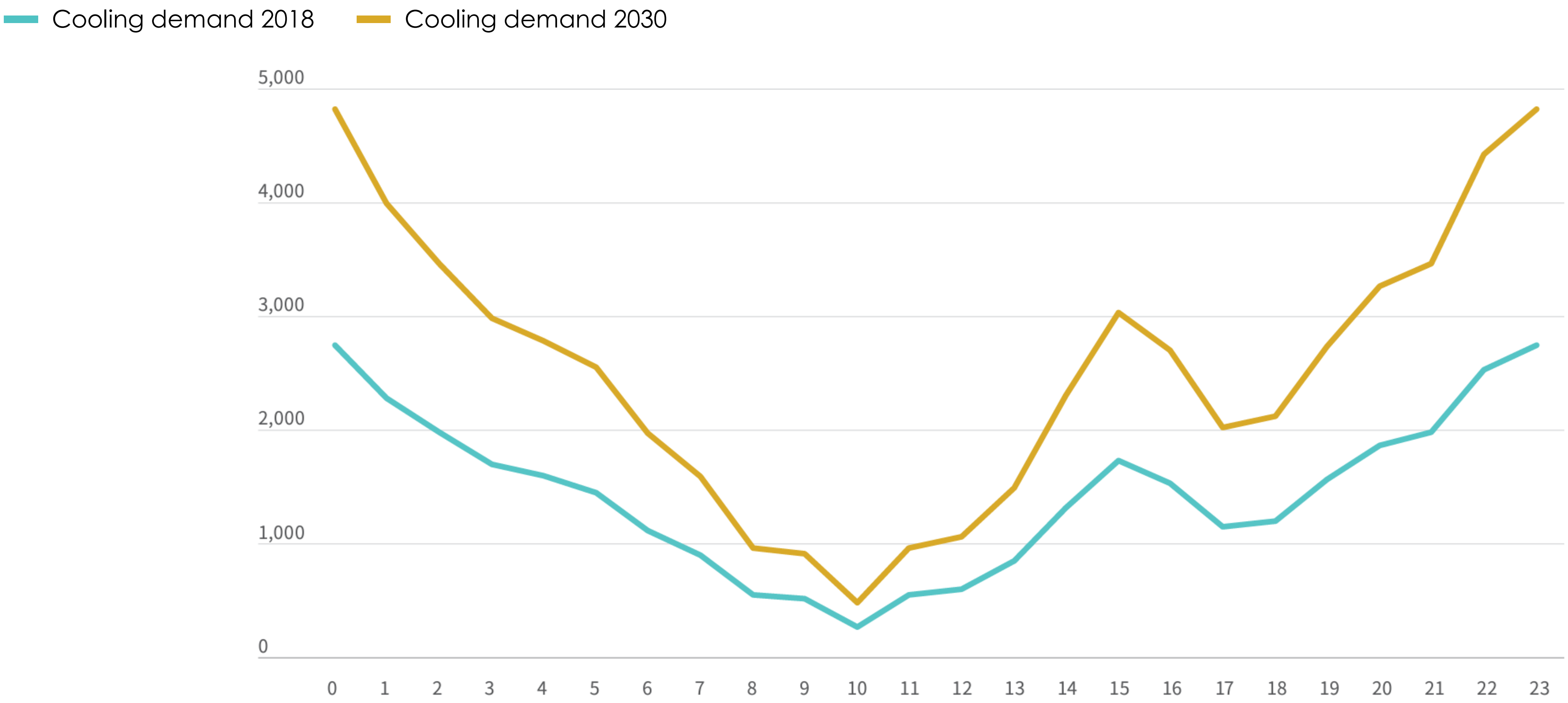
**Key assumptions:**
€0.29/kWh European electricity price
€0.1/kWh – off-peak electricity price

Source: Systemiq analysis for the ETC (2023); Eurostat (2023), Energy use in households up 6% in 2021.

# Similar to heating, cooling in the summer months creates demand peaks in the afternoon and evening and is expected to grow

**Delhi's hourly domestic cooling demand in 2018 and projected domestic cooling demand in 2030 during summer (hour of the day)**

Electricity demand in MW

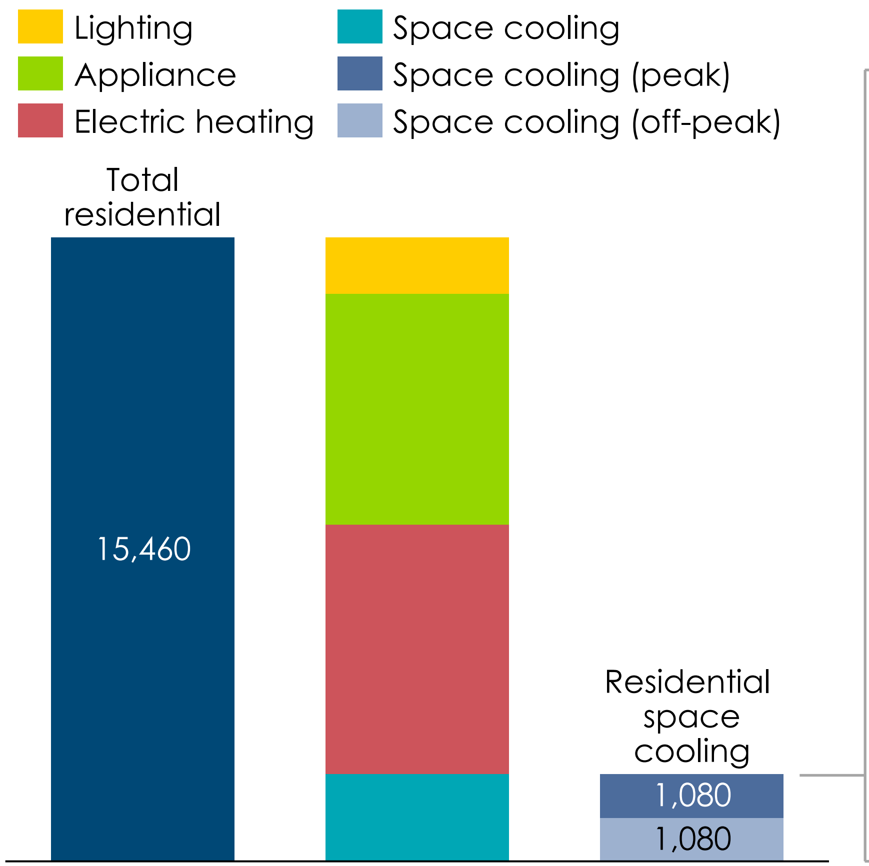


Source; RMI (2024), *Transforming Delhi's Power Grid*

# Residential cooling loads could provide a max of up to 90% flexibility of peak load as cooling demand often less sensitive to short-term variations

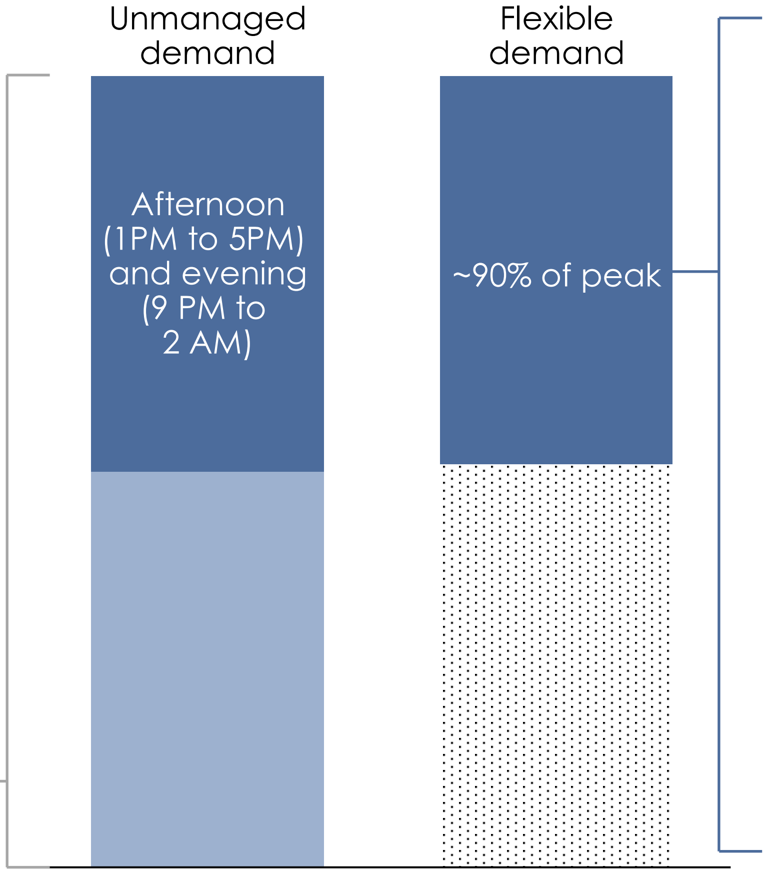
## Global residential electricity demand, 2050

TWh



## Global residential space cooling theoretical DSF potential, 2050

TWh



**Load shift**

Optimal pre-cooling scenario reduced peak AC energy consumption by **28%**

The electricity peak loads can be **reduced by 45%** by shifting cooling loads to off-peak hours using TES

**Load shed**

**5%** of the space cooling load can be shed through better thermal inertia

**20%** of the space heating load can be shed by lowering the room temperature set-point

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; Naderi et al. (2022), *Demand response via pre-cooling and solar pre-cooling: A review*; Erdemir & Dincer (2020), Potential use of thermal energy storage for shifting cooling and heating load to off-peak load: A case study for residential building in Canada

# Cooling demand is higher in lower income countries, hence cooling DSF solutions often face less development

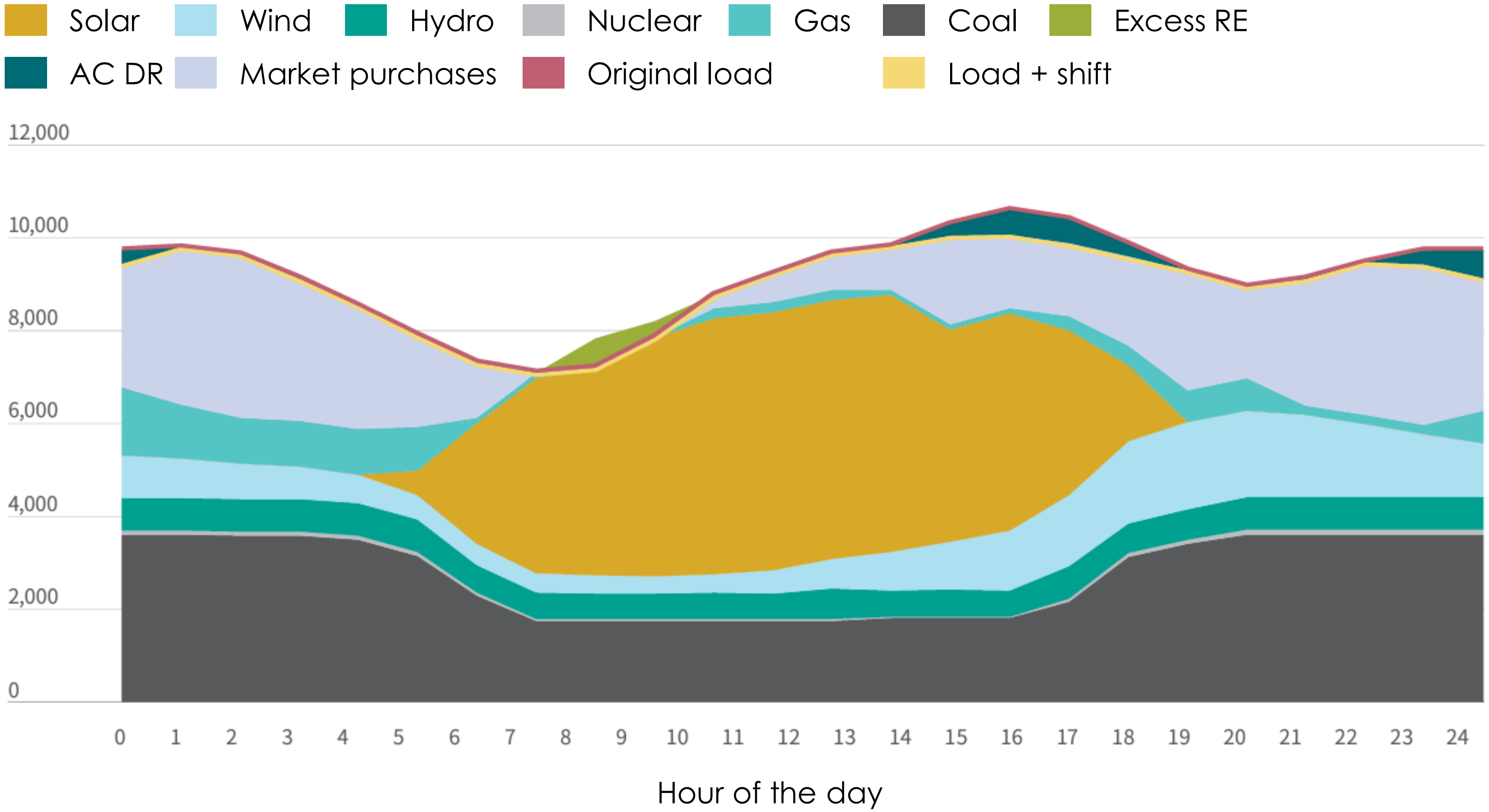
| | Criteria | Details |
|---|---|---|
| Tech | Underlying electrification technology | • Most AC sold today already allows to connect a control device to the unit |
| | Enabling technology | • Cooling regions, particularly South Asia, Latin America, and Africa, currently have a **low adoption rate (<20%)** of smart meters today<br>• However, many regional governments are more **actively driving the adoption** |
| Financial | Cost and payback period | • **Weaker economic incentives** to do insulation given AC electricity use is smaller than heating energy use, but stronger in countries with both heating and cooling need<br>• Payback **period for storage** is much shorter than heating (**4-8 years** if battery price drops) |
| | Investment attention | • The financial proposition for smart system today is too **weak** to attract much attention |
| Policy | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022, Denmark, Estonia, Finland, Norway, Spain, Sweden, The Netherlands and The United Kingdom |
| | Interoperability standards | • Crucial for seamless integration of different devices and systems |
| | Cybersecurity regulations | • Includes regulations on data collection, storage, sharing, and usage |
| | Labelling schemes | • **Over 110 countries** employ mandatory energy efficiency labels for new appliances |
| | Building energy codes | • Many cooling countries are **still developing building energy codes** |
| Behaviour | Lack of awareness | • Consumers are **not fully aware** of what DSF are, how they work, or the benefits they offer |
| | Concerns and scepticism | • **Uncomfortable with automated changes** to appliance operation based on external signals |
| | Inertia/resistance to change | • Consumers in developing countries are more **energy conservative and price sensitive**<br>• However, consumers might be **less willing to sacrifice thermal comfort** in cooling season |

Source: Carbon Trust & Imperial College London (2021), *Flexibility in Great Britain*; IEA (2022), *The Future of Heat Pumps*; Systemiq analysis for the ETC (2024), Mascherbauer et al. (2022), Impact of variable electricity price on heat pump operated buildings

# AC demand flexibility in Delhi could save up to $216,000 of power procurement costs in one day

**Delhi hourly generation dispatch and impact of AC demand response (DR) case on a summer peak day in 2030, assuming 17% domestic participation and 10% commercial and industrial participation**

Power (MW)



AC demand flexibility provides benefits by **reducing load during afternoon and midnight peak hours**, avoiding expensive market purchases, and lowering peak demand

On this day alone, AC DR is estimated to lead to **3,000 MWh in energy savings** and **18 million rupees (US$216,000) in avoided power procurement costs** via market purchases (around **17%** of total daily power procurement costs)

Source; RMI (2024), *Transforming Delhi's Power Grid*

# New cooling technologies that incorporate energy storage could provide DSF by charging themselves when renewable electricity is abundant

To test

Nostromo's IceBrick is made of individual capsules that freeze and thaw to store energy.

**Technology aim:** using freezing & thawing method to provide electricity at ideal times ('charging' at night-midday & discharging for evening peak)

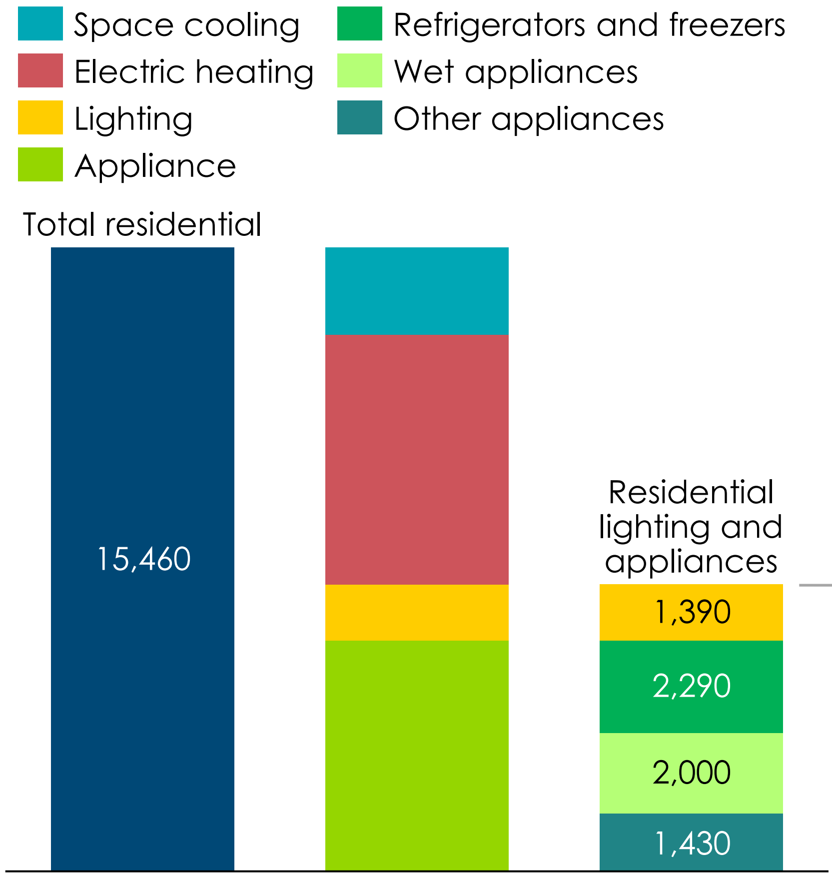
**Technology overview:**

- Nostromo Energy's IceBrick **cools down a solution made of water and glycol** that's used to freeze individual capsules filled with water. One IceBrick can be made up of thousands of these containers, which each hold about a half-gallon, or roughly two liters, of water.
- Insulation keeps the capsules frozen until it's time to use them to help cool down a building. Then the ice is used to **drop the temperature of the water-glycol mixture**, which in turn cools down the water that circulates in the building's chilling system
- It usually charges up for 10 to 12 hours, starting at night and finishing around midday. That leaves it ready to discharge its cooling power **between the late afternoon and evening, when demand on the grid is high and solar power is dropping off** as the sun sets

# For lighting and appliances, the potential for flexibility is limited; improving efficiency offers greater opportunity to provide flexibility & reduce emissions

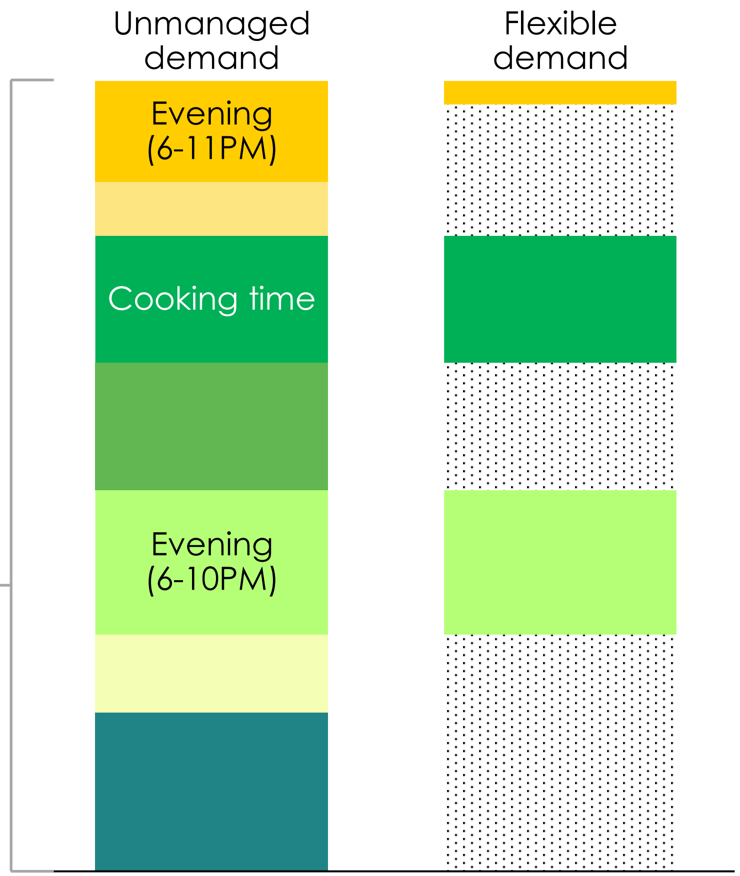
## Global residential electricity demand, 2050

TWh



## Global residential electrical heating theoretical DSF potential, 2050

TWh



Note lighting and appliance peak demand is less peaky, **their DSF potential is less critical for grid flexibility**

**Load shed**

A National Research Council-Institute for Research in Construction field study found that lighting loads could be reduced 14-23% via DSF solutions

About 15% energy can be saved by increasing fridge temperature from 4 °C to 7 °C

**Load shift**

By harnessing the full potential of phase-change materials, close to 100% of the energy used for refrigeration and freezing can be shifted to off-peak periods

Wet appliances theoretically provide **100% demand flexibility** through the occupants delaying or advancing the start of these appliances to shift away from peak demand

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; LCA (2014), Lighting Control and Demand Response; Rodrigues et al. (2022), The Load Shifting Potential of Domestic Refrigerators in Smart Grids: A Comprehensive Review

# Lighting and appliances face similar barriers to flexibility as HVAC systems, but their economics and payback periods are generally more favourable

