DOMESTIC DEMAND FLEXIBILITY IN THE GREAT BRITISH ELECTRICITY SYSTEM

SUMMARY OF WHOLE-SYSTEM MODELLING OF FUTURE ENERGY SCENARIOS IN PYPSA

March 2024

Centre for Net Zero
Powered by Octopus Energy

CENTRE FOR NET ZERO DELIVERS PIONEERING RESEARCH TO MAKE THE FUTURE ENERGY SYSTEM A REALITY

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Centre for Net Zero is a not-for-profit research unit within Octopus Energy Group. Octopus spans 18 countries and delivers energy services to 7.7 million households, driving the electrification of heat and transport through smart tariffs and innovative clean tech.

Our access to Octopus' global customer database provides us with a world-leading understanding of how the demand side of the energy system is changing.

DOMESTIC DEMAND FLEXIBILITY WILL BE A CENTRAL PART OF THE FUTURE ENERGY SYSTEM

1. The energy system is changing

We are moving to cleaner, more affordable energy to reduce our reliance on dirtier, more expensive fossil fuels. Renewable generation already accounts for over 40% of electricity generation in Great Britain.[1]

2. We need to intelligently match demand to renewable supply

Electrification and a greater reliance on renewables - which vary with the wind and sun - mean that we need to **deploy** new ways to keep supply and demand in balance.

3. Demand flexibility is critical to achieving this balance

To balance a decarbonised grid, demand flexibility needs to increase by more than tenfold from today.[2] Households, particularly those with smart technologies, can help by shifting demand to when electricity is cheapest and cleanest.

4. It can empower consumers and save money on bills

As well as saving households money on bills, flexibility will reduce system cost for everyone.

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[1] Energy trends, Department for Energy Security and Net Zero

[2] Future Energy Scenarios, National Grid ESO

WHOLE-SYSTEM MODELLING ALLOWS US TO EXPLORE THE POTENTIAL ROLE AND BENEFITS OF DEMAND FLEXIBILITY OVER TIME

We built PyPSA-FES, a cost-optimisation model adapted from PyPSA-Eur, to explore the role of domestic heat and transport demand flexibility in the energy transition in Great Britain.

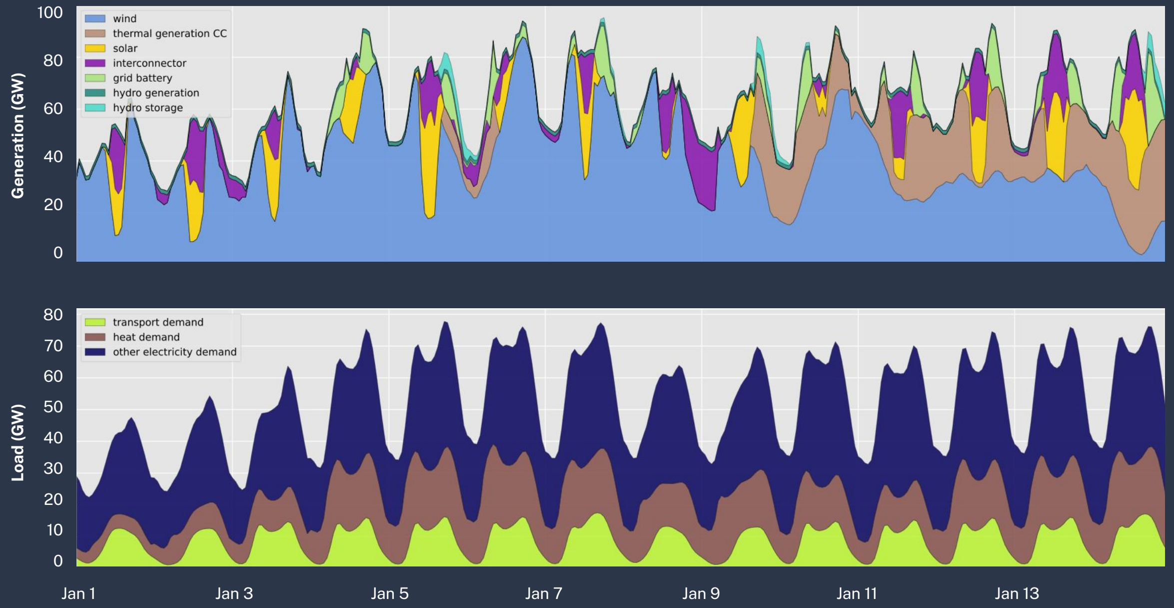
We follow the core assumptions in ESO's Future Energy Scenarios (2023), combined with insights from the Octopus Energy customer dataset.

