Electrification:

The local grid challenge

regen transforming energy

THE MCS FOUNDATION

May 2024

Purpose of this report

The electricity network is critical to decarbonising our homes.

Domestic heat pumps, electric vehicle chargers and rooftop solar panels all have one thing in common – they need a connection to the grid.

There has been extensive focus by policymakers on upgrading the transmission network.

This paper looks at what it will take to ensure the distribution network is ready for net zero. In particular, the paper focuses on the ‘local’ high-voltage and low-voltage networks.

About

Regen

Regen provides independent insight and advice to transform the UK’s energy system for a net zero future.

The MCS Foundation

The MCS Foundation drives positive change to decarbonise homes, heat and energy. The Foundation commissions robust, independent research that informs and shapes better decision-making to drive a carbon-free future for all UK homes.

Authors

Frank Hodgson, Senior Energy Analyst - Regen

Merlin Hyman, Chief Executive - Regen

regen transforming energy

THE MCS FOUNDATION

Report summary

1. Electrification of heat and transport relies on the local grid being ready to deliver more power to the consumer. If the grid is not ready, this will impact households and businesses, impede net zero and curtail growth in the low-carbon economy.
2. Today, there is significant spare capacity on local networks. For electrification at the rate required to meet carbon budgets, network operators calculate that without intervention 45% of primary substations will run out of capacity by 2035.
3. Less data is available on low-voltage secondary networks. More data and analysis are vital to reduce uncertainty and enable a smart and flexible approach with well-planned network upgrades.
4. Baseline investment budgets set by Ofgem for 2023-2028 are based on relatively low levels of electrification. Uptake of EVs and heat pumps at the rate needed to meet our carbon budgets will require networks to access contingency budgets.
5. We need to learn lessons from the transmission network and ensure we plan and invest in good time to enable households to charge their EVs and run their heat pumps – and to ensure that network upgrades are deliverable.
6. The downsides of investing early, with a small risk of regret cost, are far lower than the risk of delayed investment leading to capacity problems, which could stall the net zero transition and limit economic growth.
7. The regulatory model for Distribution Network Operators (DNOs) should adapt to require networks to produce long-term investment plans and invest in supply chains – ensuring they have the capacity in time to meet the forecasts of regional demand set out in Regional Energy Strategic Plans.
8. Increasing demands to connect EV chargers and heat pumps will put customer services under pressure before network capacity runs out. Networks need to be ready with a fully digitalised customer journey.

regen transforming energy

THE MCS FOUNDATION

Recommendations summary

UK government

The government should make upgrading the local grid in time for net zero one of the UK's critical infrastructure programmes of the next 25 years to 2050.

Ofgem

Ofgem should reform the price control process to require DNOs to plan and deliver a long-term programme of investment that will ensure the distribution network is ready for demand forecasts set in the upcoming Regional Energy Strategic Plans.

UK government and Ofgem

The government and Ofgem should ensure local and national arrangements for flexibility are coordinated to optimise the system as a whole.

Distribution Network Operators should:

- Use the mechanisms in their budgets for 2023-2028 to scale up local network upgrades.
- Produce and publish data on capacity and constraints on their secondary networks as a key priority.
- Accelerate development and rollout of local flexibility markets.
- Ensure local network planning is prepared for a reduction in diversity of demand due to stronger wholesale pricing signals and electrification of heat.
- Deliver a streamlined, digitalised connections process.

regen transforming energy

THE MCS FOUNDATION

Contents

Return to contents

Glossary of terms

regen transforming energy

THE MCS FOUNDATION

1

Increasing demand

"The mass uptake of electric vehicles and heat pumps will create significant new demands for power. Network capacity will therefore need to adapt and expand ahead of need."

Government Energy Strategy and Policy Statement

Our local electricity infrastructure is critical to the rollout of low-carbon technologies – and net zero

As electricity increasingly powers our vehicles and heats our homes, more and more of our energy will be delivered to households through the grid.

The grid is on the critical path to net zero.

While there are some uncertainties about the speed of this transition, the government and the Climate Change Committee are clear that we need to electrify heat and transport rapidly to meet emissions targets.

Network operators will need to ensure they have the capacity ready for the electrification of transport and heat at the pace required to meet carbon budgets. We can learn lessons from the transmission network, where a failure to plan and invest has led to long delays in connecting clean energy projects.

In light of the key importance of the distribution network, the government has asked the National Infrastructure Commission to undertake a review.

Preparing the local grid in time to enable net zero needs to be one of the UK's critical infrastructure programmes over the next 25 years – with the bulk of the work delivered by 2040.