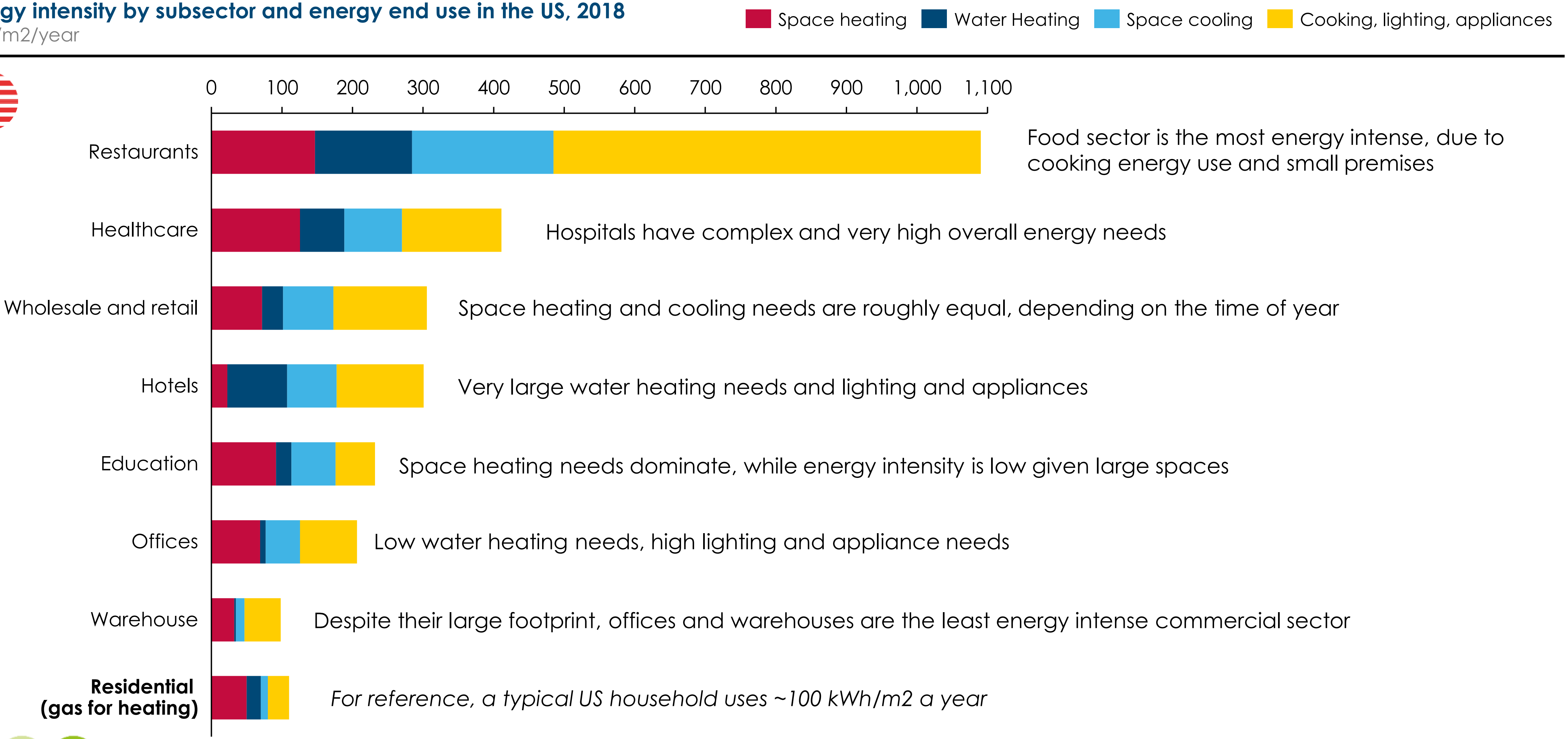
| | **Criteria** | **Details** |
|---|---|---|
| **Tech** | Enabling technology | • Smart lighting system technologies are **well-established**<br>• Phase change materials (PCMs) are not yet a mainstream component in refrigerators, study shows about **40% load-shifting** was achieved without the use of PCMs |
| **Financial** | Cost and payback period | • Smart appliances have **higher upfront hardware costs** and **installation/ maintenance costs**<br>• The payback period for the smart lighting controls (wireless) is **around 3 years** |
| | Investment attention | • The financial proposition for smart system today is too **weak** to attract much attention |
| **Policy** | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022, Denmark, Estonia, Finland, Norway, Spain, Sweden, The Netherlands and The United Kingdom |
| | Interoperability standards | • Crucial for seamless integration of different devices and systems |
| | Cybersecurity regulations | • Includes regulations on data collection, storage, sharing, and usage |
| | Labelling schemes | • **Over 110 countries** employ mandatory energy efficiency labels for new appliances |
| **Behaviour** | Lack of awareness | • Consumers are **not fully aware** of what DSF are, how they work, or the benefits they offer |
| | Concerns and scepticism | • **Uncomfortable with automated changes** to appliance operation based on external signals |
| | Inertia/resistance to change | • DSF from household appliances heavily rely on behavioural change |

Source: Rodrigues et al. (2022), The Load Shifting Potential of Domestic Refrigerators in Smart Grids: A Comprehensive Review; Azad et al. (2022), Cost Analysis of Smart Lighting Control for Residential Buildings

# Energy needs differ significantly across different types of commercial building; there are no one-size-fits all technologies

**Energy intensity by subsector and energy end use in the US, 2018**

kWh/m2/year



Food sector is the most energy intense, due to cooking energy use and small premises

Hospitals have complex and very high overall energy needs

Space heating and cooling needs are roughly equal, depending on the time of year

Very large water heating needs and lighting and appliances

Space heating needs dominate, while energy intensity is low given large spaces

Low water heating needs, high lighting and appliance needs

Despite their large footprint, offices and warehouses are the least energy intense commercial sector

*For reference, a typical US household uses ~100 kWh/m2 a year*

Sources: National Renewable Energy Laboratory

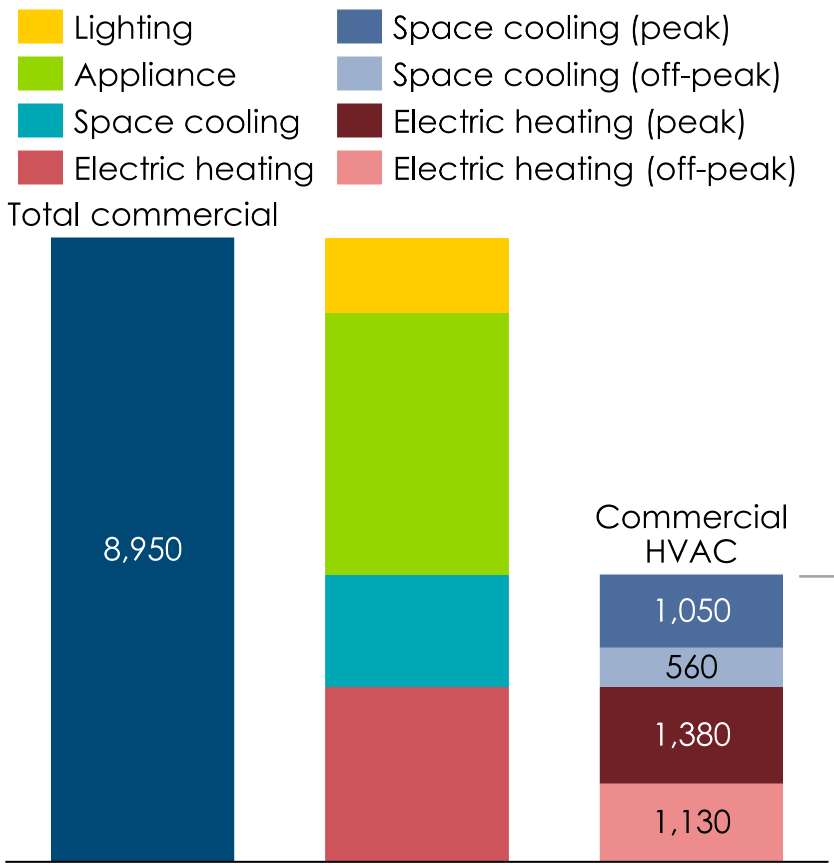
# Commercial buildings offer high DSF potential due to their large, centralized systems and operational flexibility, while unique challenges also exist

| | Larger and more complex energy systems | Operational schedules and occupancy patterns | Building structure and space | Lighting systems | Occupant comfort and productivity | Regulatory environment |
|---|---|---|---|---|---|---|
| **Difference** | • More **extensive and complex** HVAC systems, lighting, and equipment loads<br>• Often **centrally managed** | • Specific **operational hours** and occupancy patterns<br>• Office buildings demand **peaks in working hours**<br>• Retail buildings might **peak later in the day** | • Might have **higher thermal mass** (e.g., concrete structures)<br>• Have **more space** to integrate larger-scale storage solutions | • Lighting is a much **larger energy consumer** in commercial buildings | • **Occupant comfort and productivity** are paramount | • Commercial buildings often need to **comply with various regulations** (e.g., building codes, thermostat limit) |
| **Challenges / Opportunity** | • **Building Automation Systems** can integrate DSF strategies across all energy-consuming systems<br>• **More economic saving pressure**<br>• **Bigger scalability across asset portfolio** | • Requires more **schedule-aligned** DSF strategies | • **Thermal mass** can be utilized for shifting heating/cooling loads<br>• Easier to integrate **larger-scale energy storage** (battery systems, thermal energy storage) | • **Advanced lighting control systems** (e.g., LED lighting with occupancy sensors, daylight harvesting) can provide significant flexibility | • Requires more **precise and sophisticated control** of building systems to ensure thermal comfort | • Easier to regulate, with less dependence on behaviour change |

# Compared to residential buildings, commercial buildings exhibit different peak HVAC loads and generally have higher DSF potential

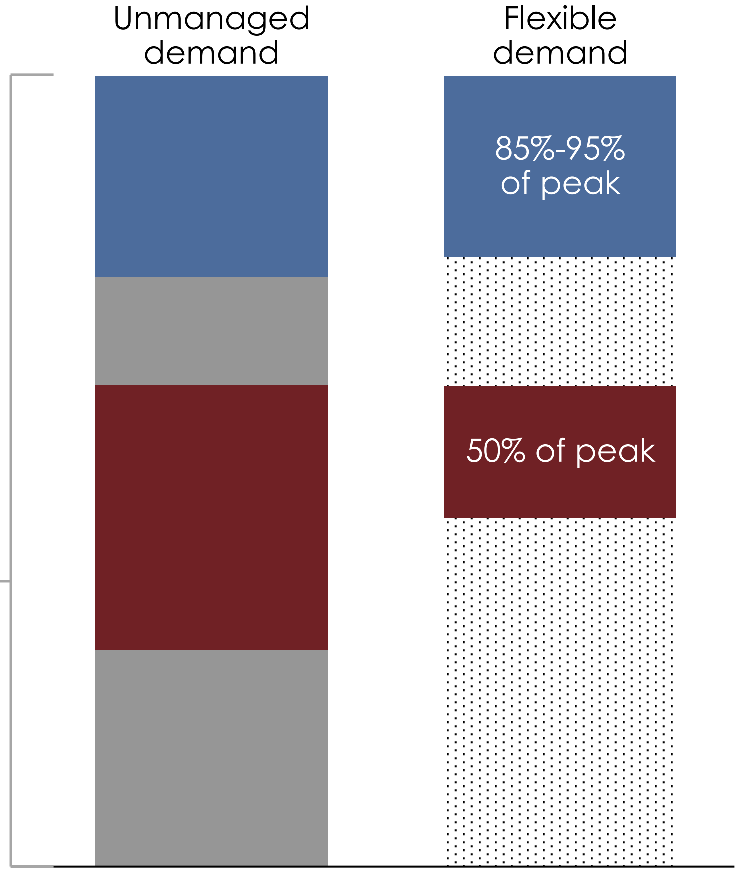
## Global commercial electricity demand, 2050

TWh



## Global commercial HVAC theoretical DSF potential, 2050

TWh



### Space cooling (load shift and shed)

Pre-cooling for load shifting measure demonstrates around **1% daily peak demand reduction** for large offices

Set-point adjustment leads to average **cooling demand reduction around 30%** for ambient temperatures over 30 ◦ C. Partial cold storage saves about **40–60%** of peak demand, up to **80–90%** using full storage

### Electric heating

Combing DSF strategies, heating load can be **reduced to 50%** during peak

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; NREL (2024), Thermostat Control for Load Shifting in Large Offices; Afroz et al. (2022), Energy Flexibility of Commercial Buildings for Demand Response Applications in Australia

# Commercial buildings have stronger economics for leveraging DSF solutions for HVAC system compared to residential buildings

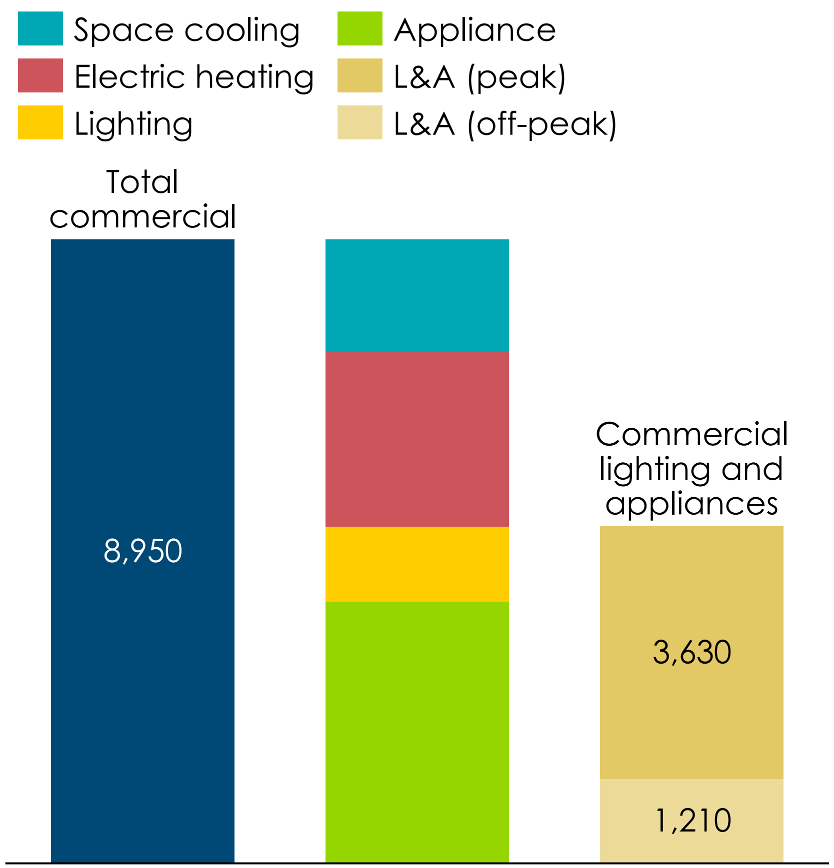
| | Criteria | Details |
|---|---|---|
| **Tech** | Underlying electrification technology | • Variable refrigerant flow systems offer huge opportunities for efficiency gains from **combined heating & cooling systems** by utilising waste heat<br>• Many commercial buildings will already have **water storage**, unlike residential buildings |
| | Enabling technology | • **Smart thermostats** and meters ensure that heating systems can respond dynamically |
| **Financial** | Cost and payback period | • Potential for **huge running cost savings and stronger paybacks** (for A2A HP) due to higher efficiencies in a combined heating + cooling system<br>• For thermal inertia considerations, the total cost of construction premium of moving from current standards to typical certification levels is typically **very manageable (1-5%)**<br>• For many commercial buildings, **the paybacks to batteries are likely to be low** as little excess generation is expected; but time of day pricing could create stronger incentives |
| | Contractual | • Leased office buildings have a disconnect between upfront capex and energy cost<br>• Complex agreements and BM arrangements |
| **Policy** | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022 |
| | Interoperability standards | • Crucial for seamless integration of different devices and systems |
| | Cybersecurity regulations | • Includes regulations on data collection, storage, sharing, and usage |
| | Building codes | • Higher health and safety standards (e.g., managing refrigerant leakage) |
| **Behaviour** | Inertia/resistance to change | • Less dependent on individuals – **~65%** of total energy use is determined at design stage, including HVAC system as part of fixed building services |

Source: Rodrigues et al. (2022), The Load Shifting Potential of Domestic Refrigerators in Smart Grids: A Comprehensive Review; Azad et al. (2022), Cost Analysis of Smart Lighting Control for Residential Buildings

# Building management systems (BMS) typically reduce non-HVAC electricity consumption by around 10-15%

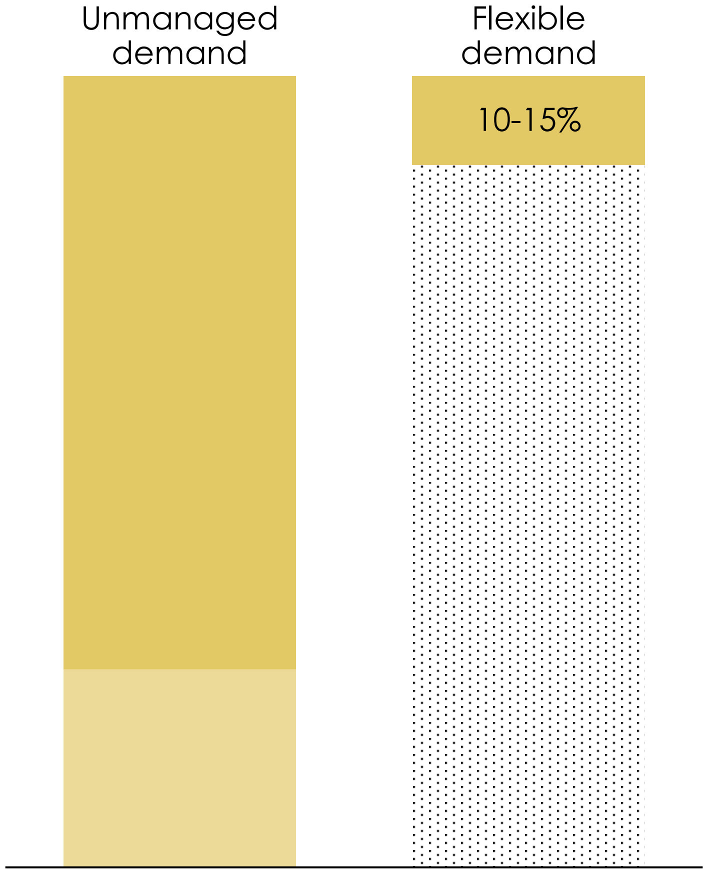
**Global commercial electricity demand, 2050**

TWh



**Global commercial L&A theoretical DSF potential, 2050**

TWh



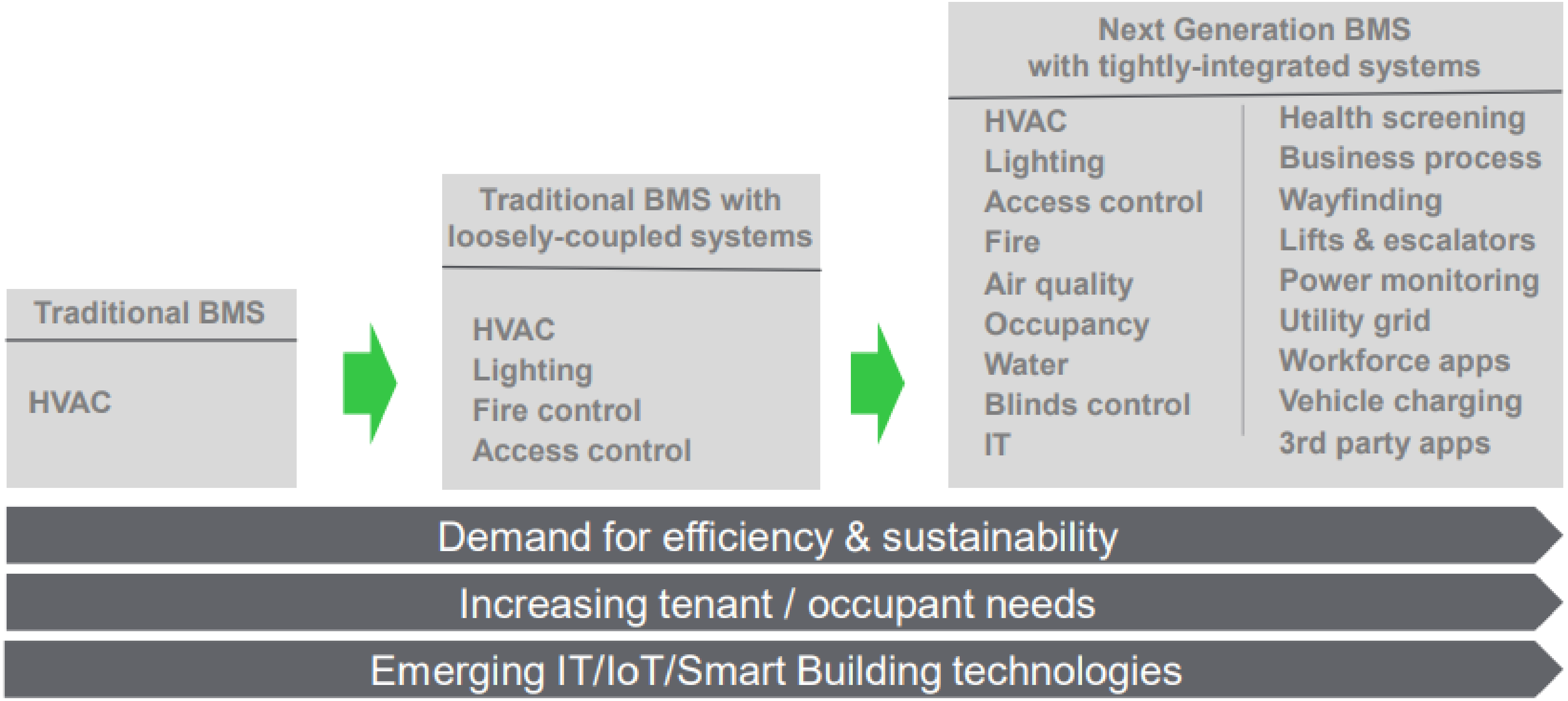
**Flexible load**

Building management systems typically reduce non-HVAC electricity consumption by around **10-15%**

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; Masy et al. (2015), Smart grid energy flexible buildings through the use of heat pumps and building thermal mass as energy storage in the Belgian context; Erdemir & Dincer (2020), Potential use of thermal energy storage for shifting cooling and heating load to off-peak load: A case study for residential building in Canada

# BMS in commercial buildings are often much more sophisticated than residential buildings

## Increasing sophistication of commercial Building Management Systems



**Traditional BMS**

HVAC

**Traditional BMS with loosely-coupled systems**

HVAC
Lighting
Fire control
Access control

**Next Generation BMS with tightly-integrated systems**

HVAC
Lighting
Access control
Fire
Air quality
Occupancy
Water
Blinds control
IT

Health screening
Business process
Wayfinding
Lifts & escalators
Power monitoring
Utility grid
Workforce apps
Vehicle charging
3rd party apps

Demand for efficiency & sustainability

Increasing tenant / occupant needs

Emerging IT/IoT/Smart Building technologies

**Key features of next generation BMS:**

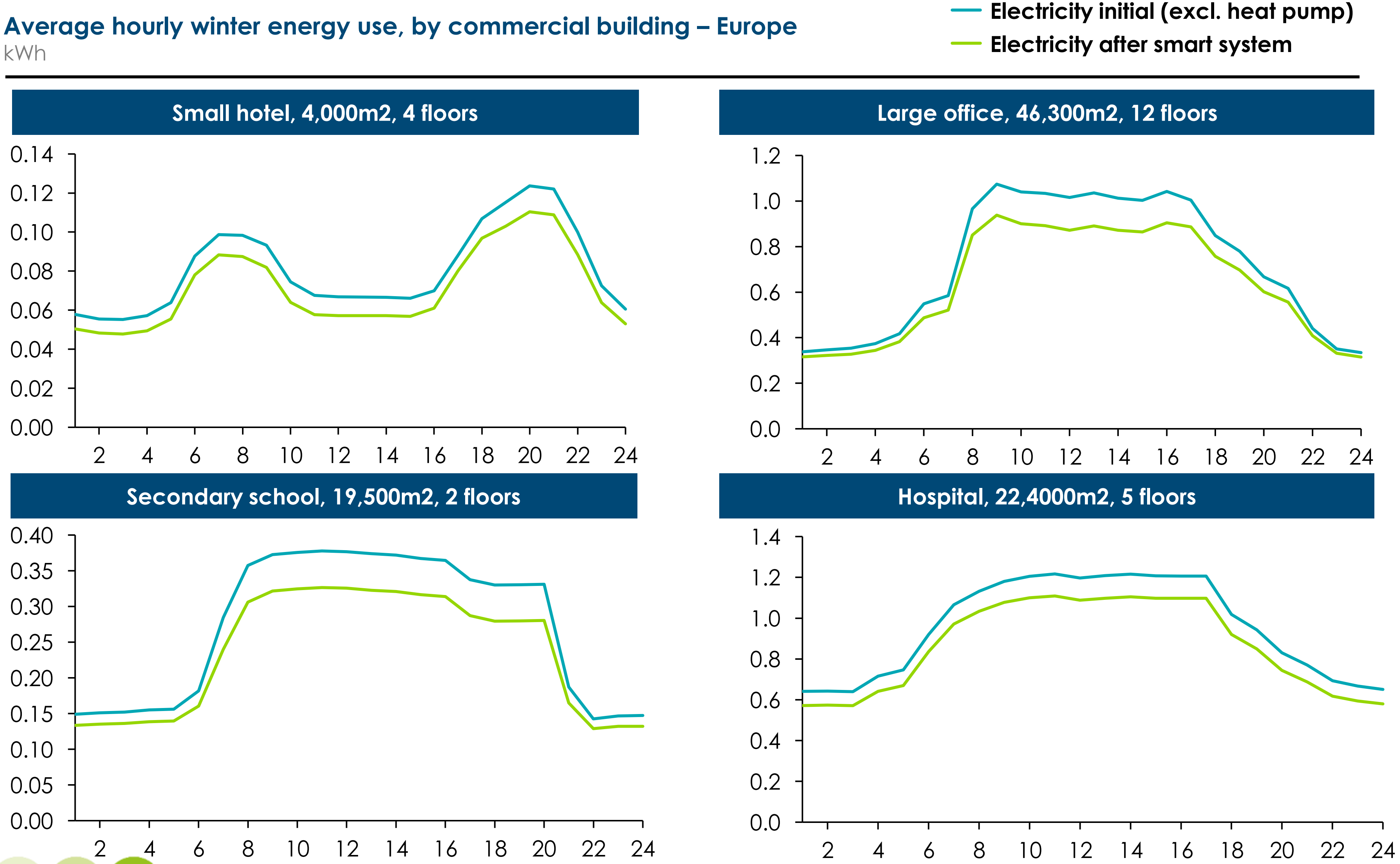
- Sensors (e.g., turning lights off automatically, sensing where office spaces are less occupied)
- Controlling heating and cooling automatically
- Application of analytics and AI (see next slide)
- Predictive maintenance and self-diagnosing
- Knowledge reporting and learning

Sources: Schneider Electric (2020), Three Essential Elements of Next Generation Building Management Systems.
Note: IoT refers to the Internet of Things – describes the network of interrelated devices which connect and exchange data with other IoT devices and the cloud.