The 17-zonal cost-optimisation model of Great Britain matches supply (see right, top) and demand (see right, bottom) hourly throughout the year, up to 2050.

It meets demand by shifting loads in time and space through storage options, interconnectors, and dispatching renewable generation based on weather.

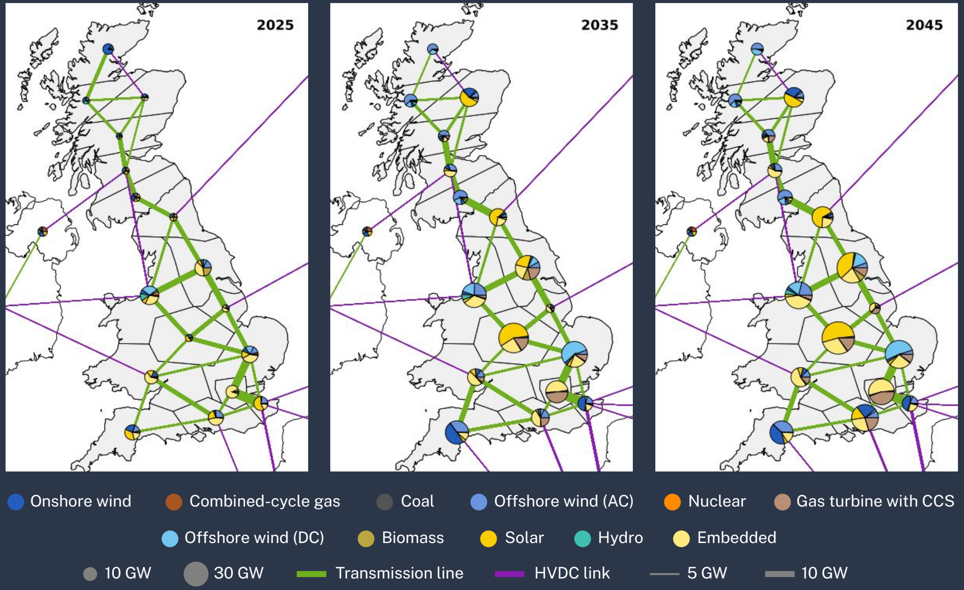
A full paper is available here.

Projected electricity supply and demand under Leading the Way in 2050



PYPSA-FES VIEWS THE ENERGY SYSTEM AS A "BLANK SHEET OF PAPER" AND CONSIDERS ONLY THE IMPACT OF DOMESTIC FLEXIBILITY

The model does not attempt to replicate the real-world market design and policy framework in Great Britain. Namely, it assumes zonal pricing without considering policy costs, implications on investment decisions, and complexity presented to operators. It is a study of the **relative value of domestic flexibility** within this theoretical framework.



Costs and benefits are observed by comparing two binary states for the energy system:

1. No domestic flexibility (counterfactual)

An energy transition up to 2050 based on ESO's *Falling Short* and *Leading the Way* Future Energy Scenarios, with demand flexibility from domestic heat and transport "switched off".

2. Domestic flexibility

The same scenario, but with domestic heat and/or transport flexibility "switched on". No other factors in the model change; we are considering only the relative impact of flexibility.

Results considered are:

- Change in use of renewable generation.
- Change in dispatchable generation capacity.
- Change in network capacity requirements.
- Resulting change in overall system costs.

WHILE THIS APPROACH CAN PROVIDE MEANINGFUL INSIGHTS, IT IS IMPORTANT TO BEAR IN MIND ITS LIMITATIONS

PyPSA-FES: a cost-optimisation model

- **Results indicate relative benefits** of the system with and without flexibility, rather than absolute measures of system need.
- **Market design and policy** assumptions are made in the model which do reflect current conditions (e.g. zonal pricing).
- **Findings on grid capacity requirements should only be interpreted as crude approximations**, as real-world details are limited by data availability and simplified for computational feasibility
- **Assumes perfect foresight**, with uncertainty explored through different decarbonisation pathways in ESO’s Future Energy Scenarios.