Our homes and vehicles will increasingly be powered by electricity

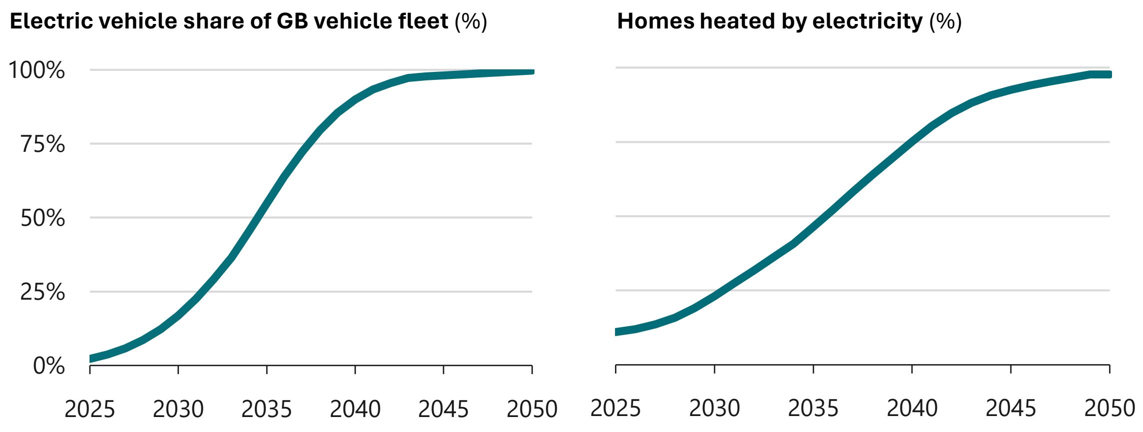


Figure 1: Electric vehicle and heat electrification uptake under ESO's Consumer Transformation Future Energy Scenario. Heat projection includes district heat.

> "Around eight million buildings in England (around 30 per cent of the building stock) will need to switch from fossil fuel boilers to heat pumps (or other electric heaters) by 2035"

National Infrastructure Commission, The Second National Infrastructure Assessment

Increasing demand
When will upgrades be needed?
How can upgrades be minimised?
How should networks plan and invest in upgrades?
How can customers get connected quickly and easily?

Upgrading local networks presents a different sort of challenge compared to transmission investment

The electricity distribution networks in Great Britain are made up of around 800,000km of overhead and underground cables, which transport power from where it is generated to homes and businesses, where it is used.

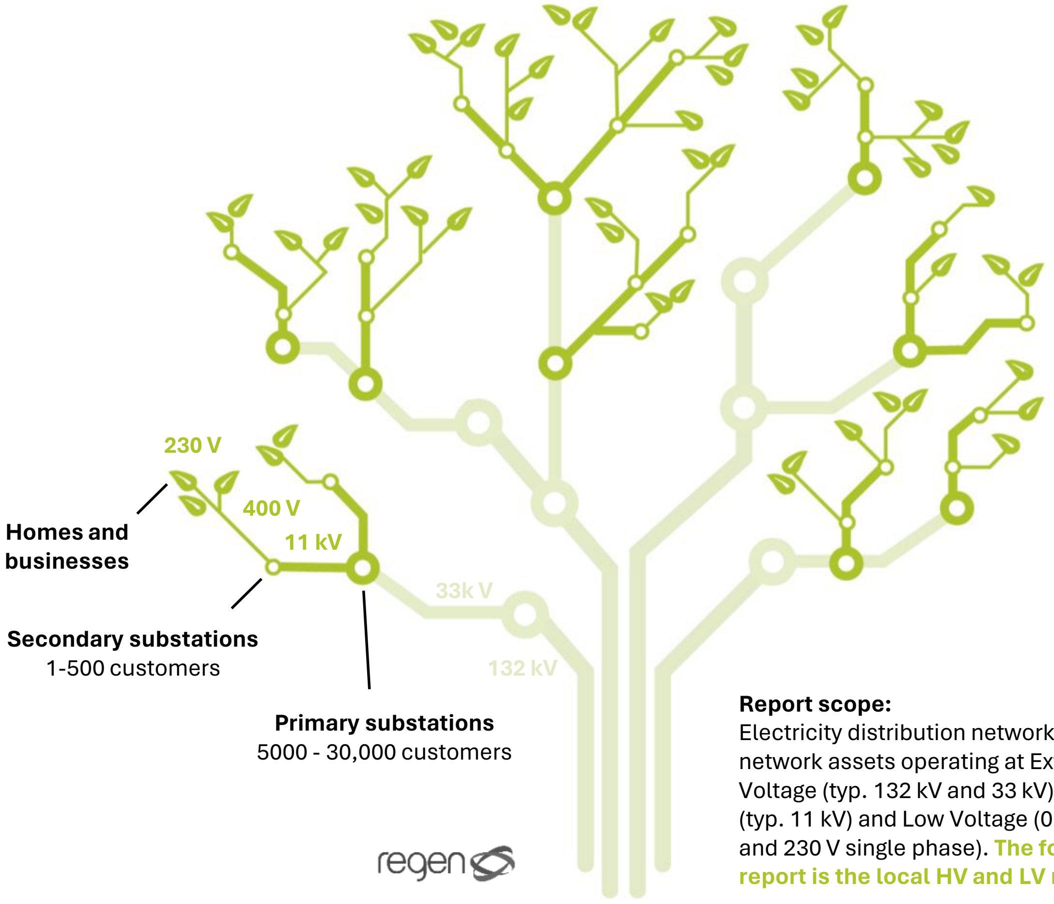
Electricity is transported over long distances at higher voltages to minimise energy lost in the form of heat. The power is stepped down from 400,000 volts on the transmission network through a series of distribution substations for use by households and businesses at 230 volts.