# Generally, BMS has very positive economic paybacks and are no-regrets solutions

**Average hourly winter energy use, by commercial building – Europe**

kWh



Paybacks to BMS go beyond just energy savings:

- Reduce HVAC runtimes and extend equipment life
- Defer capex on retrofits
- Improve comfort, wellbeing and productivity

Source: Systemiq analysis for the ETC (2024) of Schneider Electric Sustainability Research Institute
Note: winter is defined as November to February

# Example: BMS are becoming even more innovative with the use of AI, to respond in real time to changes in weather, building use and the grid

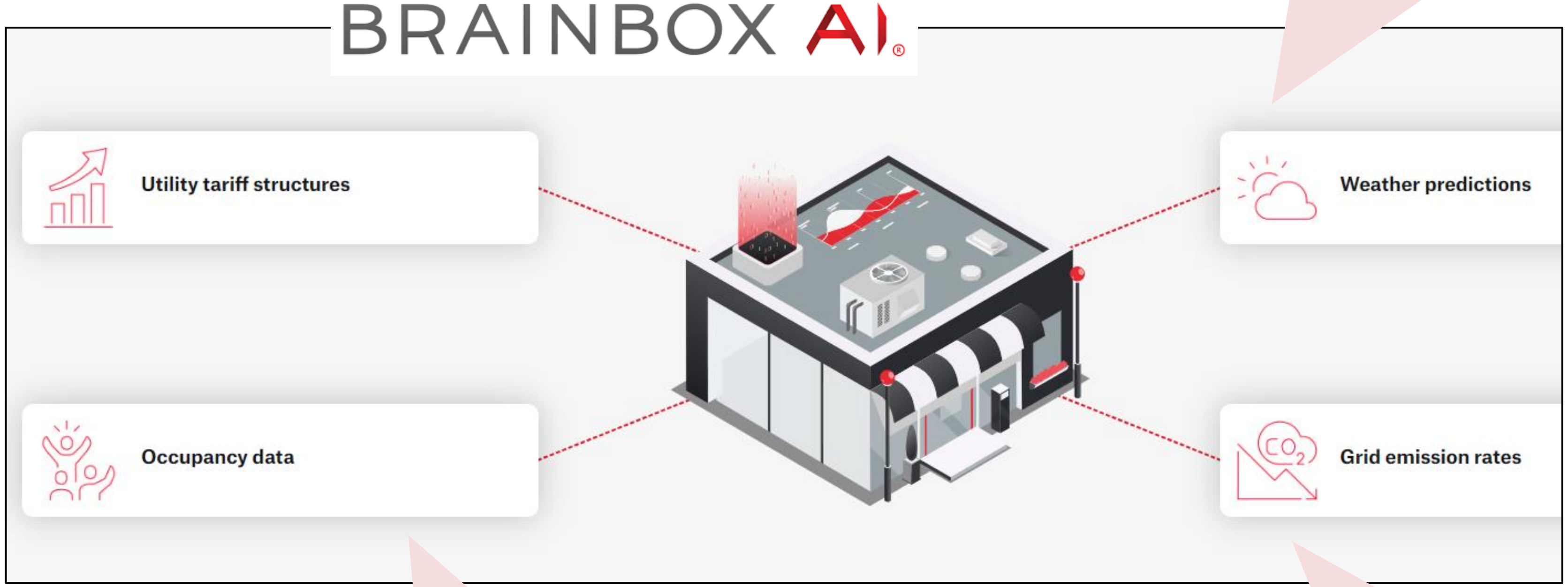
**Case study: Brainbox AI**

- System uses information on weather, occupants and grid mix/prices
- Autonomously controls individual pieces of HVAC equipment – makes adjustments every 5 minutes
- AI predicts the future state of building over time as it learns behaviours and patterns
- On average:

**10-20%**
**Reduction in HVAC energy consumption**

**5-10%**
**Reduction in total energy consumption**

**Responds in real time to changes in…**



*If the weather is expected to be warmer than normal, it can automatically reduce pre-heating overnight*

*If the building is especially busy, it can anticipate that it might be warmer and increase cooling*

*If the grid is especially fossils-dominated or if peak prices spike, it can reduce heating/cooling to lower temperature bounds*

Source: Brainbox AI

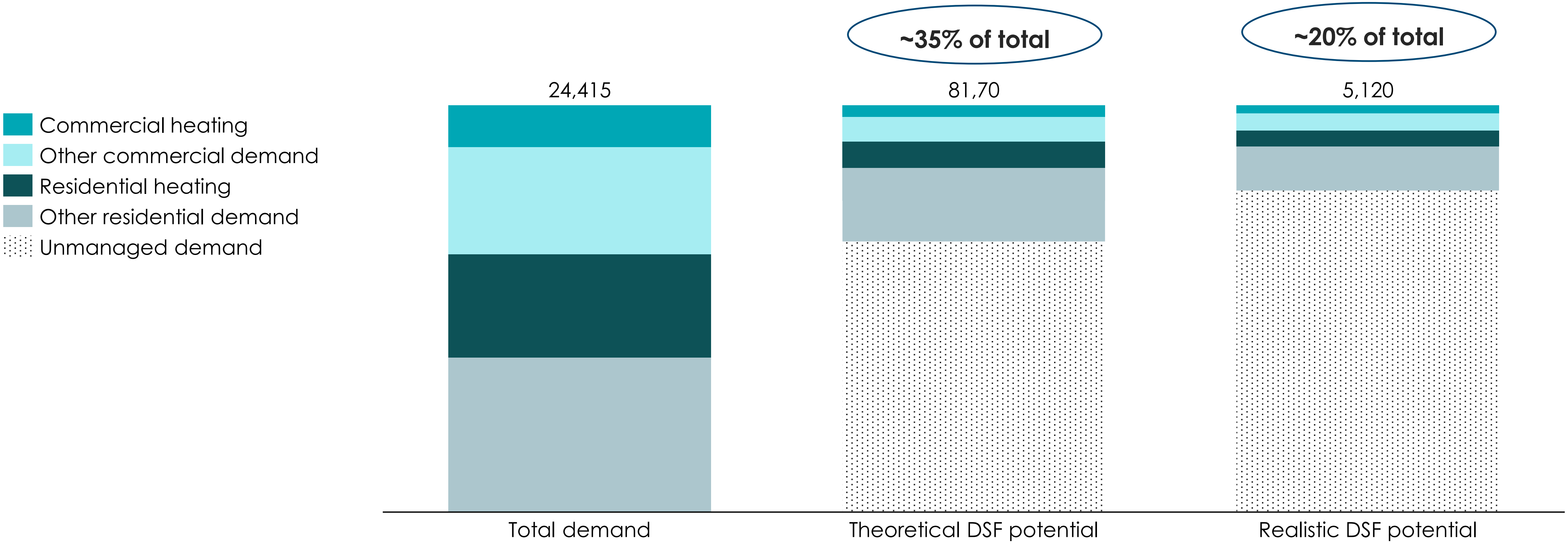
# Assessing overall potential for DSF in buildings (heating, cooling, lighting & appliances)

| Barrier Group | Rating | | |
|---|---|---|---|
| | Residential | Commercial | Key differences |
| ① **Which technological and operational barriers exist?** | 🟩 | 🟩 | • More and more residential buildings are equipped with **basic technologies** like smart thermostats, **but adoption** (e.g., integrated HVAC control, smart appliances) **is still growing**<br>• Commercial buildings often have **advanced, centralized HVAC and lighting systems**. Larger scale operations mean that technological upgrades are more common and easier to implement |
| ② **Are these solutions economically possible?** | 🟥 | 🟨 | • **Higher upfront costs combined with uncertain or longer payback periods** can be a significant barrier, especially for low-income households. Individual households also have **limited access to financial incentives** or bulk purchasing<br>• Commercial buildings have **more access to capital and financing options**, and better access to government incentives and subsidies |
| ③ **Are there regulatory and policy requirements that must be met?** | 🟨 | 🟩 | • Regulatory frameworks for residential DSF are **still evolving**, with varying support and incentives across regions<br>• Commercial buildings are more likely to be **subject to energy regulations and standards** that encourage the adoption of DSF technologies. In addition, larger businesses have **more resources** to navigate and comply with regulatory requirements |
| ④ **Are there social & behavioural barriers?** | 🟥 | 🟨 | • Household energy use is **highly individual** and driven by personal comfort, convenience, and habits, making it harder to implement consistent DSF strategies<br>• In commercial settings, energy management is **typically more structured**, with dedicated personnel responsible for energy use and efficiency |

# Around 20% of building electricity demand can be flexible in 2050

## Global electricity demand from buildings and DSF potential, 2050

TWh



Source: Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Industry

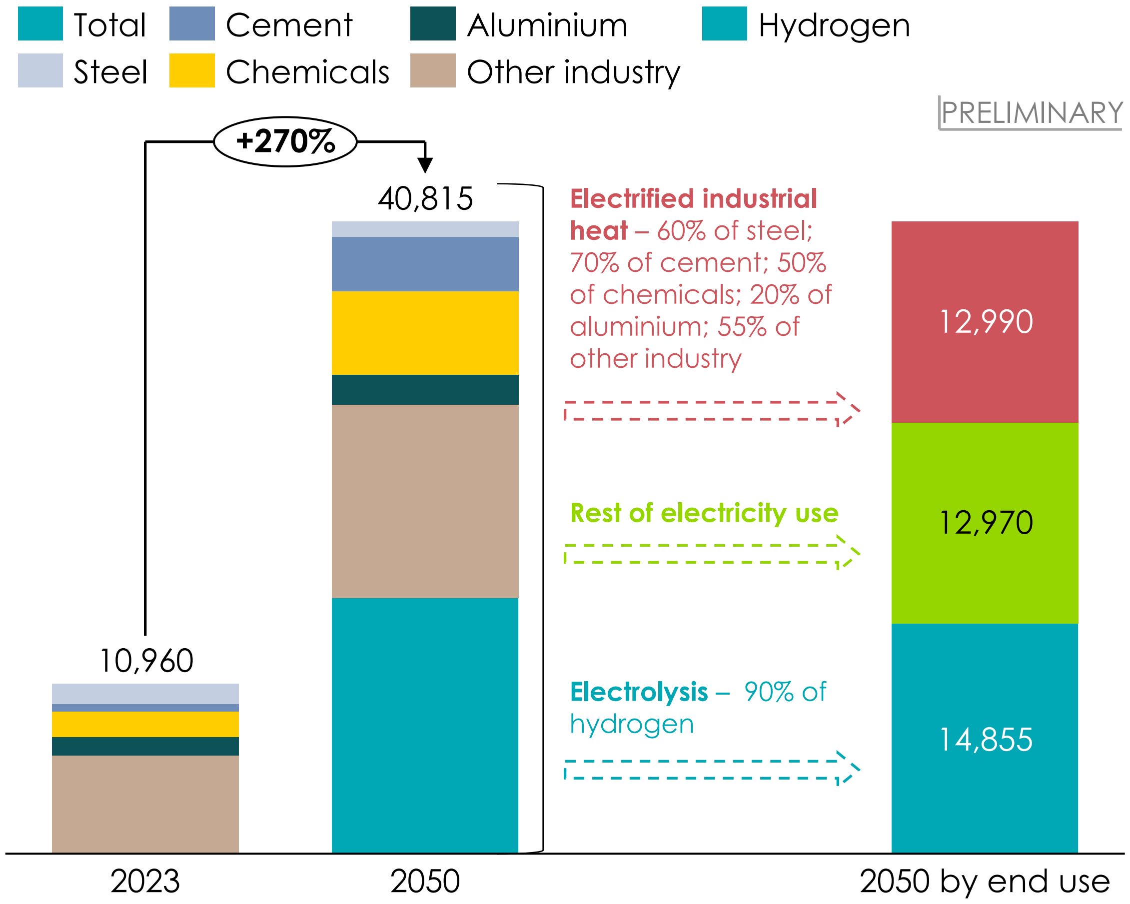
# Industrial DSF depends on industry need – with implications for flexibility route

| Key categories | % of total electricity demand in 2050 | Type of load | Key DSF route examined | Specific case studies considered |
|---|---|---|---|---|
| **Electrified industrial heat** (low-medium-high temperature) | 17% | Primarily requires a continuous electricity supply | Distributed storage (e.g. heat battery), minimal load shifting | Heat battery (e.g., Rondo) |
| **Other industrial processes** (e.g., running motors, texturing machine, air compressor, data centers, etc.) | 17% | Includes both "batch" processes where electricity consumption is stop-start (e.g., food, paper), as well as processes which primarily require a continuous electricity supply (e.g., plastic extrusion) | Load shifting/shedding | Aluminum, data centres |
| **Hydrogen electrolysis** | 19% | Highly flexible in the nature of production | Load shifting/shedding | N/a |

# Three key industrial sectors are defined based on their types of electricity demand

## Global industry electricity demand by sector, 2050

TWh



**Electrified industrial heat** – 60% of steel; 70% of cement; 50% of chemicals; 20% of aluminium; 55% of other industry

**Rest of electricity use**

**Electrolysis** – 90% of hydrogen

### Electrified heat

**A. Electrified industrial heat** covers industrial processes that require **significant heat input**, traditionally provided by fossil fuels, but increasingly electrified to achieve net zero 2050

- Examples include electric boilers, kilns, and furnaces used in industries like chemicals, cement, and glass

### Non-heat demand

**B. Other industry demand** is a variety of industrial activities such as machining, assembly, packaging, and routine maintenance. These processes can have both **batch as well as continuous consumption needs**

**C. Hydrogen production via electrolysis**

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

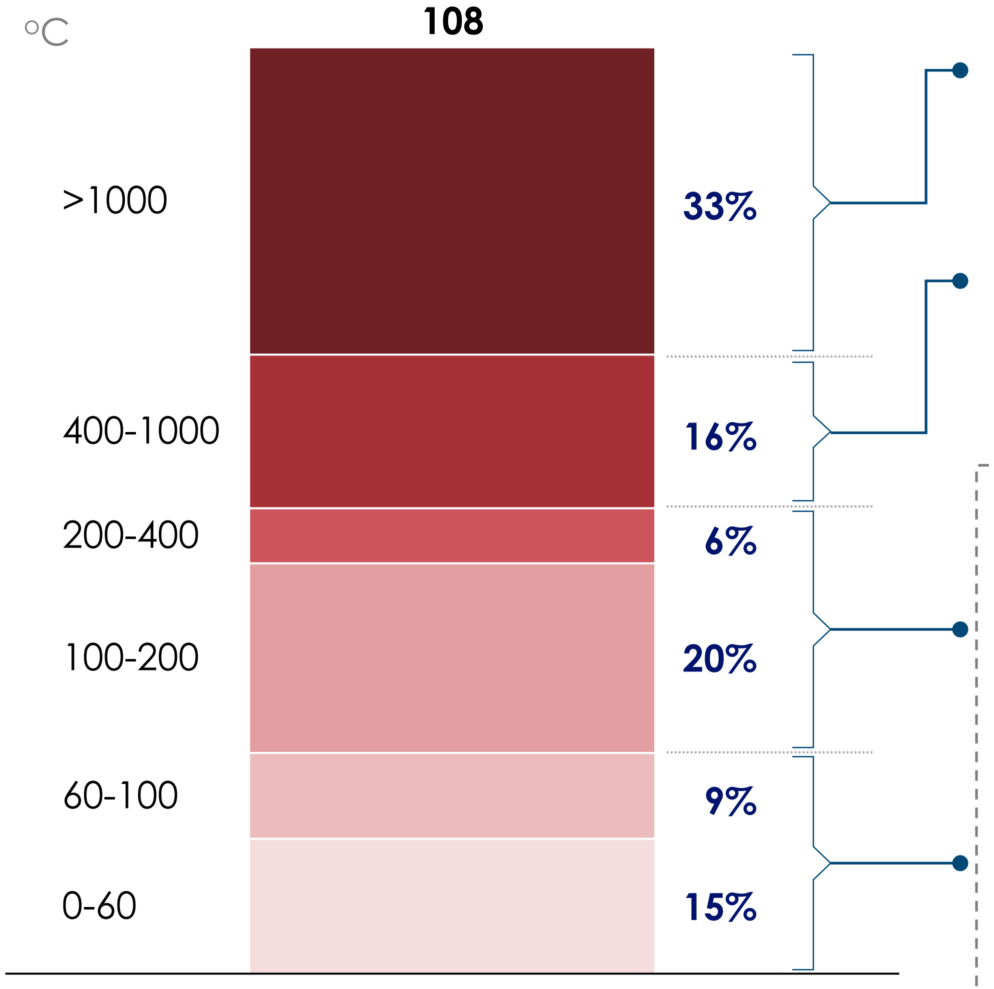
# On average, DSF potential in industrial sectors is around 20-30% of total load

| | **Major flexibility sources / devices** | | **DSF temporal parameters** | | | **DSF potential (of total load)** (based on RMI) |
|---|---|---|---|---|---|---|
| **Industry** | **Industrial heat** | **Non-heat processes** | **Lead time** | **Response duration** | **Recovery time** | |
| **Electrolytic aluminium** | | **Aluminium smelting** | 2h (aluminium reduction cell) | 1-2h | 2h (aluminium reduction cell) | 20% |
| **Steel** | **Electric arc furnace** | **Rolling line** | Per shift (steel rolling)<br>10-30 min (electric arc furnace) | 0.5-1h | Per shift (steel rolling)<br>10-30 min (electric arc furnace) | 20% |
| **Cement** | **Rotary kiln, vertical kiln** | | 1-2h | 0.5-2h | 1-2h | 24% |
| **Ferroalloy** | **Submerged arc / electric arc / reduction furnace** | | 1-2h | 0.5-4h | 1-2h | 30% |
| **Textile** | | **Loom, texturing machine** | 0.5-1h | 0.5-4h | 0.5-1h | 35% |
| **Glass** | **Annealing kiln, glass melting kiln** | **Air compressor, cold end glass cutting machine** | 0.5-2h | 0.5-3h | 0.5-2h | 25% |
| **Equipment manufacturing** | **Melting / heat treatment / high frequency furnace** | | 1-2h | 0.5-3h | dsf 1-2h | 20% |

Source: RMI (2023), *Unlocking demand-side flexibility in China*

# A Heat is required in virtually every industrial process; temperatures vary considerably across uses and sectors

**Industrial heat demand by temperature range (EJ)**



**Example heat use**

**Very high temperature (>1000°C)**

- Calcination of limestone for cement
- Melting in glass furnace

**High temperature (400-1000°C)**

- Steam reforming and cracking
- Hydrogen heating for DRI

**Medium temperature (100-400°C)**

- Drying
- Evaporation
- Distillation
- Activation

**Low temperature (<100°C)**

- Washing
- Rinsing
- Cooking
- Sterilisation

**Tech**

**Electric arc**

- 400 – 1000 C
- Limited applications

**Electro-magnetic**

- 0 –1000 C
- Potential to satisfy both light and heavy industry (low and high temperatures)

**Resistive** (E-boiler/ E-furnace, heat battery-boiler)

- 0 –1000 C
- Potential to satisfy both light and heavy industry (low and high temperatures)

**Heat pump**

- 0 –300 C
- Potential for huge efficiency gains

**Example end use sector**

Cement
Glass and ceramics
Iron and steel

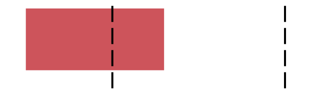
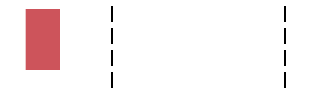
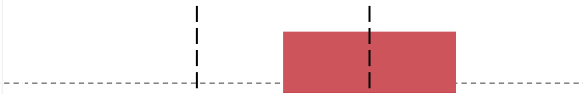
Aluminium
Chemicals

Food and beverage
Textiles
Paper, wood
Plastics
Pharmaceuticals
Agro-industry
Chemicals

Source: McKinsey (2024), *Net-zero electrical heat: A turning point in feasibility*

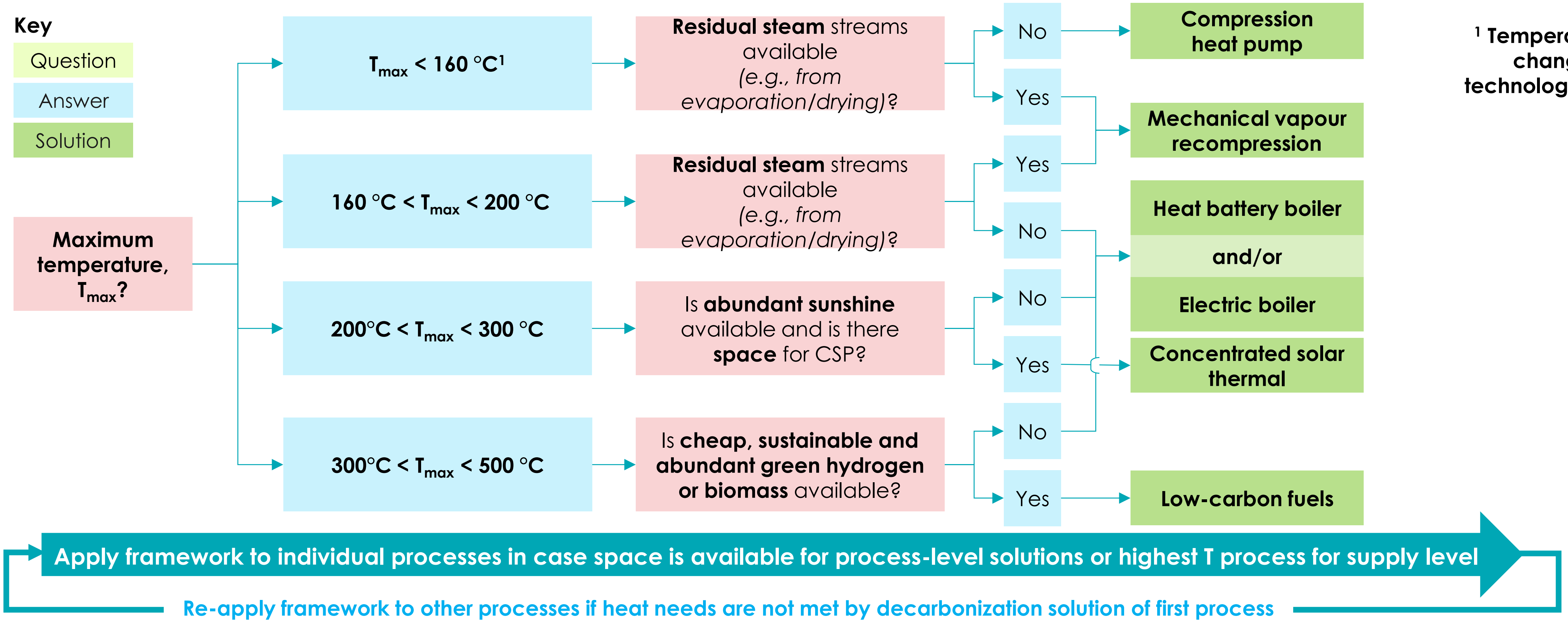
***Huge potential for cross-sectoral solutions – economies of scale + learning effects***

# Case study: Kraft Heinz has mapped its heating needs for food preparation process, typically do not exceed 200 °C

| **Process** | | | TEMPERATURE RANGE (° C)<br>0 100 200 300 | Applicable KHC products *(non-exhaustive)* | Applicable KHC sites *(non-exhaustive)* |
|---|---|---|---|---|---|
| **Pasteurization** | | A controlled heating process to remove microorganisms |  |  | Neropolis, Northgate, Champaign, Lowville, *etc.* |
| **Evaporation** | | Partial removal of water from a liquid by boiling |  |  | Hastings, Neropolis, Pudliszki, Kendalville |
| **Drying** | | Applying heat to remove water from liquid foods |  |  | Fort Myers, Dover, Ivanovo, Georgievsk, |
| **Cooking** | **Boiling** | Cooking by submersion in hot water |  |  | Kitt Green, Hastings, Latina, Tomoana, Fort Myers, Jacksonville, Kendalville, Fremont, *etc.* |
| | **Frying** | Cooking via submersion in hot oil |  | | |
| | **Baking/ Roasting** | Cooking via hot air in baking ovens |  | | |
| **Retorting** | | Heating packaged food in a pressure cooker/retort to achieve sterilization |  |  | Escalon, Garland, Kitt Green, *etc.* |
| **Sterilization** | | Destruction/elimination of all living organisms through heating |  |  | |
| **Refrigeration** | | Storage of food in walk-in cold rooms or refrigerators |  | | |

Source: Sovacool et al. (2021), Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options; Desktop research

# The proposed electrified heating solution hence depends on the maximum temperature required on-site or in a specific process



**Key**

Question

Answer

Solution

**Maximum temperature, $T_{max}$?**

$T_{max}$ **< 160 °C**[1]

**Residual steam** streams available *(e.g., from evaporation/drying)?*

No → **Compression heat pump**

Yes → **Mechanical vapour recompression**

**160 °C <** $T_{max}$ **< 200 °C**

**Residual steam** streams available *(e.g., from evaporation/drying)?*

Yes → **Mechanical vapour recompression**

No → **Heat battery boiler and/or Electric boiler**

**200°C <** $T_{max}$ **< 300 °C**

Is **abundant sunshine** available and is there **space** for CSP?