All cost-optimisation models

- **Results are highly sensitive to underlying assumptions**, which are often based on past trends or averages.
- **Make structural assumptions** (e.g. about economic systems, demand, linearity) which can reinforce the status quo and overlook tipping points in transitions.
- **Simplify agent behaviour**, including how this will change over time, e.g late adopters of technologies may behave differently to early adopters.
- **Approximate** high-level demand and supply data, and disaggregates to lower level regions as needed, which lacks granularity and accuracy.

HOWEVER, THE MODEL SUGGESTS THAT SYSTEM BENEFITS OF DOMESTIC DEMAND FLEXIBILITY ARE SIGNIFICANT

Maximising renewables

Domestic demand flexibility can contribute up to 30 TWh additional renewable generation in 2030, or 7% of total demand, reducing costlier fossil fuel generation.

Minimising grid build costs

Domestic flexibility ensures networks operate more efficiently - reducing distribution capacity needs by ~25% from 2030 compared to a scenario without this flexibility.

Reducing peak demand

The model suggests that domestic demand flexibility can shift up to ~17 GW, or ~30%, out of peak demand load by 2030.

System savings

These changes reduce system costs by ~£5 bn in 2035, and a total of ~£95 bn over the period 2025-2050. No cost is attached to domestic flexibility (e.g. EV infrastructure) and not all benefits are quantified (e.g. value of lost load).

Key results from PyPSA-FES (based on Leading the Way scenario - Falling Short delays benefits by about 10 years)

EV CHARGING HAS HUGE POTENTIAL TO MATCH RENEWABLE SUPPLY, WHILE SMART HEAT PUMPS HELP TO REDUCE PEAK DEMAND

Electric vehicles' large, flexible loads give them huge capacity to match variable renewable generation.

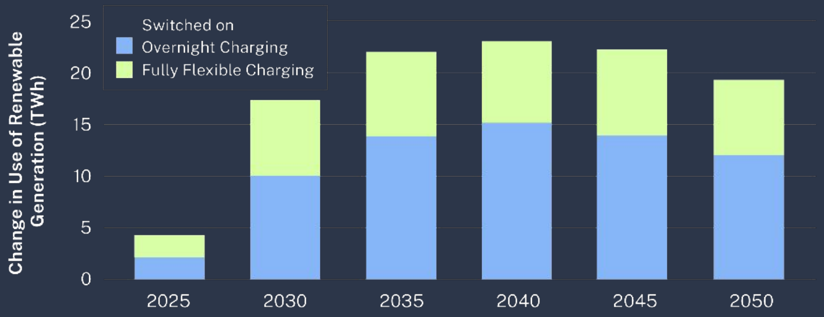
EV flexibility can absorb over **15TWh** of otherwise wasted wind and solar by 2035; similar levels of fossil fuel generation are prevented. This drops after 2040 due to greater availability of transmission-level storage (e.g. compressed air energy storage).

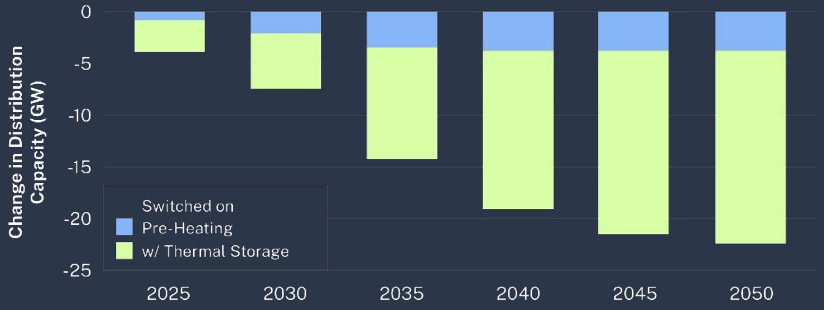
Temporal constraints on managed EV charging affect benefits - reducing the time window to 4 hours overnight ("constrained", shown left) results in ~30% less renewable energy used.