Policymakers are currently focused on connection issues at the transmission level, which require a limited number of very large upgrades.

The challenge on the lower-voltage distribution network is that:

1) The cables and substations that make up the local networks were installed over the last 100 years with limited monitoring – so network operators' understanding of capacity is limited.

2) While the local network generally comprises relatively simple passive equipment, the assets are extremely numerous. Hundreds of thousands of individual upgrades across the country will require a major infrastructure programme that could take decades and require investment in supply chain capability.



Report scope:
Electricity distribution networks include network assets operating at Extra High Voltage (typ. 132 kV and 33 kV), High Voltage (typ. 11 kV) and Low Voltage (0.4 kV 3-phase and 230 V single phase). **The focus of this report is the local HV and LV networks.**

Networks need to be ready for increased electricity demand from EVs and heat pumps

The cables and substations that make up the local distribution networks are designed to handle peak demand from groups of households and businesses.

Peak power loads will be higher following the installation of an EV charger or a heat pump as they add to electricity demand. However, significant uncertainties remain in how customers will behave and, therefore, how much peak load will increase and how the load profile might change.

Data from the Energy Systems Catapult shows that low-cost overnight electricity tariffs are leading to new peaks in household electricity demand between midnight and 2am.

Encouraging off-peak and flexible energy use is a powerful tool. However, as more people use dynamic tariffs, where electricity is cheaper or even free at times of high renewable generation, we are more likely to charge our EVs and run our heat pumps at the same time, reducing diversity and creating new localised peak loads.

How household electricity demands will change is uncertain. However, networks will need to be ready for higher peak demands as we electrify transport and heat.

Heat pumps and EV chargers will increase peak loads for most households

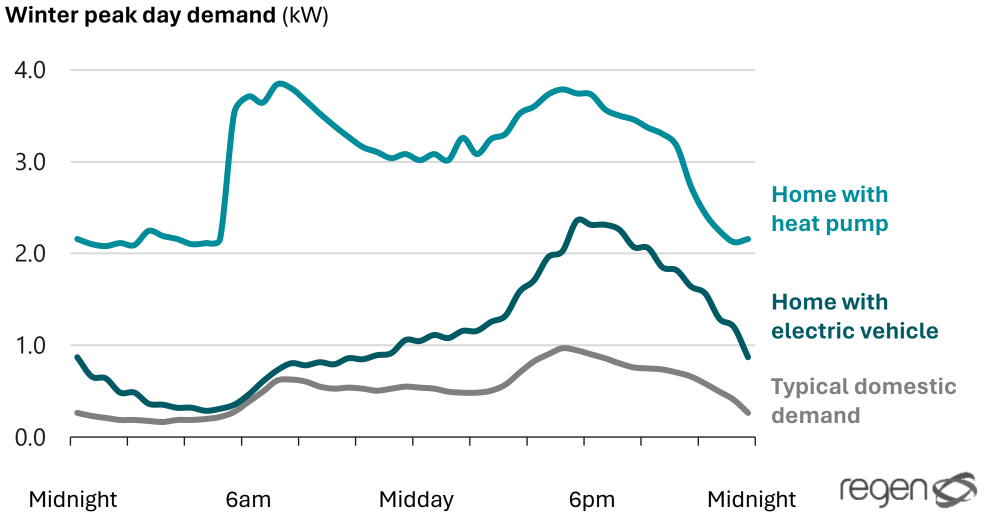


Figure 2: Winter peak daily load profiles for households with and without low-carbon technologies. Source: National Grid, DFES 2023, Customer behaviour profiles and assumptions report.