No → **Heat battery boiler and/or Electric boiler**

Yes → **Concentrated solar thermal**

**300°C <** $T_{max}$ **< 500 °C**

Is **cheap, sustainable and abundant green hydrogen or biomass** available?

No → **Heat battery boiler and/or Electric boiler**

Yes → **Low-carbon fuels**

**Apply framework to individual processes in case space is available for process-level solutions or highest T process for supply level**

**Re-apply framework to other processes if heat needs are not met by decarbonization solution of first process**

**Meeting heat demands with zero-carbon solutions *(illustrative example)***

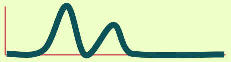
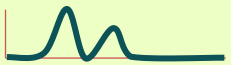
---

[1] **Temperature ranges can change subject to technological improvement**

# Ⓐ Medium-temp e-boiler/furnace (~25% heat demand) and heat battery-boiler can provide DSF among other available electrification technologies

INDICATIVE

▨ Scope 1
▨ Scope 2

| | | | | System integration | | | | | Energy cost (OpEX) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Description** | **Energy Efficiency** (incl. transmission losses) | **Grid requirement** (Load profile) | **Grid flexibility services** | | **Energy storage** | **Emissions**[1] **for full heat load,** tCO2/MWh(th) | | |
| | | | | | **Demand side** | **Supply side** | | | | |
| **Heat pump** | **Com-pression** | - Transfer of heat from outside/ground/waste heat<br>- Grid connected | High<br>200%-500% |  | No<br>Unless at partial heat load duty | No | No<br>Unless comb. w/ TES | 0.10[2] | Low | Most attractive technology for temperatures up to 160 C |
| | **Recom-pression** | - Mechanical vapour recompression<br>- Grid connected | High<br>300%-1000% | | | | | 0.06[2] | | |
| **Resis-tive** | **E-boiler/ E-furnace Full load** | - Replaces gas boiler 1 on 1 and runs 24/7<br>- Grid connected | Medium<br>95% |  | No | No | No | 0.31[2] | Medium | |
| | **E-boiler/ E-furnace 25% load** | - Used for energy arbitrage<br>- Only charges during 6 hours with lowest power prices, hence during high renewable generation<br>- Gas boiler used for remaining 75% of time | |  | ✓ | No | | 0.16[1] | Low | |
| | **Heat Battery-Boiler** | - Replaces gas boiler entirely, discharging heat 24/7<br>- Charges on 6 (distributed) hours with lowest power price, hence during high renewable generation | Medium<br>93% |  | ✓ | [4] | ✓ | 0.00 | Low | Most attractive technology for temperatures ranges 160+C |

Provides DSF

---

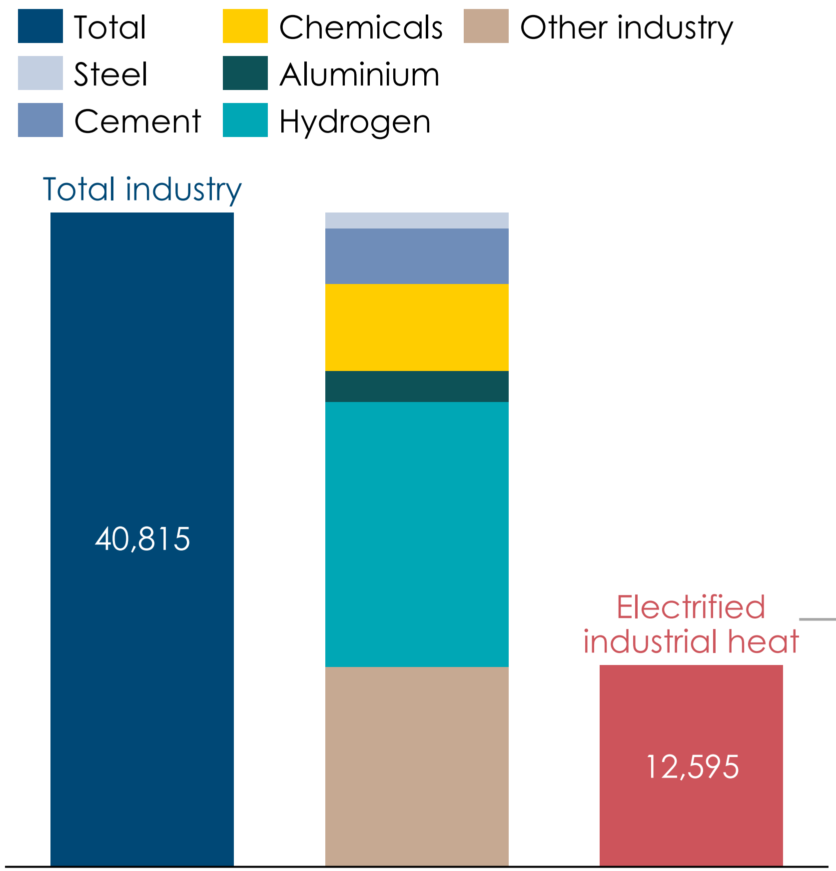
1 E-boiler & heat-pump load emissions based on NL 2020 average power grid emission intensity (0.29 tCO2/MWh, production 60% gas-based, 6% coal-based and 27% renewables-based) and 95% efficiency. E-boiler 25% load: 25% based on fully renewable power (0 t CO2/MWh) and 75% based on natural gas boiler with 95% efficiency and gas emission factor of 56.6 kgCO2/GJ. Heat Battery-Boiler assumed to charge only during fully renewable hours (0 t CO2/MWh). Hydrogen assumed to have dedicated renewables (0 t CO2/MWh). Reference natural gas boiler assumed of 95% efficiency and gas emission factor of 56.6 kgCO2/GJ. 2 Zero if green PPA / on-site renewables 3 Preferred to be produced by dedicated renewables. 0,54 tCO2/MWh(th) emissions if produced by grid power with 0,29 tCO2/MWh emission intensity. 4 In CHP mode

Source: PBL (2022), *Klimaat- en Energieverkenning*; PBL (2022), *Nederlandse lijst van energiedragers en standaard CO2-emissiefactoren, versie januari 2022*; World Bank / IEA (2018); IRENA (2018); Esteban (2021); IEA (2010); Rondo Energy; Thiel et al (2019); Ambienta (2023); Madeddu et al. (2020) *The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat)*

# A DSF for electrified industrial heat is primarily achieved through thermal energy storage (TES), which allows for the shifting of heat generation

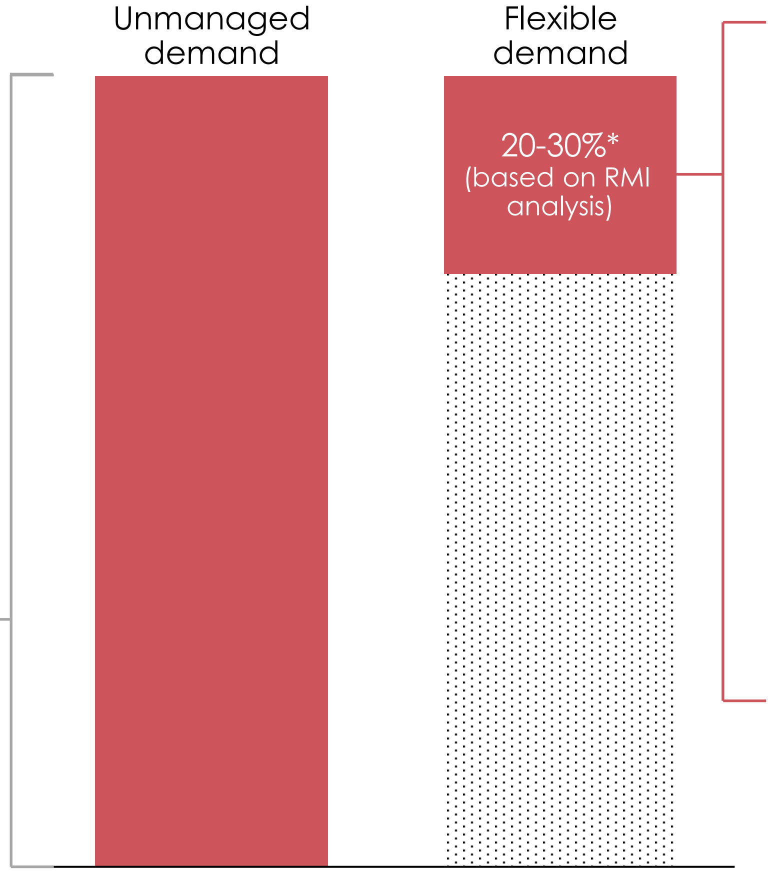
## Global industry electricity demand, 2050

TWh



## Global electrified industrial heat theoretical DSF potential*, 2050

TWh



**Thermal Energy Storage** (TES): Stores excess thermal energy (e.g., in hot water tanks, molten salts, or phase-change materials) generated during off-peak hours for use during peak

**Electrified Kilns and Furnaces**: Use electric resistance or induction heating for high-temperature processes, which can be scheduled or modulated to respond to grid conditions

**Hybrid Heating Systems**: Combine electric heating with alternative fuel sources (e.g., biofuels or hydrogen) to provide flexibility

*Note: Defining industry demand peak load is challenging due to the variability in production cycles, differing energy needs across processes, and the influence of external factors like market demand. This complexity makes it harder to pinpoint peak periods, so our analysis focuses on overall flexibility potential which could be deployed in response to peak periods on the overall grid, rather than specific peak load patterns, unlike more predictable sectors like residential heating

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; RMI (2023), *Unlocking demand-side flexibility in China*; McKinsey (2024), *Net-zero electrical heat: A turning point in feasibility*

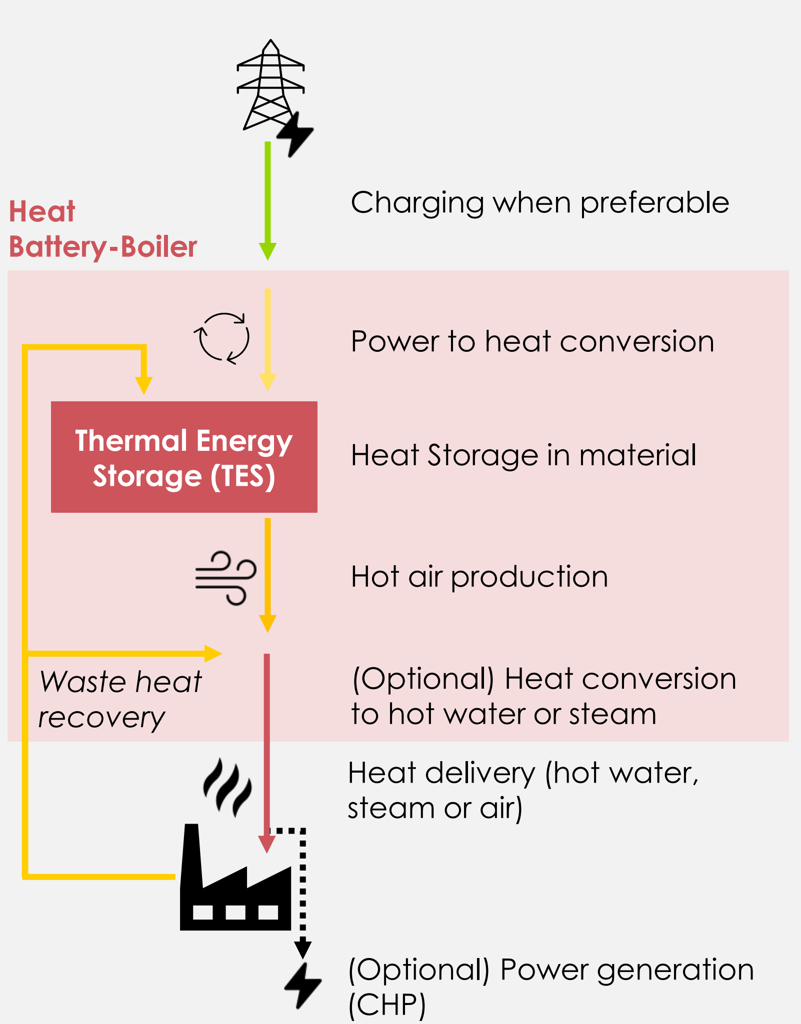
# Ⓐ Insufficient policy and the lack of standardized practices can hinder the widespread adoption and effectiveness of TES for industrial heat

| | Criteria | Details |
|---|---|---|
| **Tech** | Underlying electrification technology | • Technologies for electrification of heat up to around 600 C are **already mature**<br>• Very high-temperature heat sectors are **available** but at an early stage of market maturity |
| | Enabling technology | • Thermal energy storage are **well-established** and is gaining market interest |
| **Financial** | Cost and payback period | • The **initial capital costs** for retrofitting existing systems or installing new technologies like TES can be significant. However, the long-term operational savings and incentives (where available) can offset these costs<br>    • Thermal storage can be **combined with both grid storage and low-cost, behind-the-meter generation**<br>    • The economic is supported by the decreasing costs of renewable energy generation – under the right conditions, electrification could **pay back within a year** |
| | Investment attention | • As of January 2024, TES players have accumulated **over US$600M in funding**, to develop and commercialize their technologies, and to increase manufacturing capacity |
| **Policy** | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022, Denmark, Estonia, Finland, Norway, Spain, Sweden, The Netherlands and The United Kingdom |
| | Interoperability and other technical / safety standards | • Many industries are unfamiliar with baseline loads to ensure production quality and security |
| **Behaviour** | Lack of awareness | • Leadership may be resistant to demand response practices due to a lack of knowledge |
| | Inertia/resistance to change | • Established processes, particularly in industries with long-standing practices<br>• Employee resistance due to the need to learn new skills |

Source: RMI (2023), Unlocking demand-side flexibility in China; McKinsey (2024), Net-zero electrical heat: A turning point in feasibility

# Ⓐ A heat battery-boiler combines existing technologies by integrating a TES with electric resistance to supply heat; multiple new solutions in this category

## A heat battery-boiler combines existing tech



**Heat Battery-Boiler**

Charging when preferable

Power to heat conversion

**Thermal Energy Storage (TES)**

Heat Storage in material

Hot air production

*Waste heat recovery*

(Optional) Heat conversion to hot water or steam

Heat delivery (hot water, steam or air)

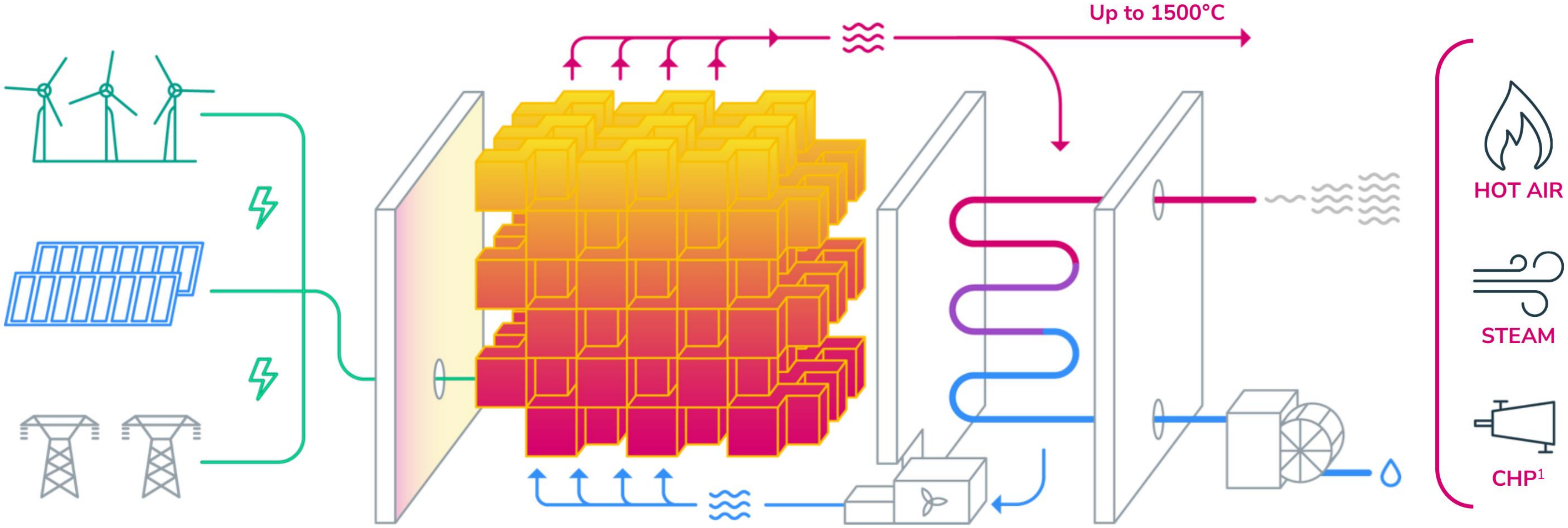
(Optional) Power generation (CHP)

## Multiple new solutions are now offered in this category

| | RONDO | KRAFT BLOCK | ENERGYNEST | And others[2] |
|---|---|---|---|---|
| **Company Origin** | US | Germany | Norway | Brenmiller<br>Kyoto Group<br>LUMENION<br>MGA Thermal<br>Polar Night Energy<br>SaltX<br>Siemens Gamesa |
| **# Units live** | 1 pilot operational, 1 under construction (Calgren) | 1 under construction (PepsiCo) | 1 pilot operating, 3 projects under construction | |
| **Temp Range** | Up to 1,500 C | Up to 1,000C (Net-Zero Heat System) | Up to 400C | |
| **Efficiency** (Roundtrip) | 98% | 98% | 95% | |
| **Storage Material** | Standard fire bricks | Iron slag | Steel and thermal concrete | |
| **Lifetime** | Up to 40 years | Up to 40 years | 30-50 years | |

**Deep dive next**

# A Rondo has developed a heat battery capable of meeting heating needs at temperatures up to 1500°C



**① CHARGE 6-8 hours / day**

The Rondo Heat Battery charges with **intermittent electricity** from local wind & solar or from the grid

**② STORE for hours or days**

Electricity powers radiant heaters with zero loss; refractory brick is rapidly and uniformly heated to **1100 - 1500°C**, and stores heat for hours or days

**③ DISCHARGE 24 hours / day**

The battery delivers **continuous superheated air** for use as process heat, steam, or electric power at over 98% total efficiency

**98% energy efficient** from electricity IN to heat/steam OUT

Source: Rondo (2024)

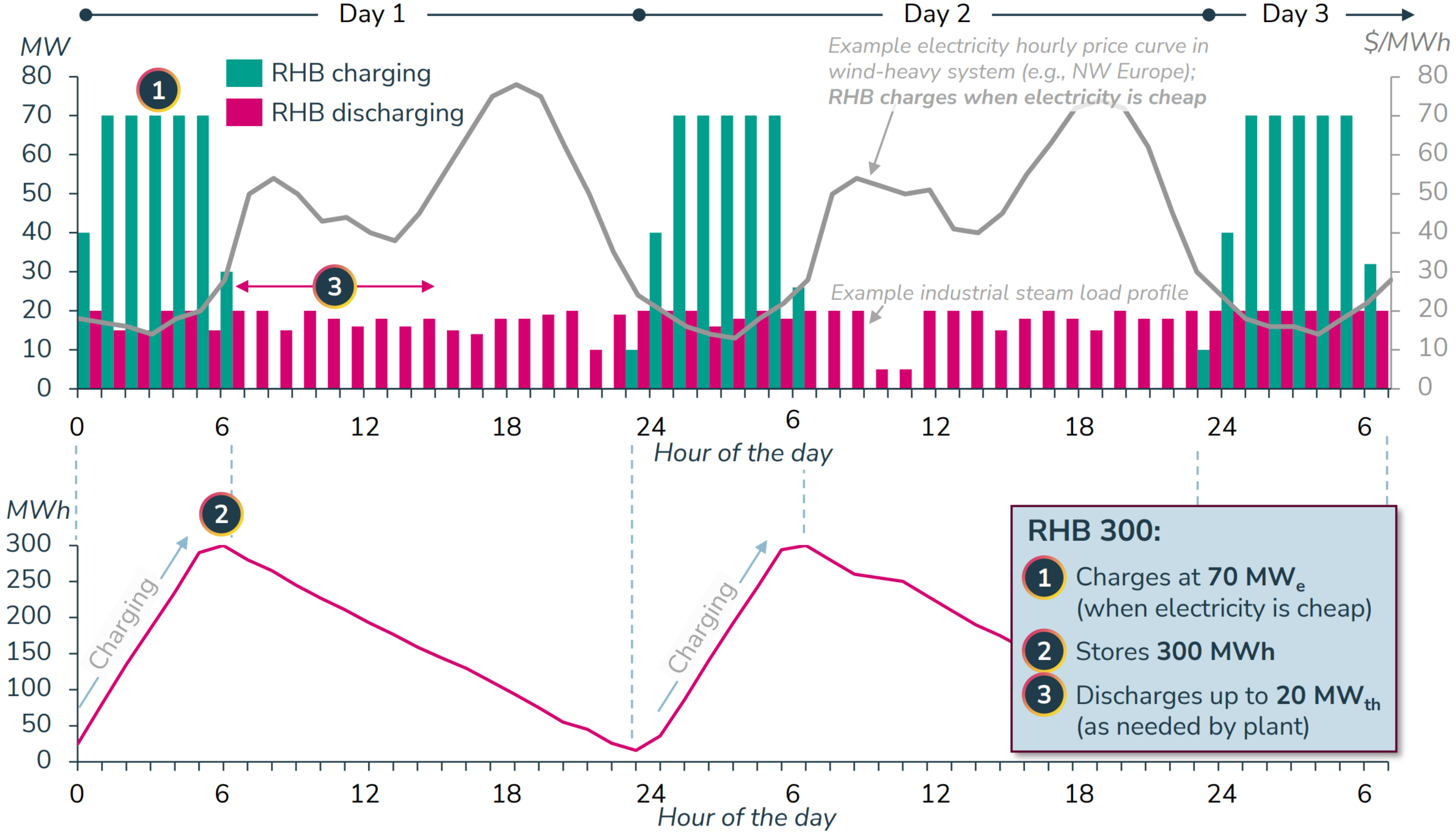
# Ⓐ The battery can leverage 6-8 hours of cheap electricity and turn it into baseload steam or hot air