Smart heat pumps help to shave peak demand; the addition of thermal storage increases the impact.

During times of high demand (morning and afternoon), the use of heat pumps for pre-heating to avoid peaks has a material impact, especially on cold days. Over the year, this reduces distribution capacity needs by **~4GW** by 2035 ("pre-heating", shown right).

Temporal constraints reduce heat pumps' ability for within-day flexibility, but the addition of thermal storage (in this case, heat batteries) improves this substantially – both in reducing peak demand and capacity needs (see right), but in particular increasing their ability to absorb renewable energy by as much as 90%.


Change in use of renewable generation from EVs (Leading the Way)


Change in distribution capacity from smart heat pumps (Leading the Way)

BENEFITS FROM TRANSPORT AND HEAT FLEXIBILITY CHANGE AND INTERACT OVER TIME

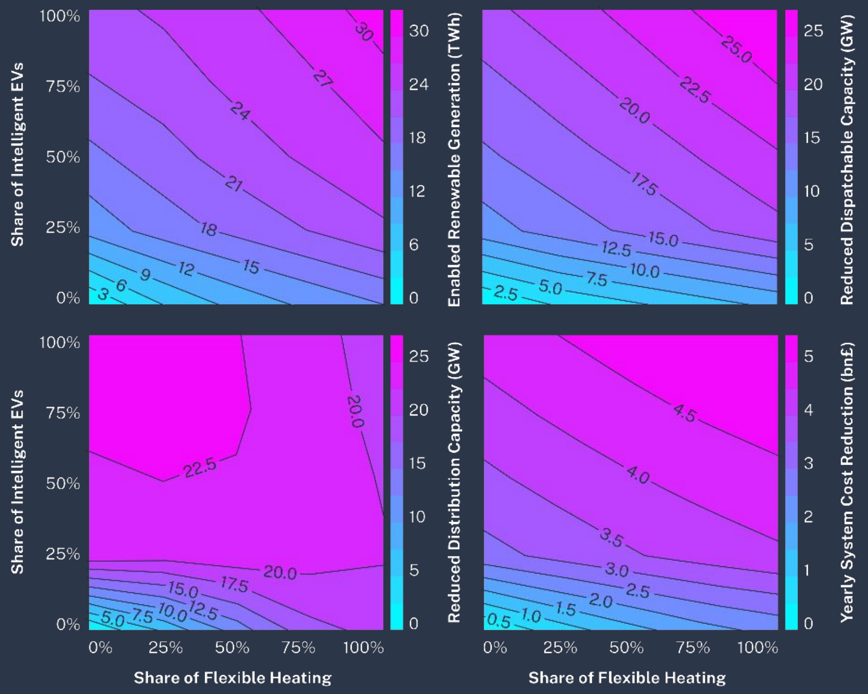
The value of flexibility per asset is greatest when the resource is most scarce (bottom-left corner of each chart), and reduces as more flexibility is activated (top right corner). However, benefits are still at their greatest with the highest share of transport and heat flexibility.

Half of the benefits from EV flexibility are achieved in the first 25% of rollout. Managed EV charging, given its capacity to absorb otherwise wasted renewables, appears to have an outsized impact early on in the transition.

Heat flexibility benefits are lower and more linear over time. When combined with thermal storage (e.g. heat batteries), within-day flexibility benefits "compete" with EV flexibility to absorb excess renewable generation - as heat flexibility is added *relative* benefits drop overall.

For distribution capacity (bottom left), we see the greatest reduction in capacity needs with low heat and high EV flexibility. As heat flexibility increases, it is cost-optimal to increase capacity to maximise other benefits. Therefore, overall system cost reductions (bottom right) remain highest with high heat and transport flexibility.