Network design assumes we don't all use power at the same time

While there are patterns in how households and businesses use energy, we don't all turn on our ovens and kettles at the same time. This is known in the industry as 'demand diversity'. Statistically, the larger the group, the greater the level of demand diversity.

The local distribution networks were designed to adequately and economically cater for peak loads after considering the diversity of demand (ADMD – After Diversity Maximum Demand).

A defining feature of low-voltage networks is that they are made up of hundreds of thousands of assets, each servicing relatively small numbers of customers. Secondary substations, which reduce the voltage of electricity from high to low-voltage for use by consumers, typically feed power to between 1 and 500 customers.

With smaller groups, there is a higher probability of all customers' peak loads coinciding. Therefore, as the chart shows, assets servicing small groups must be designed for higher loads per customer.

To understand the impact of electrification on the low-voltage network, we need to understand both the changes in peak loads per household and any changes to the diversity of demand.

After Diversity Maximum Demand (ADMD) per customer increases with smaller groups of customers

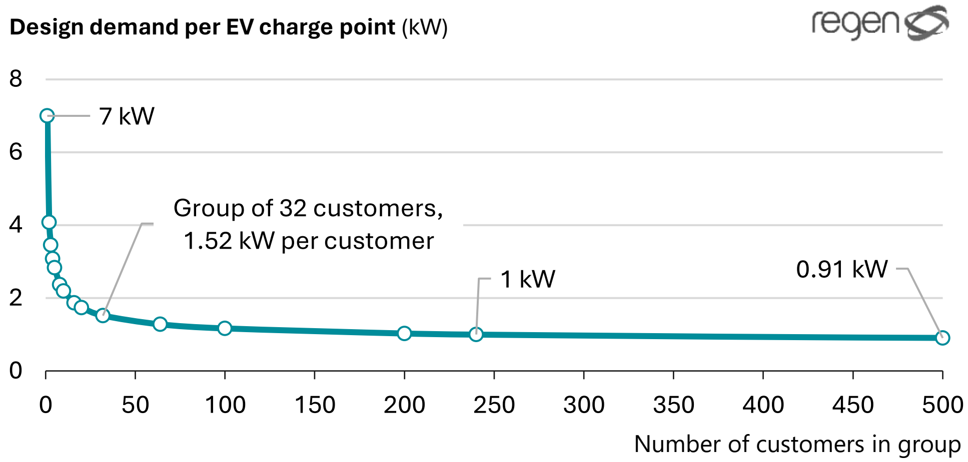


Figure 3: Design demand per EV charge point, using the ACE49 methodology and data from the Electric Nation EV charging trial (7 kW EV charge points). Regen analysis.

Consumer devices connected to the local grid will provide important energy system flexibility

Smart operation of domestic devices will provide an important source of national energy system flexibility, supporting a system powered by variable renewable generation and reducing overall peak demand.

The Electricity System Operator was able to call upon more than 300 MW of emergency demand turndown during its Demand Flexibility Service events over the last two winters. As the uptake of EVs and heat pumps progresses, the potential for flexible demand reduction will grow rapidly.

The ESO projects that households could provide 39 GW of demand reduction to support a renewable system at peak demand in 2050. Bi-directional charging could generate 40% of this domestic response, using energy stored in vehicles for use by other devices. It is not yet clear whether consumers will need to export outside their homes (vehicle-to-grid export), as opposed to using energy from the vehicle to displace conventional imports (vehicle-to-home).

In a highly electrified future, domestic demand-side flexibility connected to the low-voltage network will play a vital role in a net-zero power system.