Rondo Heat Battery (RHB)
**CHARGE & DISCHARGE**

Example pattern for RHB300¹

Rondo Heat Battery (RHB)
**STORAGE**

Energy stored in RHB



*Example electricity hourly price curve in wind-heavy system (e.g., NW Europe);*
***RHB charges when electricity is cheap***

*Example industrial steam load profile*

**RHB 300:**

① Charges at **70 MW$_e$** (when electricity is cheap)

② Stores **300 MWh**

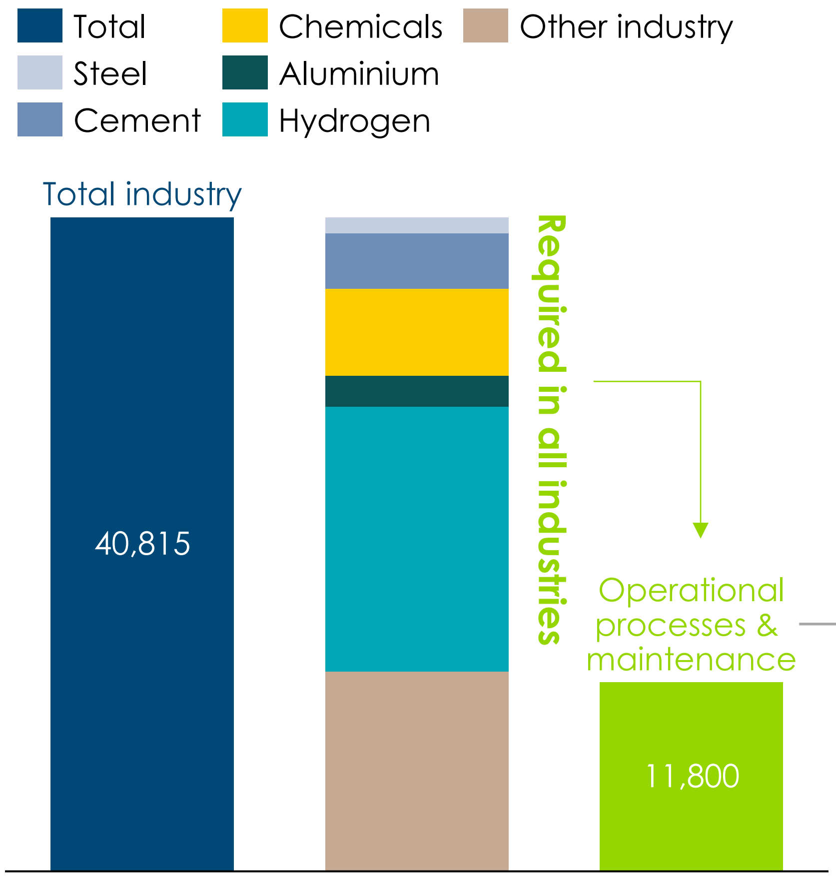
③ Discharges up to **20 MW$_{th}$** (as needed by plant)

Source: Rondo (2024)

# B Industries can adjust or shift load patterns during planned downtime and maintenance periods to enhance overall grid stability and flexibility

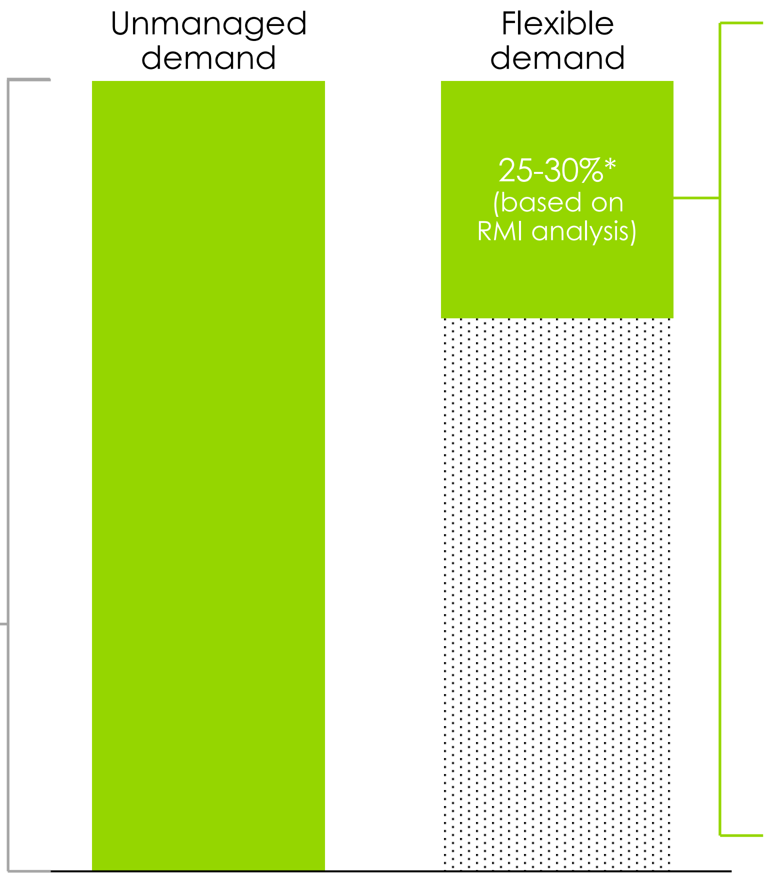
## Global industry electricity demand, 2050

TWh



## Global theoretical DSF potential, 2050

TWh



**Automated Load Management:** Systems that automatically adjust or reschedule non-essential industrial processes based on electricity pricing and grid conditions

**Flexible Manufacturing and Maintenance**:

- **For continuous processes** (e.g., steel, cement): design production lines with built-in flexibility, enabling smooth adjustments in production speed without interrupting the overall process
- **For batch processes** (e.g., food, paper, some chemicals): incorporate systems that enable entire shifts or batch runs to be easily moved, without disrupting downstream processes or overall production timelines

**Strategic Shutdowns**: In some cases, strategic, well-planned shutdowns can be scheduled during peak electricity demand periods, but this must be done cautiously to avoid damaging the equipment or disrupting production

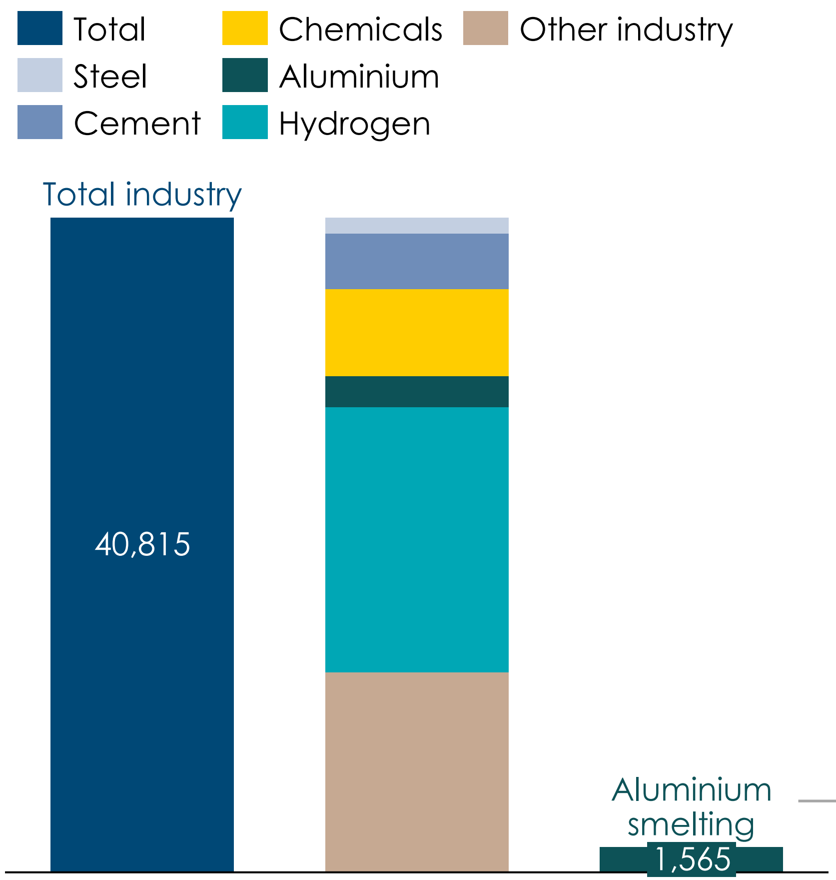
**Lighting and appliances flexibility**

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; RMI (2023), *Unlocking demand-side flexibility in China*

# B Case study: in aluminium electrolysis, real-time power consumption can be adjusted dynamically

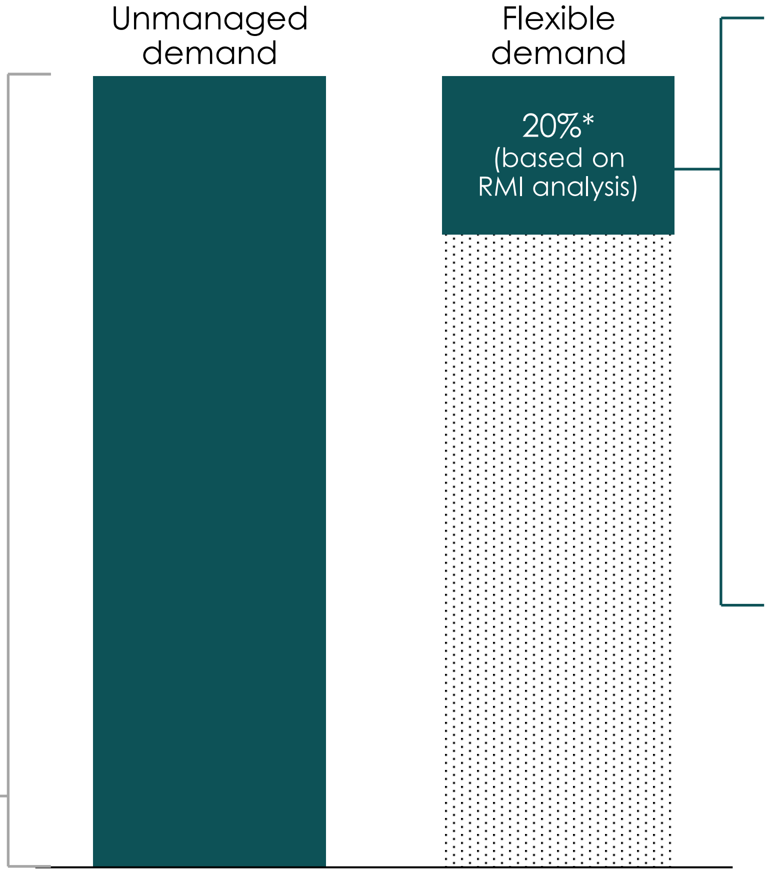
## Global industry electricity demand, 2050

TWh



## Global aluminium theoretical DSF potential, 2050

TWh

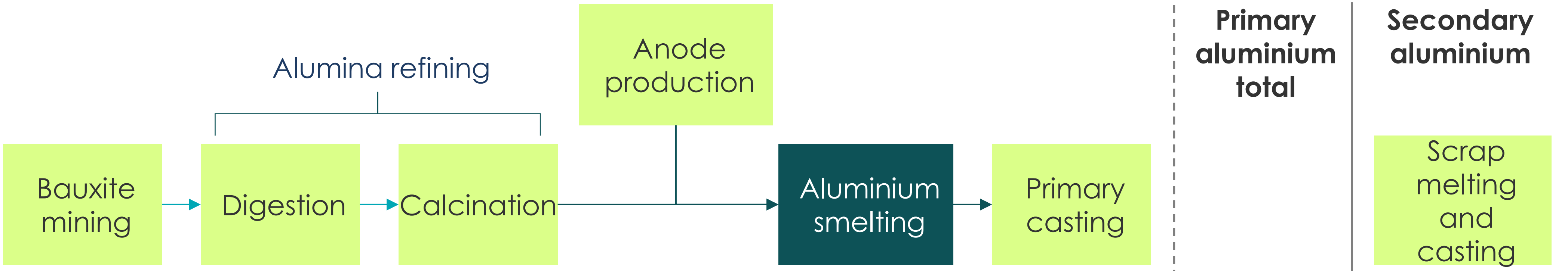


**Aluminium electrolysis**: industry can change the real-time power consumption through an automatic control system and without interrupting the melting furnace

When there is insufficient or excessive electricity supply, melting furnaces in the electrolysis tanks will reduce or increase the input voltage, respectively, or they can generate large load variation in a short time through the start and shutdown of different electrolysis tanks to provide flexibility

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; RMI (2023), *Unlocking demand-side flexibility in China*; Yu et al. (2022), *Adaptive load control of electrolytic aluminum for power system frequency regulation based on the aluminum production operation state*

# B The key DSF potential lies in the aluminium smelting process



Alumina refining

| | Bauxite mining | Digestion | Calcination | Anode production | Aluminium smelting | Primary casting | Primary aluminium total | Secondary aluminium<br>Scrap melting and casting |
|---|---|---|---|---|---|---|---|---|
| **Energy** gigajoules/t Al | 0.1[1] | 7.3[2] | 3.3[1] | 2.8[1] | 52[3] | 1.1[1] | ~66 | 3.3 |
| **GHG** t $CO_2e$/t Al | <0.1[3] | 1.8[3] | 0.8[3] | 0.5[3] | 12.8[3] | 0.1[3] | ~16 | 0.5 |
| **Material requirements** | | About 2-3 t bauxite for 1 t alumina | | About 0.4-0.45 t carbon anodes for 1 t Al | About 1.9-1.95 t alumina for 1 t Al | | | |

**Key process for demand-side flexibility**

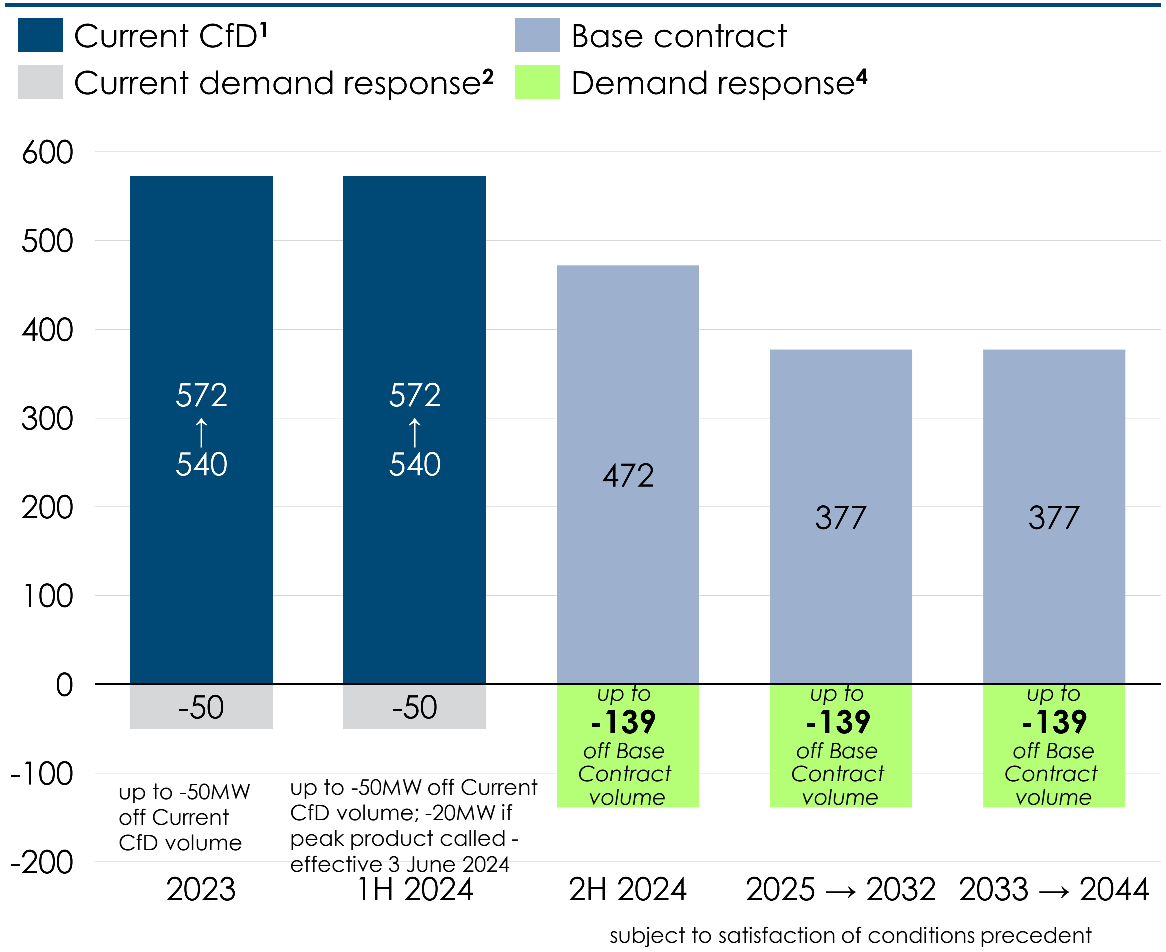
[1] 2015 IAI global average. [2] 2020 IAI global average. [3] 2018 IAI global average.

Source: International Aluminium Institute (IAI); European Aluminium; World Economic Forum

# B New Zealand’s Aluminium Smelter signed DSF agreements that turns the smelter into a giant battery

**NZAS demand-side flexibility contracts**

MW



Meridian Energy and Rio Tinto have conditionally signed a package of long-term contracts for part of the New Zealand’s Aluminium Smelter (NZAS) Tiwai Point aluminium smelter’s electricity needs

The package includes a **long-term fixed price contract for wholesale electricity price cover** (Base Contract) **and a DSF agreement**

- The DSF agreement gives Meridian four DSF options that **incentivise the smelter to reduce consumption**, through **reduced voltage, flexible maintenance** and **strategic shutdown**
- The sizes of the four demand options are **138.75MW, 75MW, 37.5MW, 18.75MW**
- Exercise of a demand option will **incentivise NZAS to reduce consumption by 185MW, 100MW, 50MW or 25MW** (as applicable)
- **Payment of half of the annual premium depends on NZAS's compliance with DSF calls**
- **Strike price payable based on actual reduction**

1. Follows smelter load, with minimum volume of 540MW and maximum volume of 572MW. 2. If called, the current demand response reduction volume of up to 50MW comes off the volume of the Current CfD between Meridian and NZAS. Meridian and NZAS have separately agreed an up to 20MW peak demand response agreement for winter 2024 (effective 3 June 2024). 3. If called, the demand responsereduction volume comesoff the volume of the Base Contractbetween Meridian and NZAS.

Source: Meridian Energy (2024), *NZAS Contract Announcement*

# B Aluminium has low technological barriers and strong economics, making it a viable option for industry flexibility

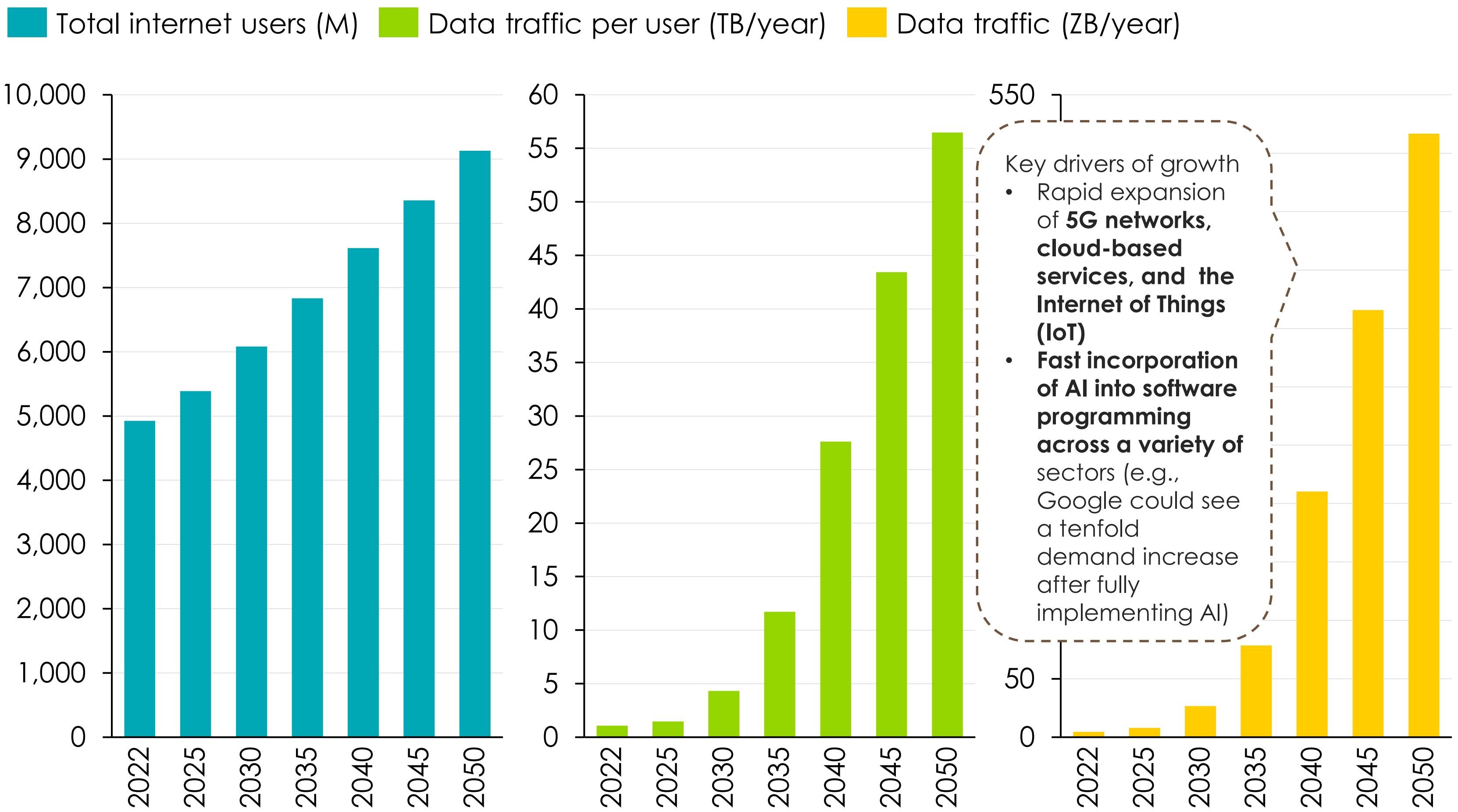
| | Criteria | Details |
|---|---|---|
| Tech | Enabling technology | • The necessary technology, such as automated control systems, is **being integrated into modern aluminium smelters**. The operational processes are **inherently capable of providing flexibility** without major modifications |
| Financial | Cost and payback period | • While the cost of implementing advanced control systems might be a consideration, the ability to participate in ancillary services markets or benefit from dynamic pricing provides a clear economic incentive |
| Policy | Dynamic pricing mechanisms | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022, Denmark, Estonia, Finland, Norway, Spain, Sweden, The Netherlands and The United Kingdom |
| | Guidelines for load modulation | • Required specific regulatory frameworks to support industry's participation |
| Behaviour | Lack of awareness | • Leadership may be resistant to demand response practices due to a lack of knowledge |

Source: RMI (2023), Unlocking demand-side flexibility in China

# B Case study: the climate impact of data centres and internet services is growing as demand rises

## Total internet users and data traffic, 2022 – 2050

Total internet user (M); Data traffic per user (TB/year); Data traffic (ZB/year)