Benefits achieved from different levels of flexibility from heating and transport in the system (Leading the Way Scenario, 2040)



DEMAND FLEXIBILITY SUPPORTS SPATIAL OPTIMISATION OF GRID INFRASTRUCTURE

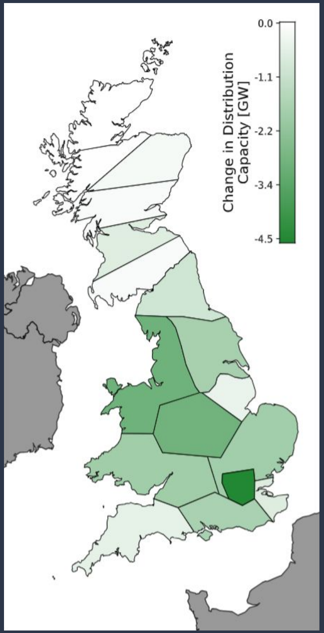
At distribution level, flexibility makes dispatch more efficient, reducing build requirements (left chart), e.g. a reduction of 4.5 GW in Greater London.

At transmission level, flexibility enables more efficient integration of renewables without additional expansion along the north-south axis (centre). To maximise transmission of renewable energy, it is cost-optimal to increase capacity *within* certain regions, e.g. Scotland and South England.

For renewable generation, flexibility leads to siting assets closer to demand centres – e.g. ~20 GW moves to Greater London – which corresponds with a reduction in dispatchable generation needs (right).

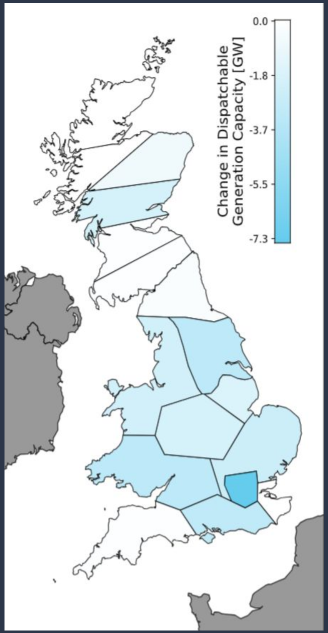
This illustrates **potential spatial optimisation** from flexibility, noting implicit zonal pricing in the model. As this is also implicit in the counterfactual, we cannot attribute all benefits to locational pricing.

Distribution capacity



Transmission capacity

Dispatchable generation



KEY TAKEAWAYS FOR THE ENERGY TRANSITION IN GREAT BRITAIN

System-wide benefits of domestic flexibility are significant

It maximises renewables, optimises grid buildout and reduces system costs overall. Policymakers should build on the *Smart Systems and Flexibility Plan* with a targeted strategy to scale domestic demand flexibility in Great Britain. This could include using whole-system modeling to set load-shifting targets which galvanise efforts to scale flexibility - following the example of others, such as California and Ireland.

EV flexibility brings significant benefits in successfully integrating renewables

In particular, during the early stages of rollout; a critical mass (e.g. around a quarter) of flexible EVs could achieve outsized benefits. As part of supporting EV adoption and charging infrastructure, policy should seek to encourage flexible charging as the default.

Heat flexibility has a steady and material impact as rollout increases over time

In particular to shave peak demand on cold days with low renewable generation. The use of smart thermal storage significantly increases within-day flexibility potential – although its relative impact reduces in a scenario where it “competes” with high flexibility from EVs.

Impact may be highest during early adoption

Policy should pursue heat and transport flexibility as a ‘low regrets’ action, but look to accelerate early uptake in particular. Slower rollout of low-carbon technology also delays benefits - by a decade under ESO’s *Falling Short* scenario.

Grid infrastructure operates more efficiently with flexibility

It reduces distribution capacity requirements while supporting cost-optimal transmission expansion. Spatially, under a nodal pricing framework implicit in the model, demand flexibility helps to optimise the matching of renewables supply with demand geographically. The proposed *Strategic Spatial Energy Plan* must ensure it properly accounts for, and benefits from, demand-side changes to the system.

Centre for Net Zero is developing data and models to help transform energy systems, with a particular focus on improving "bottom-up" understanding of demand. This will bring to bear evidence from our consumer trials and make use of synthetic smart meter data produced using our generative AI model, Faraday.

Get touch to discuss this project or our wider work:
info@centrefornetzero.org.

You can find out more about our range of ongoing research on our website:
centrefornetzero.org

Code and data used is openly available at:
github.com/centrefornetzero/pypsa-fes

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