The bulk of GB's peak demand-side response will come from households

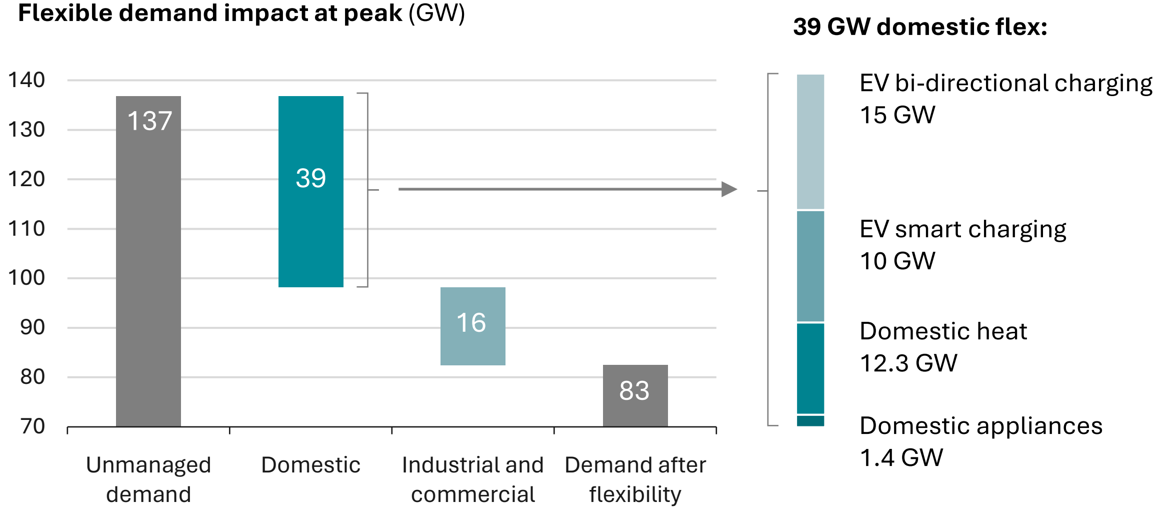


Figure 4: Regen analysis of GB-wide demand side flexibility projections in 2050 from FES 2022, Consumer Transformation Scenario.

1

Section summary: **Increasing demand**

- **Our local electricity infrastructure is critical to the nationwide rollout of low-carbon technologies** – households and businesses rely on local energy networks to charge their electric vehicles and run their heat pumps.
- **The local distribution networks are made up of millions of assets** – this means that, despite their relative simplicity, preparing them for net zero will be a major long-term infrastructure programme.
- **Networks need to be ready for increased peak electricity demand due to heat pumps and EVs** – it is the peak demand from a group of houses, rather than energy demand over the year, that determines the need for electricity network upgrades
- **Local networks need to be ready to enable households to use power flexibility** – charging our EVs and running our heat pumps in response to price signals may reduce diversity and increase or move peak loads on the low-voltage networks.

Recommendations ▶▶▶

1.1 The government should make upgrading the local grid in time for net zero one of the UK's critical infrastructure programmes for the next twenty-five years to 2050.

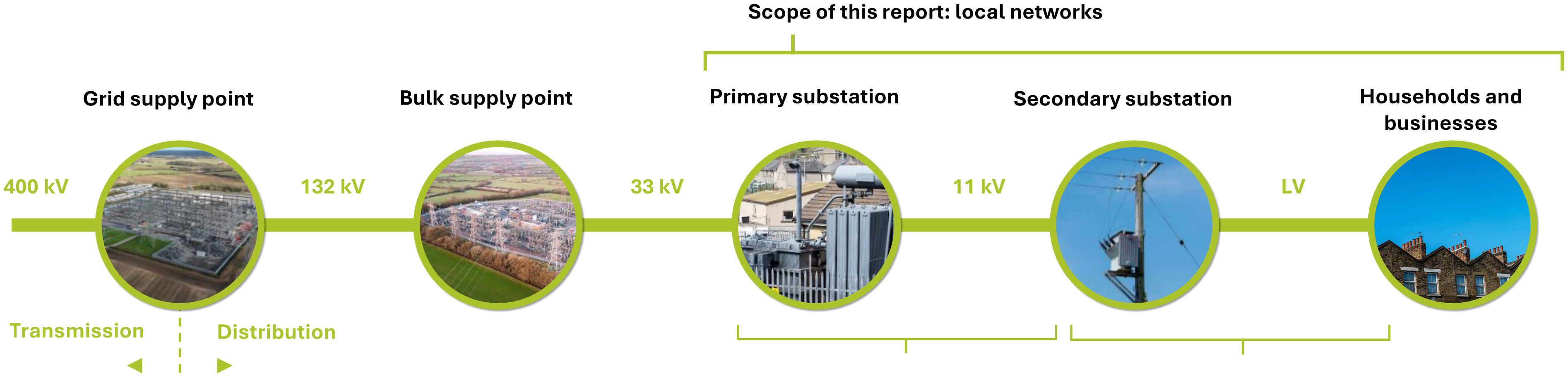
We have the opportunity to learn from the failure to plan and invest in the transmission network to ensure we prepare our local grids to be ready for demand increases as we take up electric vehicles and heat pumps.

2 When will upgrades be needed?

"The key drivers expected to impact the low voltage and high voltage networks are the increased penetration of low-carbon technologies projected to connect at a household level."