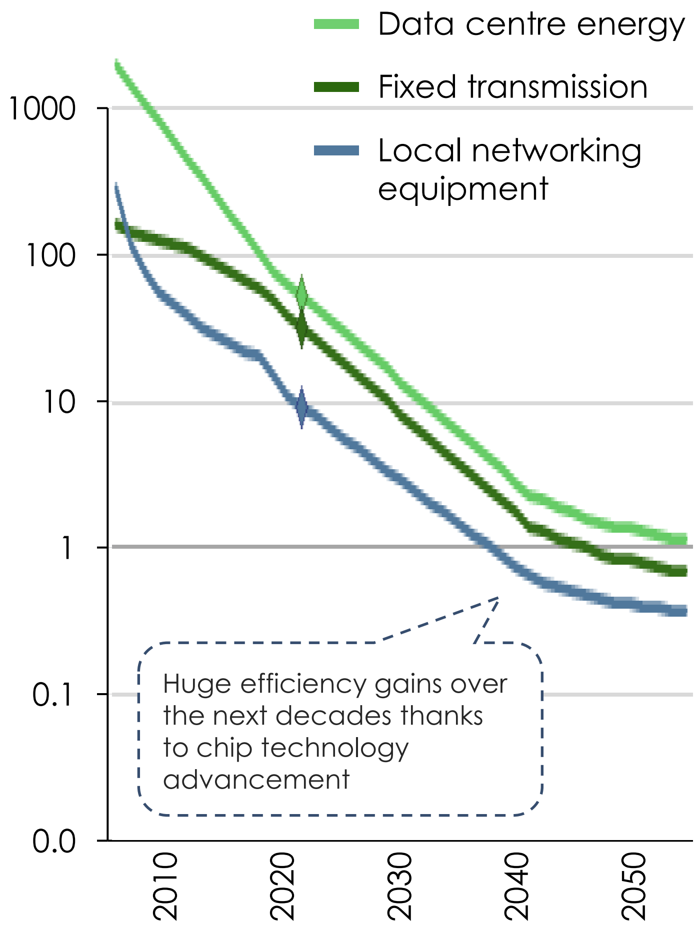


Key drivers of growth

- Rapid expansion of **5G networks, cloud-based services, and the Internet of Things (IoT)**
- **Fast incorporation of AI into software programming across a variety of** sectors (e.g., Google could see a tenfold demand increase after fully implementing AI)

## Internet energy intensity, 2010 – 2050

Wh/GB



Huge efficiency gains over the next decades thanks to chip technology advancement

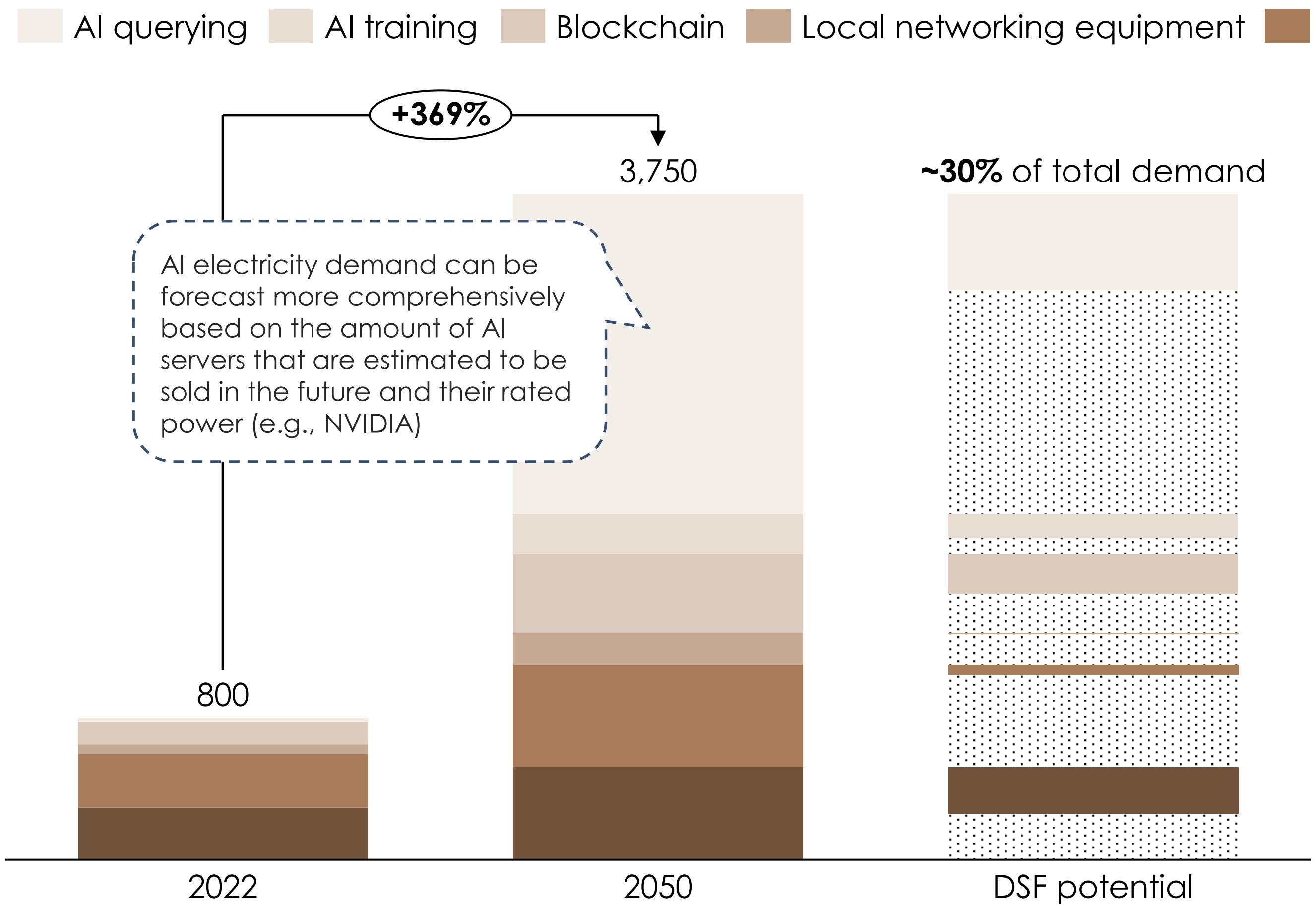
Source: Thunder Said Energy (2024), Internet energy consumption: data, models, forecasts

# B Data centres, blockchain offer the largest DSF opportunities, while transmission and networking have limited flexibility

## Global internet electricity demand and theoretical DSF potential, 2050

TWh

✓ High DSF potential



AI electricity demand can be forecast more comprehensively based on the amount of AI servers that are estimated to be sold in the future and their rated power (e.g., NVIDIA)

- ✓ **Dedicated AI data centres – AI querying** (e.g., using ChatGPT) is largely real-time and demand-driven. Such services often rely on **AI training models,** which can be **postponed or shifted** to low-demand periods without real-time constraints
- ✓ **Blockchain** (crypto mining and transaction) validations can be **scheduled for off-peak hours**
- **Transmission** infrastructure and **local networking equipment** can optimize energy use, but operates continuously and **flexibility is limited**
- ✓ **Traditional data centres'** workloads **can be shifted**, and **backup power utilized** during off-peak times, especially for non-critical processes

Flexibility also exists when companies run computing centres across different countries / regions to allow **load shifts over different centres**

*Note: Electricity demand in data centres is mainly from two processes, with computing accounting for 40%; and cooling requirements for another 40%.
Source: Own analysis, 2022 and 2050 demand data from Thunder Said Energy (2024), Internet energy consumption: data, models, forecasts; RMI (2024), How Data Centers Can Set the Stage for Larger Loads to Come; SIP (2014), Data center flexibility: a call to action

# B Google has enabled the company to match resource-intensive data centre tasks to times when the grid can supply low-carbon power

**Example of demand response in practice at a Google data centre**

- When Google receives **notice from a grid operator** of a forecasted local grid event, for example an extreme weather event that will cause a supply constraint, Google would **alert its global computing planning system** to when and where it will take place
- This alert **activates an algorithm that generates hour-by-hour instructions** for specified data centres to **limit non-urgent compute tasks for the duration of the grid event**, and allows them to be **rescheduled after the grid event has passed**
- When feasible, some of these tasks **get rerouted to a data centre on a different power grid**
- All of this is done **without additional computer hardware and without impacting the performance of Google services** like Search and Maps that people, businesses, and public sector organizations rely on around the clock.

Source: Google (2023), *Supporting power grids with demand response at Google data centers*; Verrus (2024), *How Verrus Is Powering the Data Future*

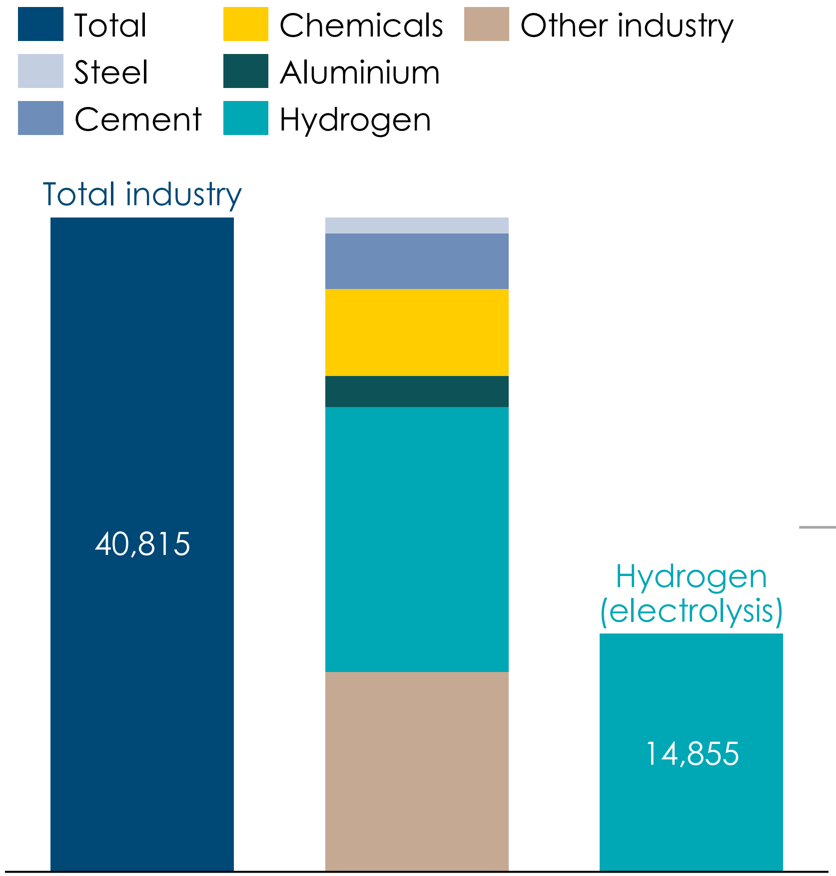
# Industrial heat faces stronger barrier because it often relies on continuous high-temperature processes that are challenging to interrupt

| Barrier Group | Rating | | Key differences |
|---|---|---|---|
| | Industrial heat | Other industry demand | |
| ① **Which technological and operational barriers exist?** | 🟨 | 🟩 | • Industrial heat faces higher barriers due to the **need for new infrastructure and retrofitting**<br>• Other industry demand has the lower barriers thanks to **energy management systems and other automation technologies** |
| ② **Are these solutions economically possible?** | 🟨 | 🟩 | • Industrial heat has higher economic barriers due to **significant upfront costs**<br>• Other industry demand benefits more easily from DSF due to **existing capabilities and lower additional costs** |
| ③ **Are there regulatory and policy requirements that must be met?** | 🟨 | 🟨 | • Both sectors face medium barriers, but the nature of these barriers varies<br>  • Industrial heat needing more policy support for electrification<br>  • Other industry demand requires sector-specific regulations, for example, aluminium needing market access |
| ④ **Are there social & behavioural barriers?** | 🟥 | 🟨 | • Industrial heat may require significant behavioural adjustments, depending on the process and sector<br>• Other industry demands can be better managed via automation |

# D Electrolysis offers high flexibility to ramp up or down based on electricity availability during hydrogen production

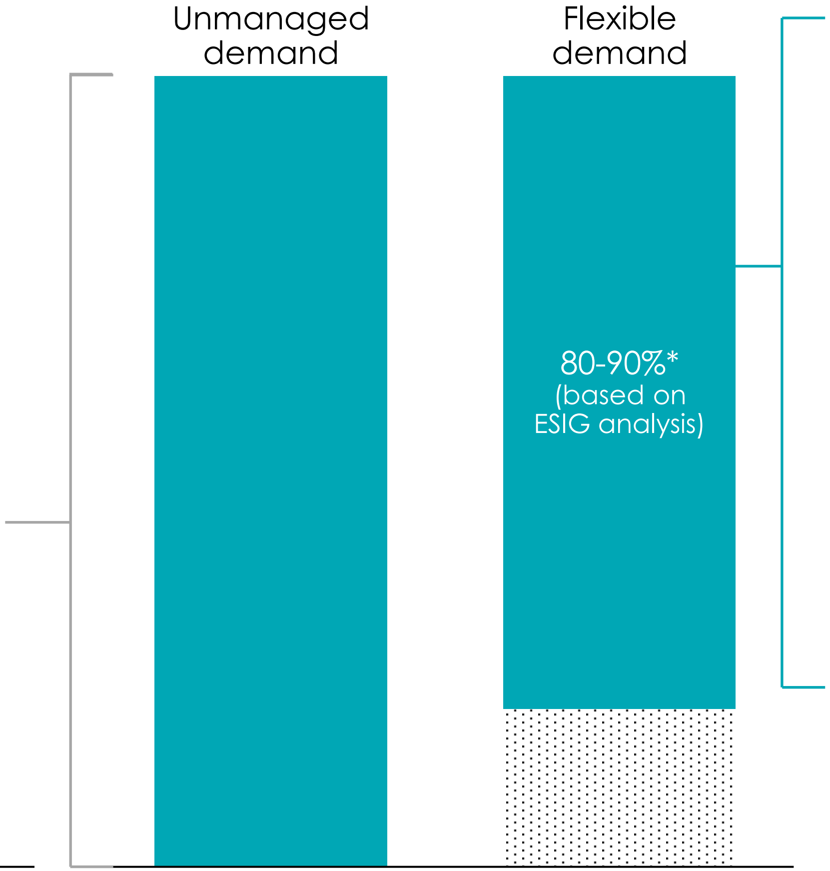
## Global industry electricity demand, 2050

TWh



## Global hydrogen theoretical DSF potential, 2050

TWh



**Electrolysers**: The core technology for producing hydrogen via electrolysis, offering high flexibility to ramp up or down based on electricity availability

**Hydrogen Storage**: Allows for the decoupling of hydrogen production from immediate electricity demand, enabling large-scale load shifting

**Power-to-X**: Technologies that convert surplus electricity into hydrogen (Power-to-Gas), synthetic fuels, or chemicals, enabling storage and use during peak demand

Source: Own analysis, 2023 and 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS; Macquarie (2020), *Flexibility of Hydrogen Electrolysers*; ESIG (2024), *Assessing the Flexibility of Green Hydrogen in Power System Models*

# D Hydrogen production faces fewer barriers to demand side flexibility, as it can easily adjust electricity use based on supply availability

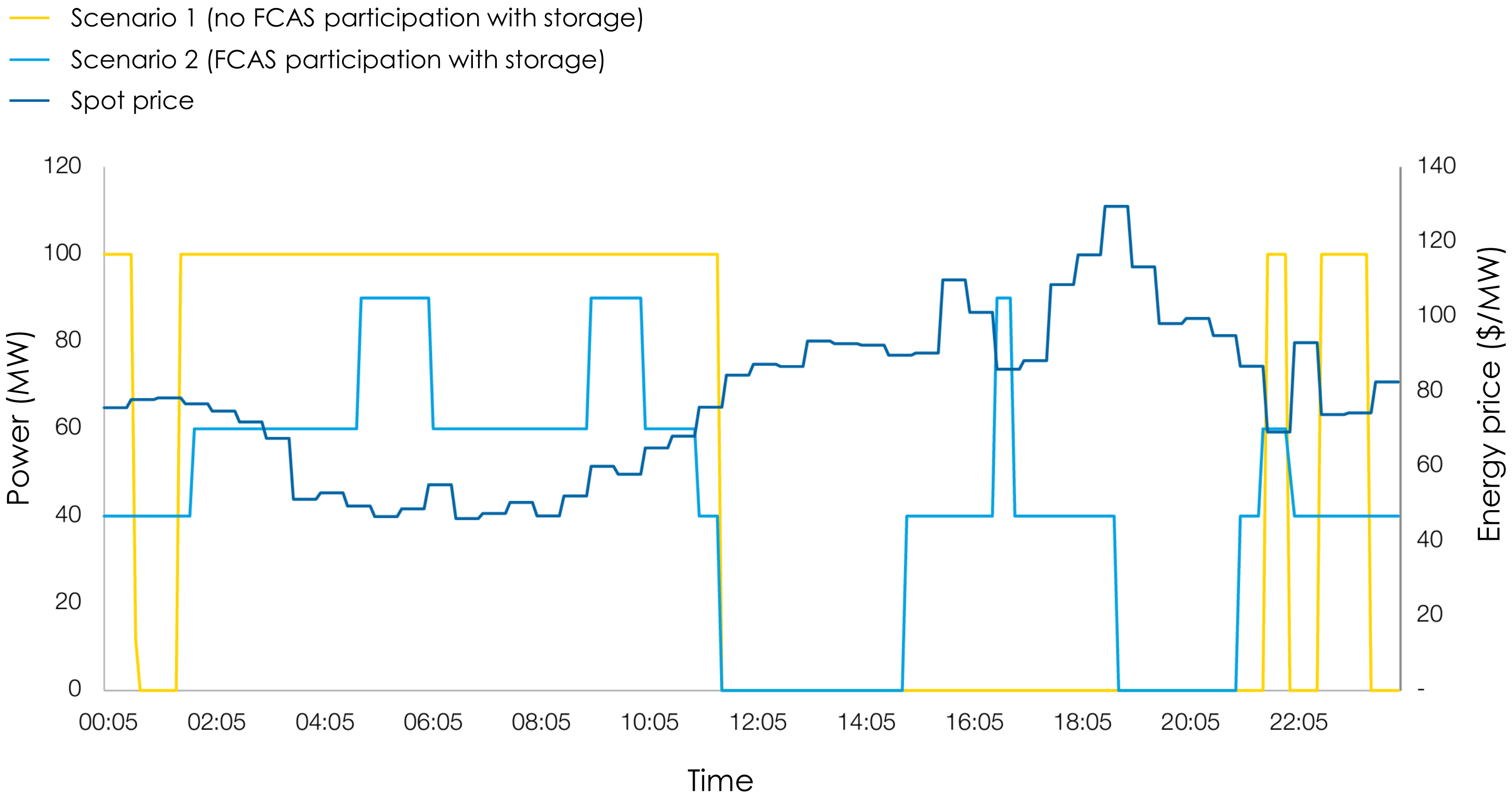
| Barrier Group | Rating | Details |
|---|---|---|
| ① **Which technological and operational barriers exist?** | 🟩 | • Hydrogen production via **electrolysis** is highly flexible, and the technology is **relatively mature**<br>• Integrating electrolysers with grid systems is **increasingly common**<br>• **Physical-based hydrogen storage** systems have already reached **commercial maturity**, however, **only a few materials-based techniques** seem close to a breakthrough |
| ② **Are these solutions economically possible?** | 🟩 | • The cost of the electrolyser stack can **vary from 24% to 44%** of the total capital required, varied by<br>  • Location<br>  • The scale of production – centralized production are more cost-effective than distributed<br>• The operational flexibility they offer can lead to **significant cost savings** and participation in demand response programs<br>  • Flexibility in the hydrogen demand can **reduce the cost by more than 30%**<br>• Support for R&D is growing, with Europe and the United States spearheading efforts<br>  • EU Clean Hydrogen Partnership opened a **EUR 195 million** call for proposals<br>  • US DoE announced a **USD 750 million** R&D programme for advanced clean hydrogen tech |
| ③ **Are there regulatory and policy requirements that must be met?** | 🟨 | • Only **8 countries** have implemented dynamic electricity prices as of Dec 2022<br>• The development of **standards and certification schemes** for low-emission hydrogen production is gaining pace. However, the methodologies defined for these certification schemes **are not necessarily aligned** |
| ④ **Are there social & behavioural barriers?** | 🟩 | • The industry is relatively **new and forward-looking**, with a strong emphasis on **innovation and flexibility** |

Sourcee: IEA (2024), *Hydrogen*; PV magazine (2022), *Solid-state hydrogen storage techniques at a glance*; ESIG (2024), *Assessing the Flexibility of Green Hydrogen in Power System Models*; Öberg (2022), *The cost dynamics of hydrogen supply in future energy systems – A techno-economic study*

# D Dynamic pricing incentivises the electrolyser to vary the load in such a way as to optimise revenue from the energy markets

**Power consumption of a 100 MW electrolyser over a day in New South Wales**

Power (MW); Energy price ($/MW)



- Without Frequency Control Ancillary Services (FCAS)* participation, the electrolyser **reacts to lower energy prices by ramping to full capacity**
- The enablement of FCAS participation incentivises the **electrolyser to vary the load in such a way as to optimise revenue from the FCAS markets**
    - This can sometimes lead to unintuitive behaviour – it is observed that the electrolyser is not running at full capacity during periods of low electricity prices and is running to some extent during periods of higher electricity prices
    - This is to **allow for greater participation in particular FCAS markets** by offering to raise or lower the load of the electrolyser

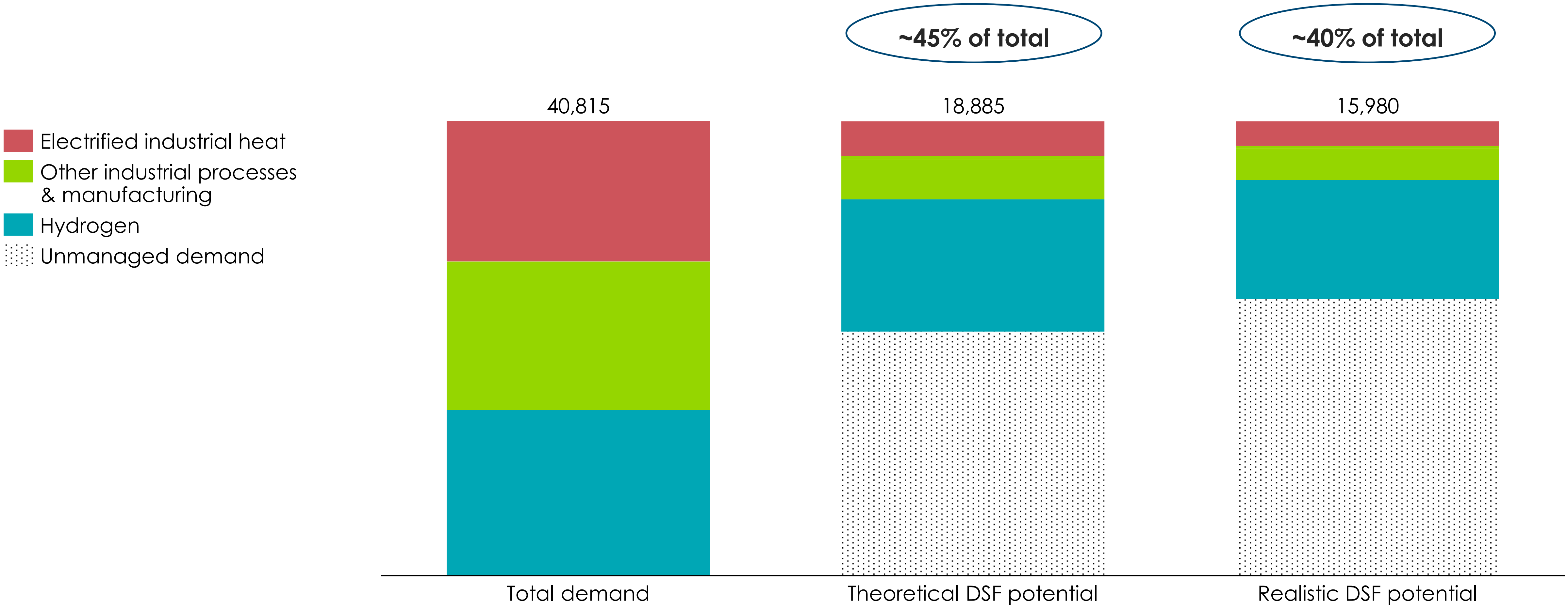
Note: This case study explores the **net electricity costs of hydrogen production from electrolysis** within the Australian National Electricity Market (NEM) with a key focus on operation of an electrolyser as a scheduled load participating in the wholesale energy and Frequency Control Ancillary Services (FCAS) markets