National Grid Electricity Distribution ED2 Business Plan

Local network overview



The capacity on the local distribution networks is limited. There are three principal technical limits: thermal, voltage and phase imbalance (see glossary for definitions). As low-carbon technologies connect, the likelihood of these constraints being breached will increase.

Analysis for the Climate Change Committee found that voltage constraints will drive around half of low-voltage network upgrades, while high-voltage 11 kV reinforcement will be almost exclusively driven by thermal constraints. Breaches of the statutory voltage limits are more likely on rural low-voltage networks with longer lengths of line.

Some technical limits can be exceeded temporarily, with impacts on asset lifetimes and fault rates. Significant or prolonged exceedances of thermal constraints are likely to lead to network outages.

	High Voltage (11 kV) Networks	**Low Voltage (LV) Networks**
Key assets	Primary substations (33/11 kV), 11 kV underground cable and overhead lines.	Secondary substations (11 kV/LV), LV mains and LV services (underground cable and overhead lines).
Likely constraints	Thermal, phase imbalance and fault level.	Voltage, thermal and phase imbalance.
Existing capacity	Well understood – monitoring at all primary substations.	Historically, there has been very little monitoring of the LV networks. DNOs are now installing monitoring equipment and aggregating smart meter data to build a complete picture of LV network utilisation. Data suggests networks are 30-40% utilised.
Future constraints	Well understood. Ofgem requires DNOs to publish thermal constraint projections at all primary substations.	DNOs have started projecting constraints and are in the process of publishing their analysis.
Key challenges	Larger, more complex substation sites with longer lead times for upgrades.	Accurately predict LCT uptake at local level makes proactive reinforcement challenging. Vast number of assets.

Increasing demand
When will upgrades be needed?
How can upgrades be minimised?
How should networks plan and invest in upgrades?
How can customers get connected quickly and easily?

Network operators model when and where to expect demand increases

Network operators develop comprehensive forecasts of changes to demand and generation on the distribution networks.

This process, known as Distribution Future Energy Scenarios (DFES), was pioneered by Regen, working with National Grid and SSEN, and continues to develop, for example, by integrating with local authority decarbonisation plans.

DFES takes the Electricity System Operator's Future Energy Scenarios and uses local stakeholder and market input to create detailed load forecasts. Network planners can use these forecasts to assess how network assets will be impacted under different scenarios and to plan upgrade programmes.

Ofgem is introducing a new Regional Energy Strategic Planners (RESP) function to be delivered by the National Energy System Operator. The RESPs are expected to develop whole-system regional energy plans to reflect regional, local and devolved government priorities. These plans could then provide a primary input to network planning.

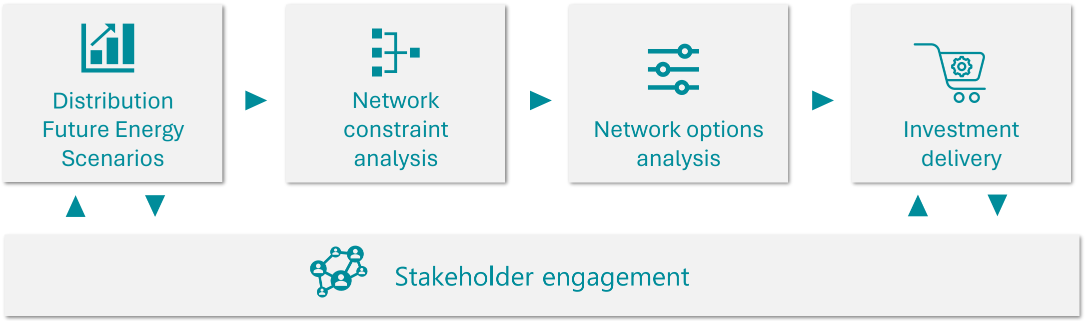


Figure 5: Overview of the distribution network development process. Distribution Future Energy Scenarios are created annually. Network development plans are developed every two years.