Source: Macquarie (2020), *Flexibility of Hydrogen Electrolysers*

# Around 40% of industry electricity demand can be flexible in 2050

## Global electricity demand from industries and DSF potential, 2050

TWh



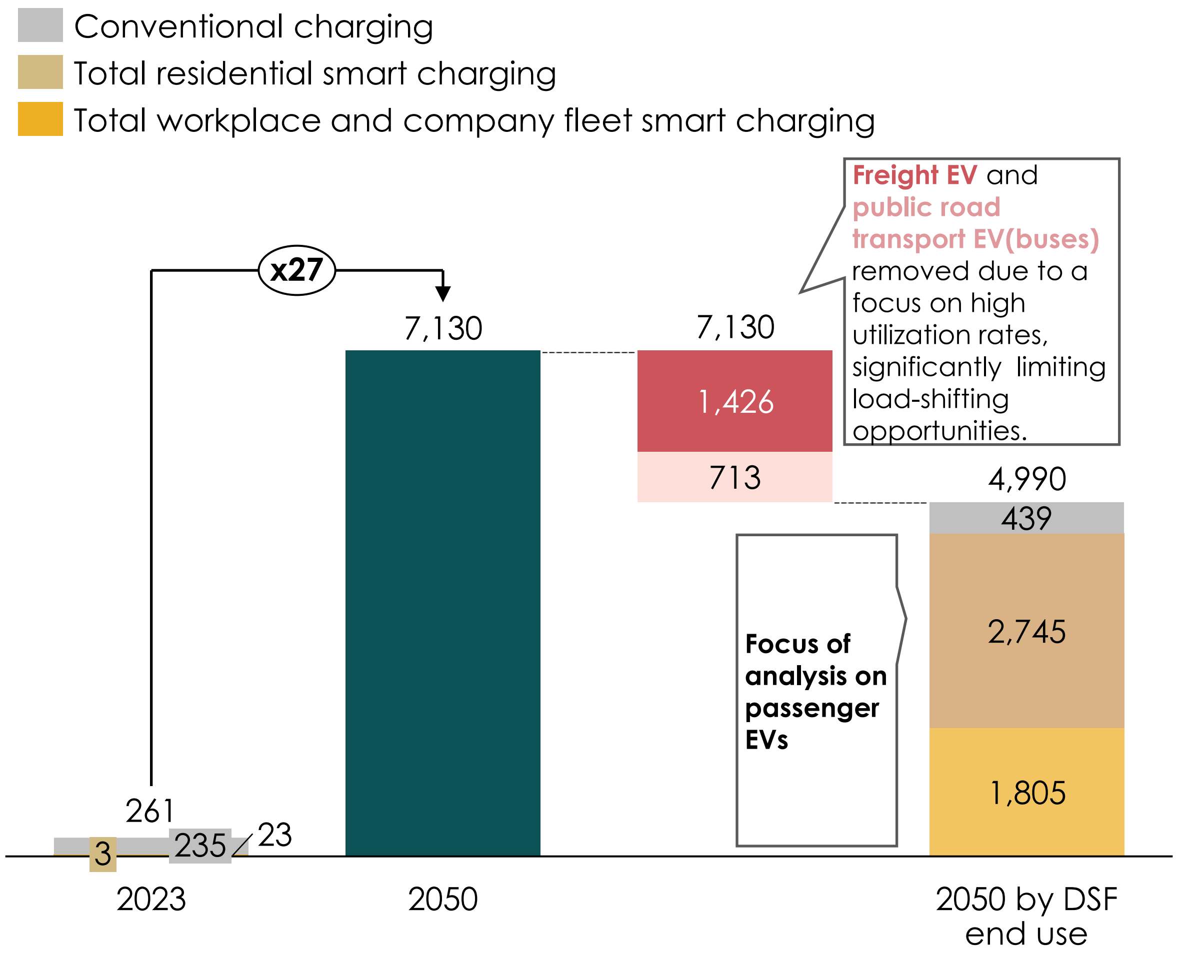
Source: Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# Transport

# Assessing DSF potential across residential and commercial EV smart charging

## Global electricity demand for road EV charging, 2023 & 2050

TWh



**Freight EV** and **public road transport EV(buses)** removed due to a focus on high utilization rates, significantly limiting load-shifting opportunities.

**Focus of analysis on passenger EVs**

**Conventional charging (no flexibility potential)**

Charging from public charging stations that do not adapt charging times to grid peak/off-peak times

**Residential smart charging potential**

Charging from private wall box charging stations at home that enable smart charging

**Workplace and company fleet smart charging potential**

Charging private cars and company fleets from office or public wall box charging stations that enable smart charging

Source: Own analysis, based on data from BNEF (2024); *NEO;* DNV (2023), *Energy Transition Outlook 2023*
Note: 2050 electricity demand based on BNEF net zero scenario. Share of freight EV and road transport EV to total EV charging electricity consumption from DNV (2023)

# Classic smart charging and advanced smart charging can be applied to commercial and residential charging solutions

**Residential Smart Charging**

**Charging at home,** using a wall-mounted charger: wall box

- Typically installed in garages

**Workplace and Company Fleet Smart Charging**

**Charging of private and company EVs at charging stations with multiple wall boxes.**

- Office parking areas
- Company fleet depots
- Public areas like shopping centres, airports, etc

Source: GreenFlux (2024), *GreenFlux supplies the largest smart charging plaza in the Netherlands*; (2023), *Installation d'une Wallbox en garage à faire soi-même;* Business Indisder (2024), *Electric semi-trucks are ready to be deployed, but there aren't near enough plugs to charge them*

# Smart charging enables EV owners to contribute to DSF via its classic variant (V1G) for shifting load, while its advanced version (V2G) additionally allows EVs to supply power back to the grid for load shedding

**Smart Charging:**

- **Conventional EV charging charges EVs without data exchange between end users and grid operators** (thus also called *dumb charging*).
- **In contrast, smart charging can adjust the timing and rate of charging based on grid demand, electricity prices, and user needs,** thereby contributing to demand-side flexibility.

***Two versions of smart charging technology exist:***

**Classic Smart Charging**

**Known as V1G**

**V1G: Unidirectional Vehicle-to-Grid**

**One feature:**

1. **Enables EV users to shift charging** from grid peak to off-peak demand periods.

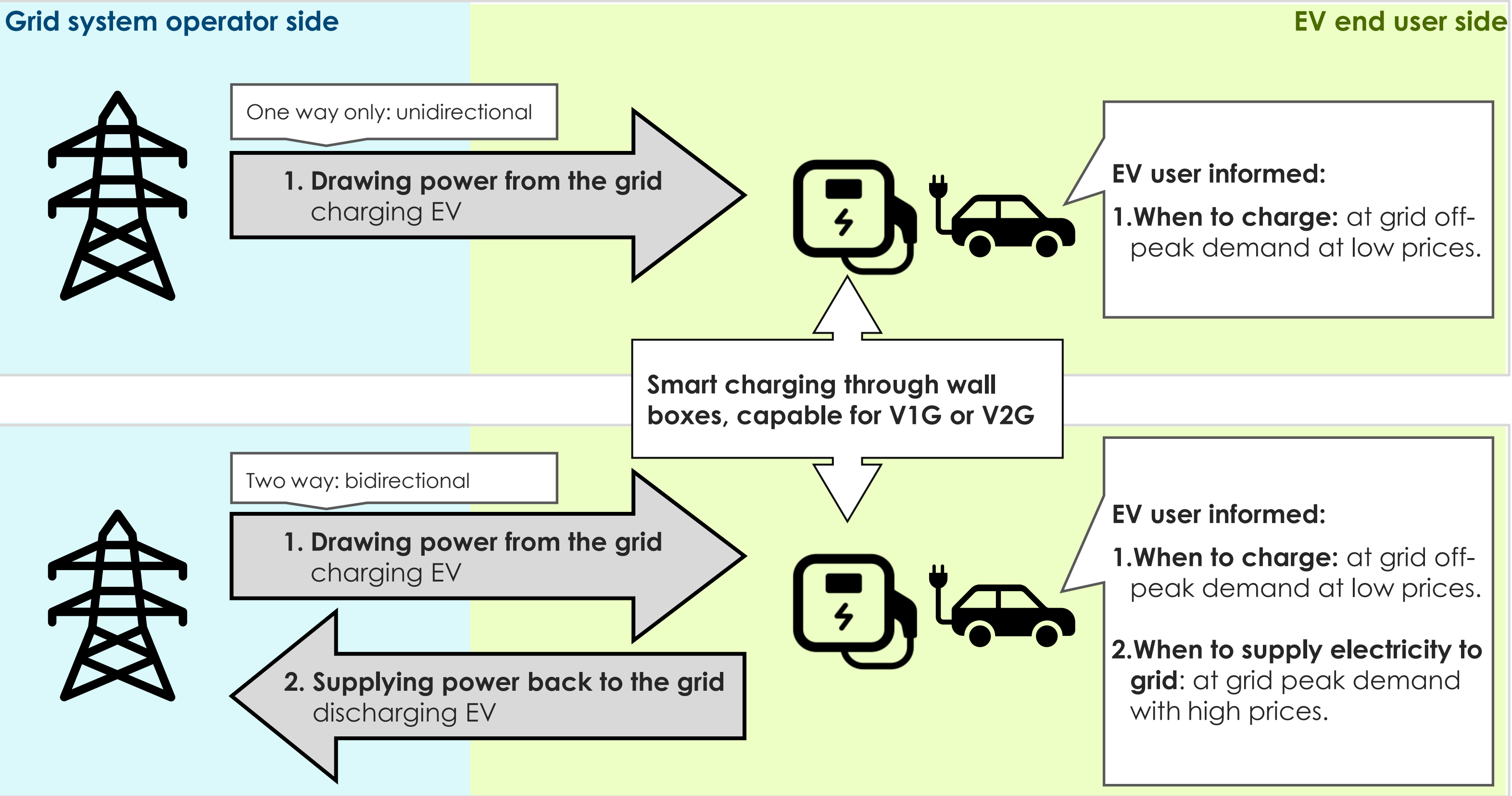
**Advanced Smart Charging**

**Known as V2G**

**V2G: Bidirectional Vehicle-to-Grid**

**Two features:**

1. **Enables EV users to shift charging** from grid peak to off-peak demand periods.
2. **Enables EV users to return excess energy stored in EV battery back** to the grid at peak demand periods.



**Grid system operator side**

**EV end user side**

One way only: unidirectional

**1. Drawing power from the grid** charging EV

**EV user informed:**

**1.When to charge:** at grid off-peak demand at low prices.

**Smart charging through wall boxes, capable for V1G or V2G**

Two way: bidirectional

**1. Drawing power from the grid** charging EV

**2. Supplying power back to the grid** discharging EV

**EV user informed:**

**1.When to charge:** at grid off-peak demand at low prices.

**2.When to supply electricity to grid**: at grid peak demand with high prices.

# Classic smart charging (V1G) and advanced smart charging (V2G) are built on the same enabling solutions to provide demand side flexibility

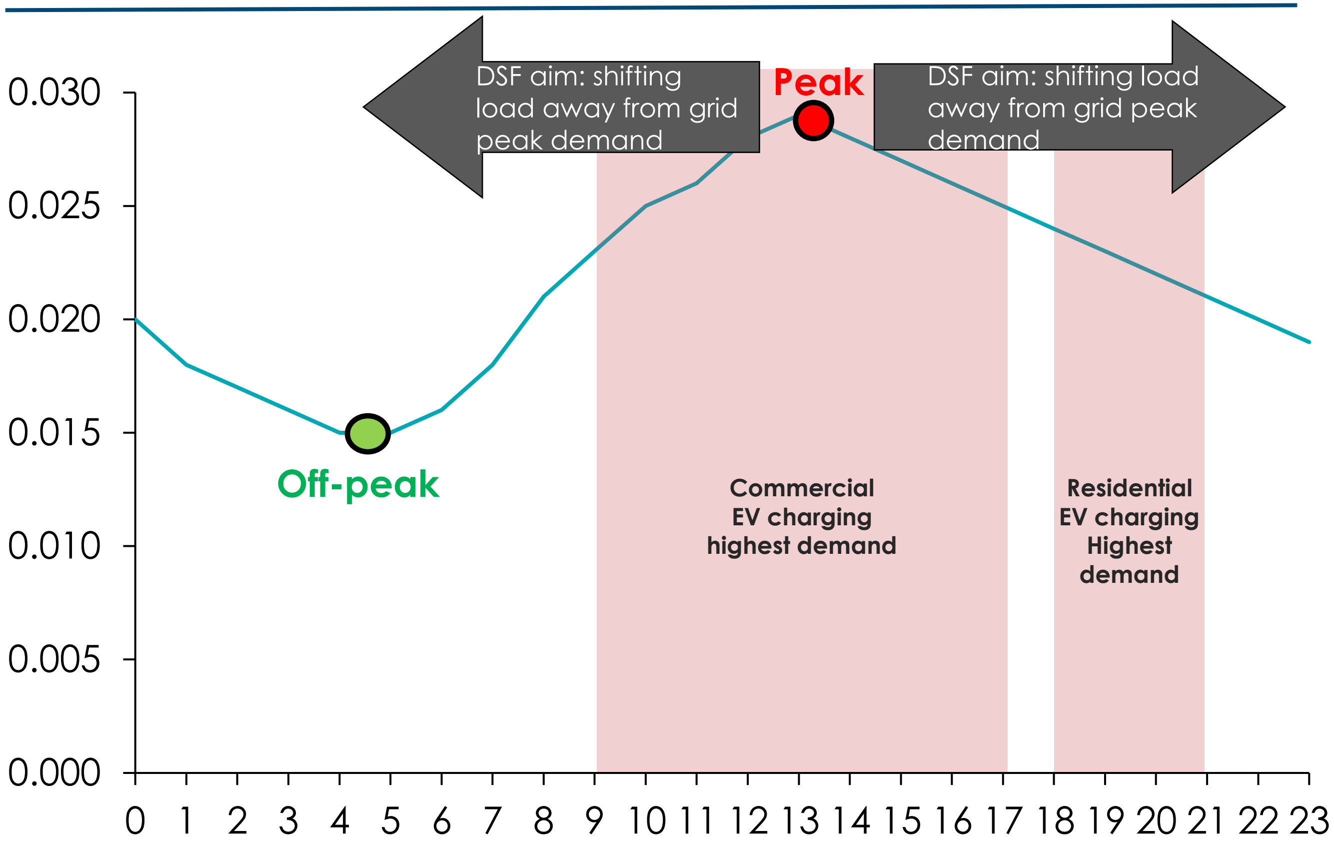
| | | Response time | Ramping time | Response duration | Load shifting |
|---|---|---|---|---|---|
| Direct response | **Classic smart charging (V1G), shifting EV charging**<br>• Incentivizes EV users to charge during periods of low grid demand. | Few seconds | Instantly or within few seconds | ~5 hours, typically during the night | ✓ |
| | **Advances smart charging (V2G), shifting charging + supplying power back to grid**<br>• Incentivizes EV users to charge during periods of low grid demand.<br>• Enables EV users to feed and sell electricity back to the grid during grid peak demand. | Few seconds up to a minute depending on grid signals | Within 10 seconds | ~3 hours, typically in evening hours | ✓ |
| Enabling solutions | **On the EV end user side: Wall boxes for smart charging – enabling automated charging**<br>• Charges EV (V1G capable wall box), V2G capable wall boxes also enable EV users to supply electricity back to the grid. | | | | |
| | **On the end user side: Demand Response System – enabling automated charging**<br>• For V1G - **Notifies EV users of low electricity prices (dynamic tariff)** during the day **(*Supplier Managed Charging*)** or sets the wall box to automatically charge during pre-arranged **time-of-use tariff windows (*User Managed Charging*)**<br>• For V2G - Notifies EV users of periods of high electricity prices during the day.<br>**On the grid system operator side: Load Distribution Management System**<br>• System operator **receives smart charging demand and power supply data** from wall boxes to optimize grid flexibility. | | | | |

Source: California Energy Commission (2024), *Vehicle-Grid Integration Program;* ESO & Octopus Energy (2023), *Powerloop: Trialling Vehicle-to-Grid technology;* World Electric Vehicle Journal (2020), *Test and Modelling of Commercial V2G CHAdeMO Chargers to Assess the Suitability for Grid Services*
Note: response durations as results from ESO and Octopus Powerloop pilot findings.

# Grid peak demand coincides with commercial EV charging peak demand

**Total grid electricity consumption – hour by hour on a typical day in the UK, showing grid peak/off-peak demand, against EV charging patterns**

TWh



**Workplace and company fleet charging mostly during times when total grid electricity demand is the most.**

**Thus, residential smart charging in better starting position** to contribute to effective load shifting.

**To consider:**

**Until 2050, grid peak/off-peaks can change.**

- **Peak Demand: May shift or become more pronounced** due to increased electrification (e.g., EVs, heat pumps) and renewable energy adoption.
- **Off-Peak Demand: Could rise** with smart appliances, EV charging at night, and energy storage systems.

Source: Data from NationalGrid ESO (2024)

# Today: commercial and residential EV charging have distinct charging patterns throughout the day, with residential charging showing greater potential for shifting to grid off-peak demand times by 2050

| | Today | | | By 2050 |
|---|---|---|---|---|
| | EV optimal charging times during the day | | Optimal charging times during grid peak or off-peak demand times | Impact of smart charging on optimal charge times |
| **Residential charging** | Highest charging demand | In the evening<br>▪ Especially: 6 PM to 9 PM | During peak times | Residential evening charging expected to loose relevance, in favour of nighttime smart charging |
| | Lowest charging demand | Overnight and during the day<br>▪ Especially: 11 PM to 6 AM | During off-peak times | **Residential nighttime smart charging at off-peak times can be implemented at minimum effort** |
| **Workplace and company fleet charging** | Highest charging demand | During business hours<br>▪ Especially: 9 AM to 5 PM | During peak times | Largest share of workplace charging expected to remain during times of peak demand |
| | Lowest charging demand | When businesses are closed<br>▪ Especially: 12 AM to 6 AM | During off-peak times | **Difficult to shift to off-peak demand smart charging when businesses are closed** |

Source: ESO & Octopus Energy (2023), *Powerloop: Trialling Vehicle-to-Grid technology;* EM (2024), *The Power of Off-Peak Charging for Electric Vehicle Owners;* ACEEE (2024), *Charging ahead: how EV could drive down electricity rates.*
Note: Data for electricity demand based on BNEF NZS; load % required during peak/off-peak demand patterns based on total electricity demand and share of load used between peak/off-peak times, interpolated from data from NationalGrid ESO (2024).

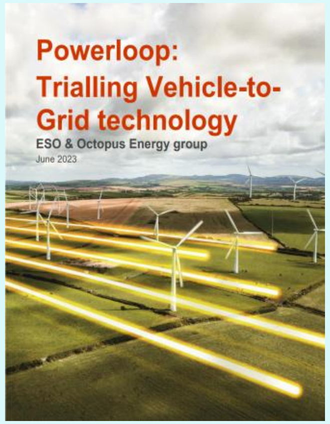
# 2050: Estimate of the load-shifting potential of smart charging by 2050

**Load shifting potential per EV and day**

**Based on results from Octopus Powerloop study**

Considering EV battery capacity of 40-60 kWh

**Up to 9 kWh**



Powerloop:
Trialling Vehicle-to-Grid technology
ESO & Octopus Energy group
June 2023

Load shifting per EV and day from real world study

×

**Number of EVs in 2050 expected to participate in smart charging**

**Based on industry expectation**

**~860 million**

Growing fleet of EVs by 2050

=

**Global 2050 EV fleet load shifting potential per year**

**Result**

**Up to 3,890 TWh**

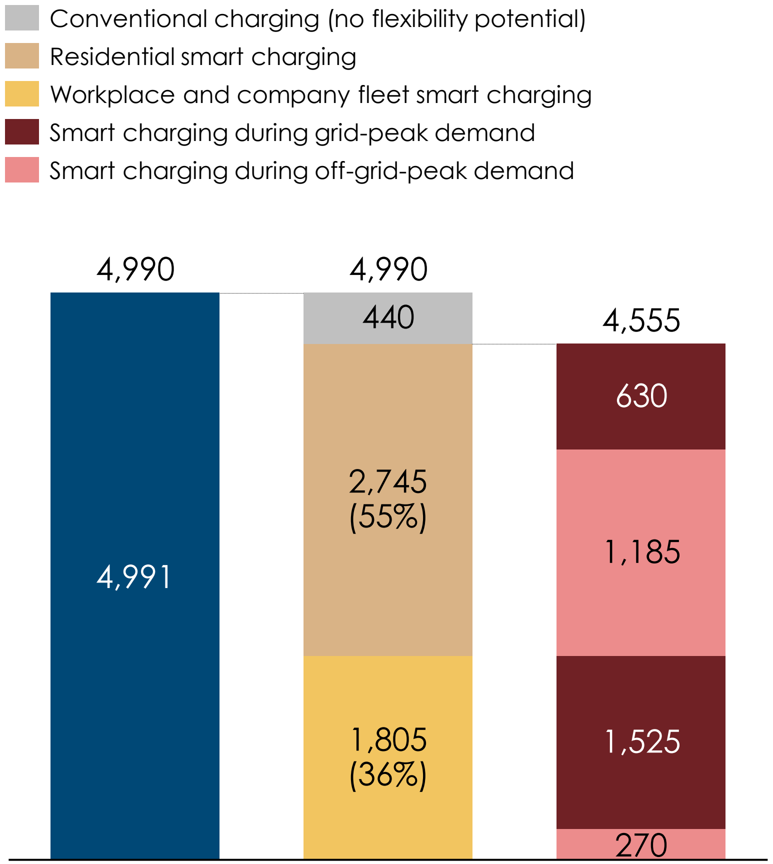
Global EV fleet load shifting potential

Source: BNEF (2023), *Electric Vehicle Outlook*, ESO & Octopus Energy (2023), *Powerloop: Trialling Vehicle-to-Grid technology;* IEA (2024), *Global EV outlook 2023.*
Note: 1,3 billion EV projected by BNEF Net Zero Scenario by 2050, of which ~¾ are passenger EV, of which 91% (=885million) are expected to participate in smart charging.

# Smart charging theoretical potential

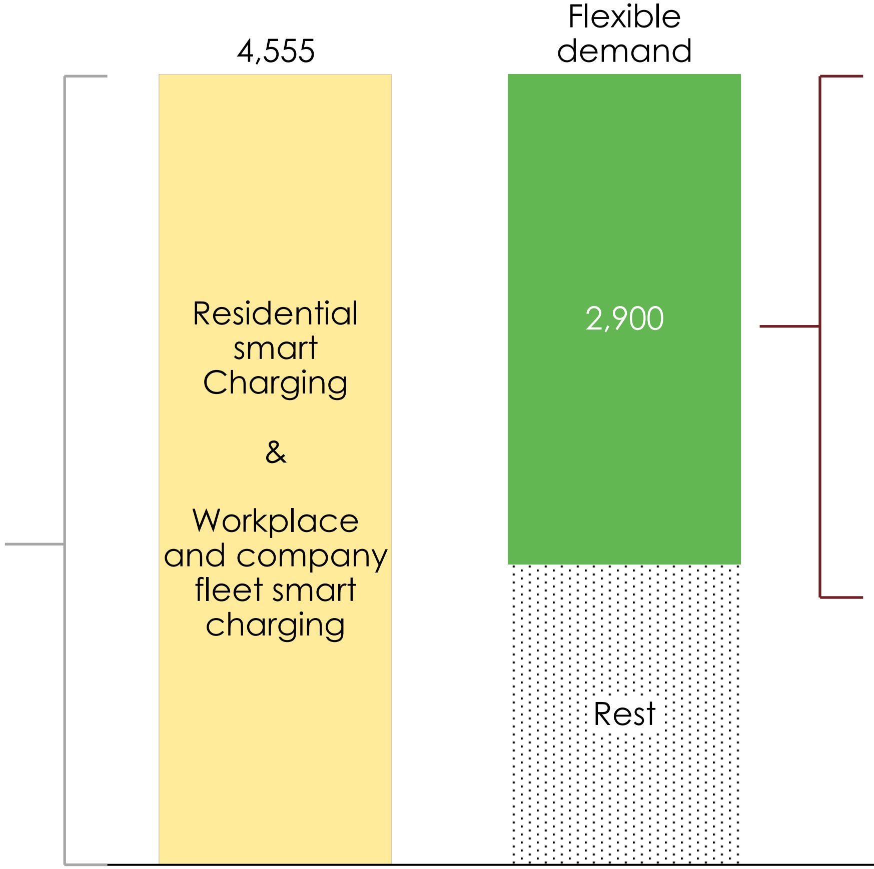
## Global EV charging electricity demand, 2050

TWh



## Global EV charging DSF potential, 2050

TWh



**Load shift**

**Up to 60%** of smart charging electricity demand could be shifted.

**Load shifting from residential smart charging expected to account for the lion share of this potential.**

**Smart charging is designed - by principle - to minimize EV charging during peak** grid demand, maximizing charging during off-peak times.