HV network forecast granularity **LV network forecast granularity**

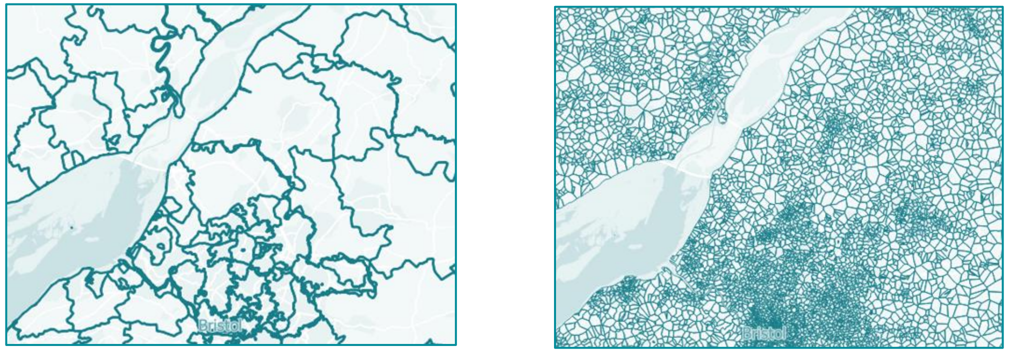


Figure 6: Left graphic shows Severn Estuary area illustrating primary substation level granularity of DFES projections. DNOs create more granular projections, down to LV feeder, for electric heat, electric vehicles and rooftop solar (right).

Network operator projections suggest that 45% of primary substations will need upgrades by 2035

Networks have a good understanding of the upgrades required at primary substation level. Ofgem requires DNOs to generate and publish projections of primary substation capacity.

Regen analysis of this DNO open data suggests that electrification of heat and transport at the rate needed to meet our carbon budgets could lead to widespread constraints by the mid-2030s. This analysis used the DFES Consumer Transformation scenario, which aligns most closely with the CCC's Balanced Pathway and NIC's 2nd assessment.

This data is only available at primary substation (33 kV to 11 kV) voltage level and above.

Upgrades to primary stations are already required in some areas during the current price control period (2023-2028). By 2035, electrification at the rate needed to hit our net zero targets will require DNOs to upgrade primary substations across the country.

Significant network upgrades will be needed to achieve heat and transport electrification

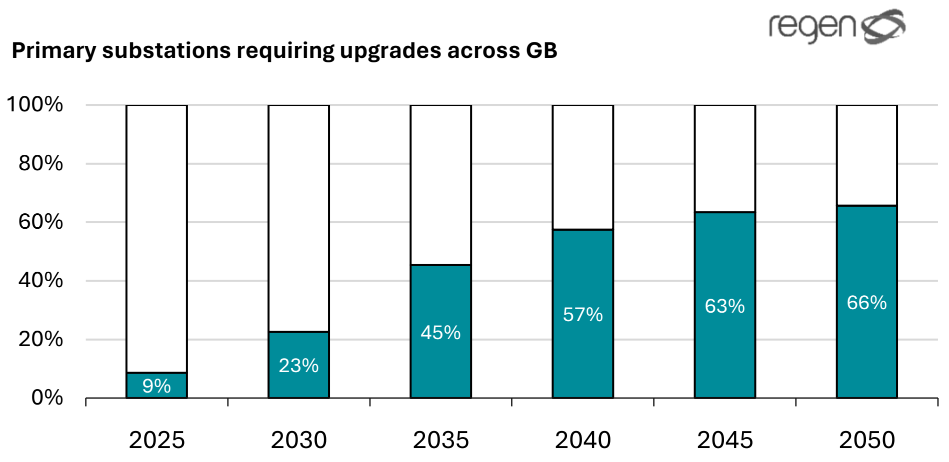
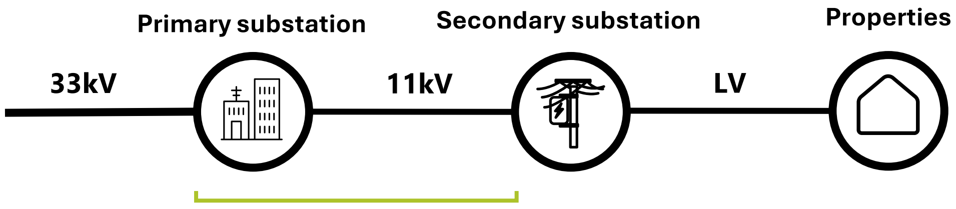


Figure 6: Chart showing the proportion of primary substations across GB with no remaining thermal capacity for demand under the Consumer Transformation DFES scenario. This decarbonisation scenario aligns closest to the CCC's Balanced Pathway scenario and the NIC's Second Assessment. Source: DNO data provided with the support of DNO open data platforms. Net Zero High demand used for SP Energy Networks licence areas.