Source: Own analysis, data from BNEF (2024), *NEO*; European Environment Agency (2022), *Annex Vehicle-grid integration*; IEA (2024), *Global EV Outlook 2024*, World Electric Vehicle Journal (2019), *Flexibility of EV demand.*

Note: Data for total EV charging demand from BNEF (2024), share of conventional to smart charging from European Environment Agency (2022).

# Classic smart charging (V1G) actual potential: assessment and justification

| | Criteria | Details |
|---|---|---|
| **Tech** | Underlying electrification technology | - V1G wall boxes are technologically mature, but **significant shortage of skilled labour** – one in four will be missing by 2032 in the UK[1] – could halt their installations. |
| | Enabling technology | - Load management systems face **implementation challenges such as compatibility with varying wall box designs and integration with diverse grid operators' standards and infrastructure settings**, especially for workplace smart charging station with multiple charging points. |
| **Financial** | Cost and payback period | - Payback periods are ~2-5 years[2,3] depending on initial investment cost of wall box, making especially cheaper **V1G wall boxes a quickly rewarding investment** thanks to V1G's smart charging electricity price savings. |
| | Investment attention | - **Financial institutions and EV OEMs are increasingly supporting V1G installations**, with major projects like VW's investment in 17,000 smart chargers[4] exemplifying **large-scale rollout efforts**. |
| **Policy** | Dynamic pricing mechanisms | - **Globally only 15-20%[4] of grid operators currently offer dynamic pricing options**, calling for more policy action while currently implementation is focused on the EU, China, and parts of the US. |
| | Interoperability standards | - There is a **lack of standardization**, with only ~20% of grid operators supporting unified communication protocols[5], forming a bottleneck for seamless V1G deployment. |
| | Cybersecurity regulations | - Secure data encryption forms basis of V1G, but ~50% of required guidelines are currently implemented to ensure cybersecurity in the US[6], **indicating significant vulnerabilities globally**. |
| **Behaviour** | Lack of awareness and understanding | - **Social and behavioral barriers hinder V1G adoption**, with 52% of users preferring late evening charging[7], conflicting with optimal use. |

Source: 1. Professional Electrician & Installer (2023), *Demand for electricians set to soar as trade sector vacancies hit record highs;* 2. Ampcontrol (2022), *What is the difference between V1G and V2G?* 3. Clean Energy Reviews (2024), Bidirectional EV chargers review; 4. Electrice (2023), *Volkswagen invests in CAMS charging network in China;* IEA (2024), *Global EV Outlook 2024;* 4. GridX (2024), *Dynamic Electricity Pricing;* 5. Resources for the Future (2022), *Using Prices, Automation, and Data to Shape* Electricity Demand; 6. NIST (2023), *Cybersecurity Framework Profile for Electric Vehicle Extreme Fast Charging Infrastructure;* 7. EY (2024), *Mobility Consumer Index.*

# Advanced smart charging (V2G) actual potential: assessment and justification

| | Criteria | Details |
|---|---|---|
| **Tech** | Underlying electrification technology | • **Only 5-10% of all deployed wall boxes are V2G capable**[1], due to their more complex design against V1G.<br>• **Labour shortages constrain installations**, while rollout of cheaper V1G wall boxes may take away space for deployment of more efficient V2G wall boxes. |
| | Enabling technology | • EV user load management systems face increasing compatibility challenges with V2G compared to V1G, resulting in **currently only ¼ of systems being compatible.**[2]<br>• For grid system operators, integrating V2G **increases load distribution system complexity by around 30%,** requiring advanced data exchange with end users, which can be a significant barrier.[3] |
| **Financial** | Cost and payback period | • V2G wall boxes – **around 2x as expensive as V1G**[4] – can create initial capex burden for EV users. However, while V1G pays back after ~2-5 years[3], V2G offers 25%[4] more annual cost savings, making it **in the long run more rewarding** after its payback period of 4-8 years |
| | Investment attention | • **Financial institutions are making increasing investments**, with ~$100 m spent in 2023 to enhance the US grid for V2G.[5] This is a **small fraction of $55 bn estimated for a full V2G upgrade of the US grid.**[6] |
| **Policy** | Dynamic pricing mechanisms | • **Globally only 15-20%**[7] **of grid operators currently offer dynamic pricing options**, calling for more policy action while currently implementation is focused on the EU, China, and parts of the US. |
| | Interoperability standards | • **Currently, only 15% of EVs are V2G compatible.**[8]<br>• There is a **lack of policies for data exchange standards**, with only ~20%[9] of grid operators supporting unified communication protocols, forming a basis for seamless V2G deployment. |
| | Cybersecurity regulations | • Secure data encryption forms basis of V2G, but ~50%[10] of required guidelines are currently implemented to ensure cybersecurity in the US, **indicating significant vulnerabilities globally** |
| **Behaviour** | Lack of awareness and understanding | • **Only 20% of compatible EV users are expected to participate in V2G by 2035**[11]. This development is expected to stem mostly from high V2G upfront cost and unawareness about cost saving and revenue gains possible from V2G. |
| | Concerns and scepticism | • **Concerns over battery degradation decrease** in light of new and more resistant battery chemistries like LFP. |

Source: 1. Professional Electrician & Installer (2023), *Demand for electricians set to soar as trade sector vacancies hit record highs;* 2. Ampcontrol (2022), *What is the difference between V1G and V2G?;* IEEA (2022), *Integration of EVs in smart grids;* 4. Clean Energy Reviews (2024); 5. **V2G Hub (2024),** ***V2G around the world;*** **6.** US NREL (n.a.), *Critical Elements of V2G Economics;* 7. PV Magazine (2023), *V2G inches closer to reality;* 8. **ARENA (2023),** ***V2x.au Summary Report;*** 9. Resources for the Future (2022), *Using Prices, Automation, and Data to Shape* Electricity Demand; 10. NIST (2023), *Cybersecurity Framework Profile for Electric Vehicle Extreme Fast Charging Infrastructure;* 11. ESO & Octopus Energy (2023), *Powerloop: Trialling Vehicle-to-Grid technology*

# Residential smart charging has proven itself in real word, powered by end user load management systems

## Case study: Octopus Powerloop

Real-world case study **testing smart charging's contribution to flexibility and Octopus Kraken** as the enabling load management system.

octopusenergy

**Setup**

### Grid system operator

nationalgridESO

### Kraken as critical link for smart charging to contribute to EV DSF

Manages the charging and discharging of EVs to align with grid demands & energy prices.

✓ **Data exchange**

- **For EV users**: real-time information on electricity prices, indicating, when to charge and discharge
- **For System operators:** real-time electricity demand for EVs

✓ **Load forwarding**

- **Manages load inflow** to meet EV charging demand
- **Manages power supply** back to the grid

KRAKENTECH

### EV end user side

135 EVs participated across UK

NISSAN MOTOR CORPORATION

**Results**

### Benefits for grid system operators and DSF

| | Shifting load (per day) | Supplying electricity (per day) |
|---|---|---|
| **Duration of flexibility** | **~3 h, evening** | **~5 h, after midnight** |
| **Amount of energy shifted (per participating EV)** | **Up to 9 kWh** | **Up to 22 kWh** |

### Benefits for EV end users

| | Shifting load (per year) | Supplying electricity (per year) |
|---|---|---|
| **Cost saving per year (compared to conventional EV charging)** | **$ 800** | **$ 1,000** |

## Conclusion for DSF potential

**Powerloop highlighted the technical and economic viability of smart charging**

- EV owners can be significantly encouraged to charge during off-peak hours

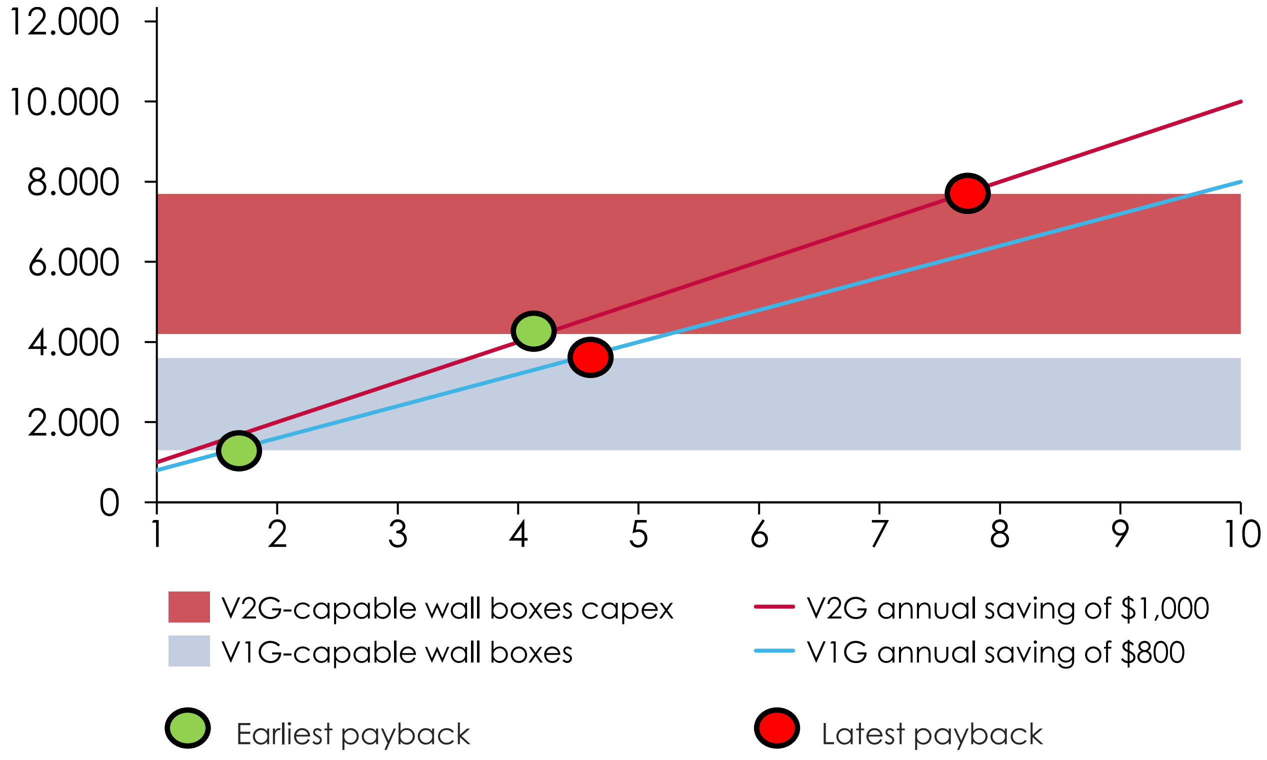
Source: company logos from respective websites (2024); : Octopus Energy (2024), *Octopus Power Pack: the UK's first Vehicle-to-Grid Tariff;* ESO & Octopus Energy (2023), *Powerloop: Trialing vehicle-to-Grid Technology;* BNEF (2024), *2024 NEO;* The Carbon Trust/Imperial (2021), *Flexibility in Great Britain;* Flag from Britannica (2024); Company/Government logo from respective website (2024); Logos from respective company websites (2024).

Note:: *amount of energy derived from possible EV discharge range for grid balancing per day, incl. a buffer (between 30% < State-of-Discharge < 85% per day), Nissan LEAFs 40 kWh battery capacity, and most significant discharge slot from 16-19 h. Per EV: 40 kWh*(0.85-0.3) = 22 kWh. *Smart charging refers to a charging asset in which electric vehicles, charging stations and charging operators use shared data connections to minimize power use; UK annual electricity demand: 316.90 TWh; 2035 35 GW capacity which is "equivalent to the peak asset demand on a mild winter's day today", is based on 7 kW charge points; ~74 GW 2050 Demand Side Flexibility includes industrial-, smart appliances-, EV DFS.

# Smart charging payback periods differ, depending on vast capex range for V1G and V2G wall box investment options and therefore different periods to break even

**Payback periods: V1G/V2G wall boxes capex and annual savings**

USD (y-axis); Years after wall box purchase made (x-axis)



**Cost of wall box installation, incl. installation:**

- For V1G: $1,300 – 3,600
- For V2G: $4,000 – 7,500

**Annual savings:**

- For V1G: $800
  (From charging at lower cost)
- For V2G: $1,000
  (From charging at lower cost + selling electricity back to grid)

**Result - payback period:**

- For V1G expected after 2-5 years
- For V2G expected after 4-8 years

**Take-away:**

- V1G is cheaper with a quicker payback
- The more expensive upfront V2G offers better long-term returns

Source: Data from ESO & Octopus Energy (2023), *Powerloop: Trialling Vehicle-to-Grid technology;* FIXR (2024), *How much does it cost to install an electric vehicle charging station at home?*

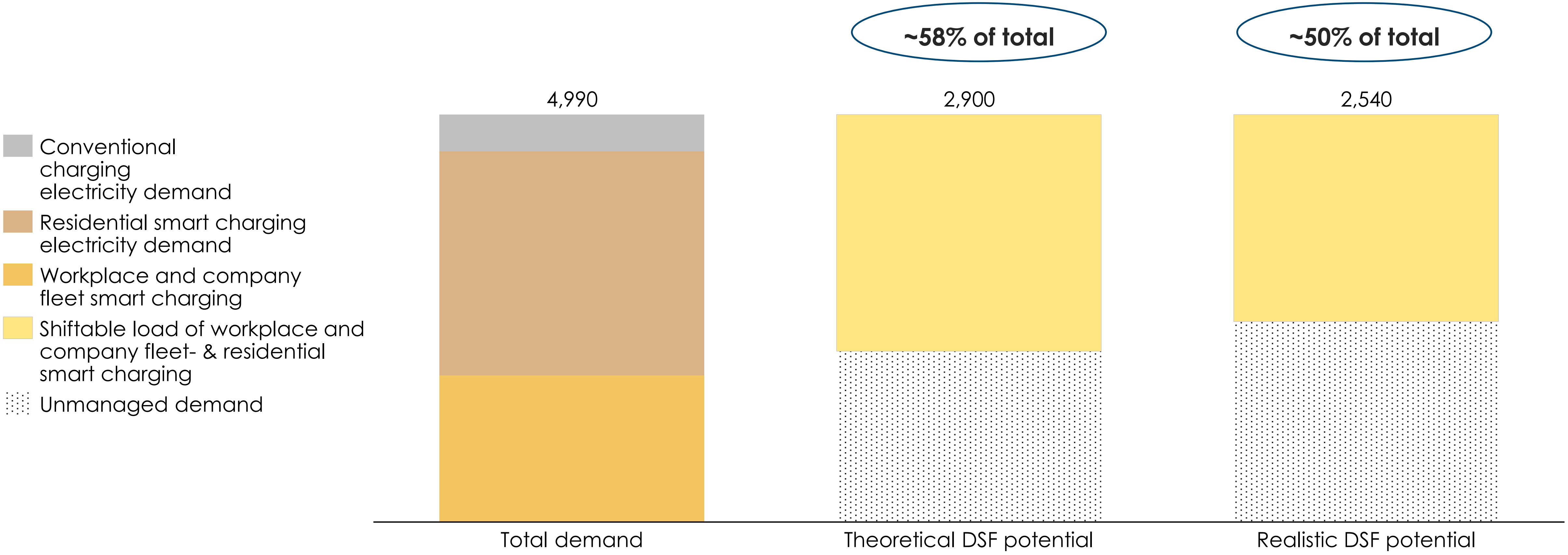
# Commercial V1G shows strong short-term potential, with V2G poised for long-term growth, but both V1G and V2G face higher barriers in residential smart charging to unlock its actual potential for DSF

| Barrier Group | Rating | | |
|---|---|---|---|
| | Residential | Commercial | Details |
| ①<br>**Which technological and operational barriers exist?** | 🟨 | 🟥 | • V1G and V2G wall box **deployment is limited by skilled labor shortages.**<br>• **Compatibility challenges exist between end-user load management and wall box designs**, with V2G's bigger complexity creating greater issues, especially at commercial stations with multiple charging points.<br>• **V2G adds substantial complexity to system operator load distribution management**, making its integration more difficult.<br>• **Overall, unlocking smart charging's DSF potential poses a challenge, particularly for V2G and in commercial setups.** |
| ②<br>**Are these solutions economically possible?** | 🟨 | 🟩 | • **V1G is in general cheaper** with a quicker payback, though having higher upfront cost, **V2G offers better long-term return.**<br>• **Overall, smart charging can be accessible for end users, but it is an easier investment for commercial- than private EV users.** |
| ③<br>**Are there regulatory and policy requirements that must be met?** | 🟥 | 🟥 | • **Lack of interoperability standards and cybersecurity guidelines** hinder the deployment of V1G and V2G.<br>• **Overall, more regulatory support is essential to unlock smart charging's DSF potential, for both V1G and V2G.** |
| ④<br>**Are there social & behavioural barriers?** | 🟥 | 🟨 | • **Low awareness of V1G and V2G and its energy cost saving potential,** combined with lingering fear of battery degradation from V2G, **pose significant barriers to smart charging adoption.**<br>• **Overall, barriers are lower for workplace and company fleet smart charging setups, which can benefit from higher smart charging asset utilization throughout the day.** |

# ~50% of passenger EV electricity demand (private and company passenger EV fleets) can be flexible in 2050

**Global electricity demand from passenger EV charging (private and company fleet EVs) and their DSF potential, 2050**

TWh

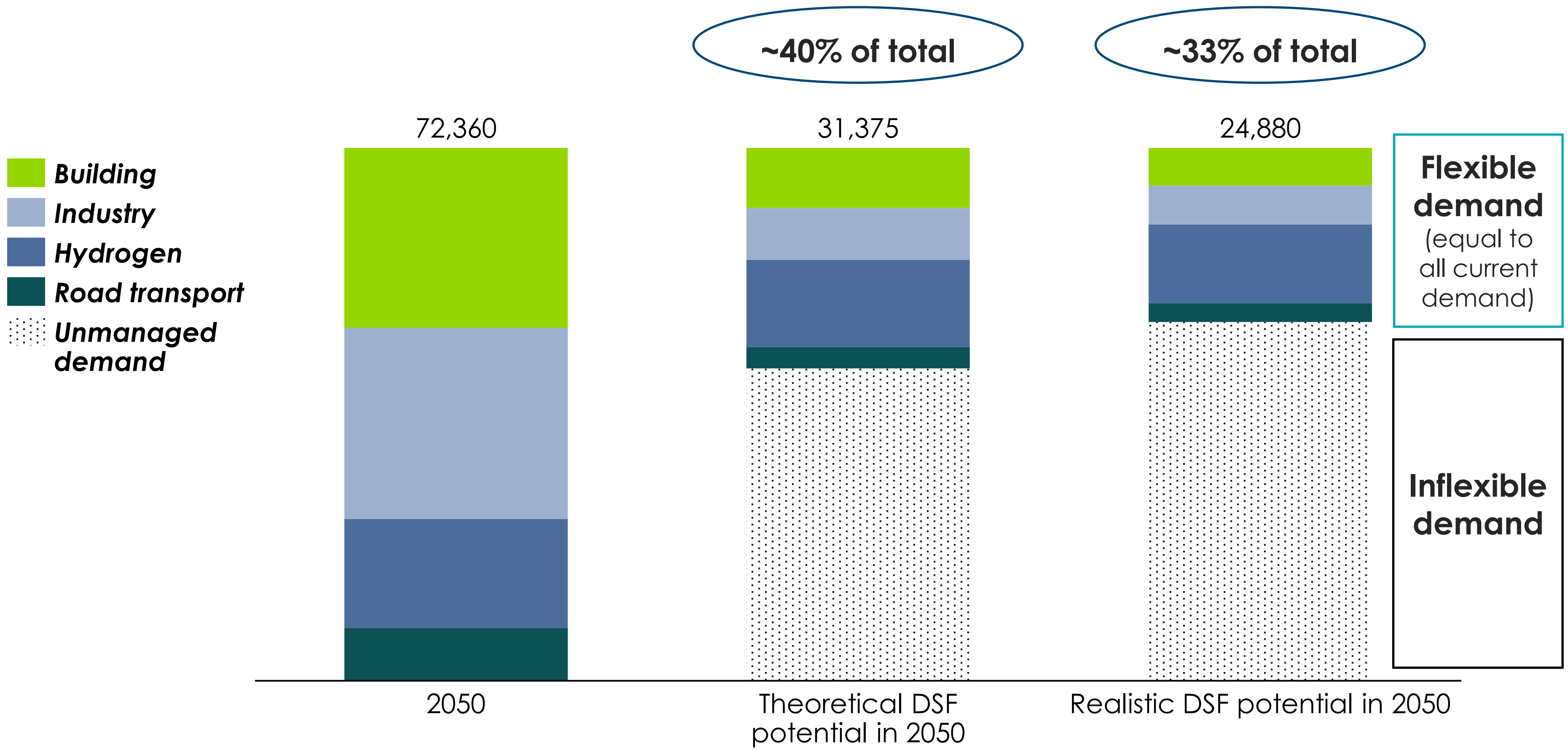


Source: Own analysis, based on data from BNEF (2024); *NEO*

# Conclusions

# ~33% of total electricity demand in 2050 could be flexible on hourly basis

**Global electricity demand and DSF potential, 2050**
TWh



*Suggests that 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*

Own analysis, 2050 demand data from BloombergNEF (2024), New Energy Outlook 2024 NZS

# The key enablers for driving DSF adoption is through the integration of incentives, financing, and behavioural change

| Capabilities | High-potential policy enablers | Examples |
|---|---|---|
| **Hardware** | • Accelerate adoption of **smart meters** and **asset metering devices** | • Rollout of smart meters is already regulated by EU law |
| **Data exchange** | • Establish clear rules on **data exchange** and **interoperability standards** | • EU Smart Grids Task Force serves as guidance on data protection and privacy for data controllers and investors in smart grids |
| **Pricing structures** | • Implement **time-of-use tariffs**, **real-time pricing**<br>• Wholesale **price signals** for supplier half hourly settlement | • California Public Utilities Commission (CPUC) requires utilities to **ToU rates** for V1G and V2G<br>• The EU Clean Energy for All Europeans package promotes **dynamic tariffs** by setting frameworks for energy suppliers |
| **Cost** | • **Reduce barriers to entry** via financing through **financial institutions and government-backed grants**<br>    • Upskilling **retail banks** to understand and appreciate DSF<br>    • **Development banks** are crucial for reducing risk of projects<br>    • Blended finance<br>    • ESCOs – Energy Service Companies | • Energy Service Companies (ESCOs) operate in many countries around the world, using **performance-based contracts to guarantee energy savings**<br>    • Guaranteed savings model: U.S., Germany<br>    • Shared savings model: China, Chile |
| **Market reform** | • Enable DSOs to expand their flexibility procurement capabilities and streamline the export licensing process for V2G tech | |
| **Behaviour change** | • Clearly reveal the value of DSF to consumers through transparent billing, mobile apps, and personalized reports, including for those without all electrified loads | • Hong Kong consumers are incentivised to lower load during events by **earning reward points**. They can redeem these points for supermarket coupons, food coupons, smart appliances, and more |
| **Other** | • Leverage other policy as incentives, such as building codes, EPCs | |

# Workshops

Briefing note published in September 2024

| | |
|---|---|
| **Grid build challenge** | March 26th |
| **Key technologies to balance the system**: *dispatchable generation, energy storage, heat storage* | June 18th |
| **Key technologies to balance the system**: *demand side flexibility* | Oct 9th |
| **Sizing balancing needs across key regions & role of interconnectors** | Oct 24th |
| **Key enablers** | Early 2025 |