Network constraints will affect all regions, but the level and timing of upgrades will vary

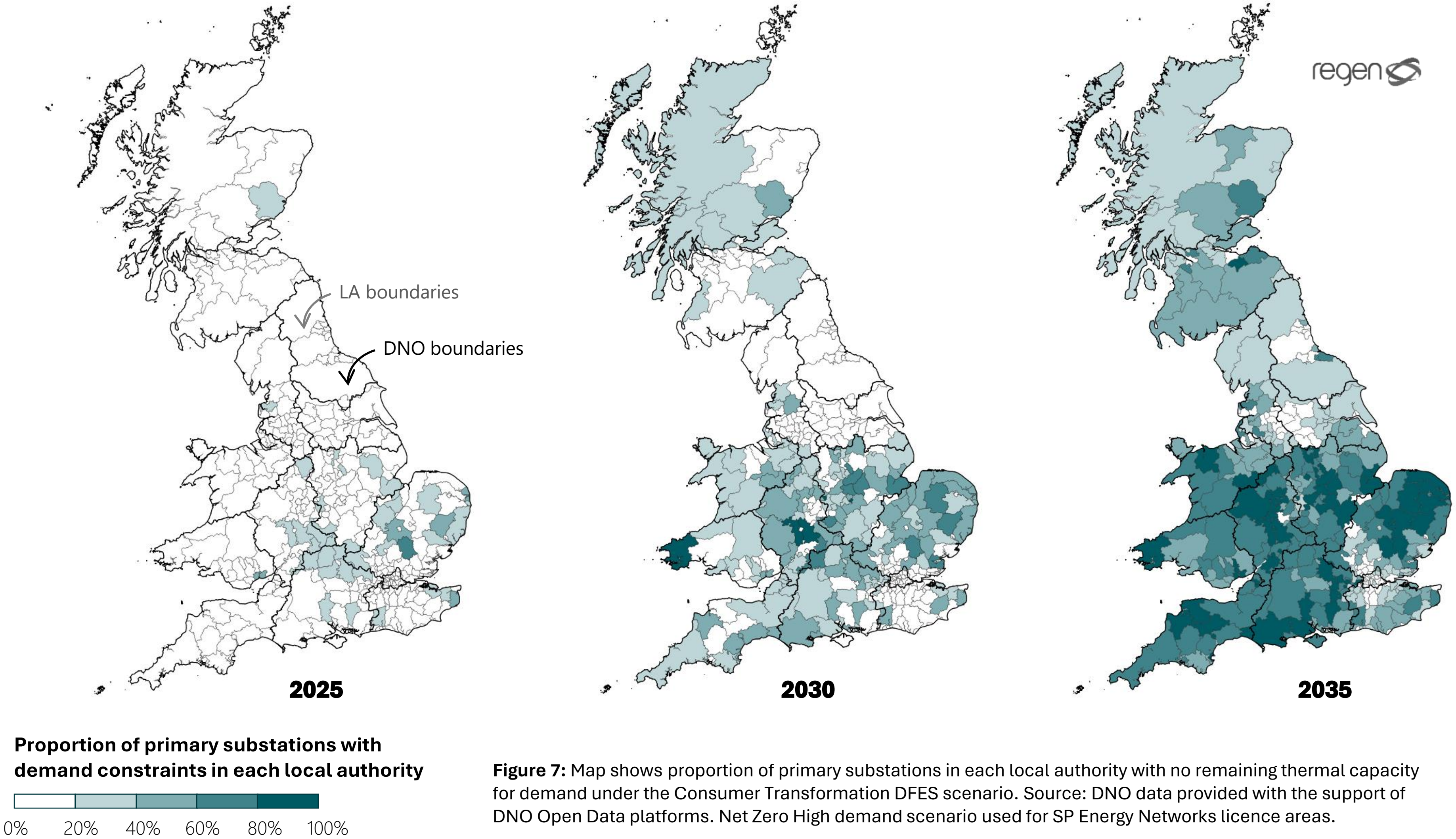


Figure 7: Map shows proportion of primary substations in each local authority with no remaining thermal capacity for demand under the Consumer Transformation DFES scenario. Source: DNO data provided with the support of DNO Open Data platforms. Net Zero High demand scenario used for SP Energy Networks licence areas.

Estimated low-voltage network utilisation data suggests there is currently spare capacity

"At present we have almost no visibility of consumption, generation and power quality on our Low Voltage (LV) networks."

SSEN LV Monitoring Paper, 2022

Network operators have now begun modelling loads on their LV networks below secondary substation level. A utilisation snapshot of NGED's secondary network suggests that the median average substation is only 36% utilised (i.e. under peak demand conditions, power flows are 36% of rated capacity).

Major strides have been made in improving the visibility of the LV network in the last few years but these utilisation estimates are still highly uncertain. The DNOs are in the process of rolling out network monitors to a sample of their LV network and combining this with aggregated smart meter data to build a complete picture of network loads at half-hourly intervals.

It is critical that all DNOs undertake and publish secondary network headroom analysis so that stakeholders, including the government and Ofgem, understand the scale of the challenge and when and where constraints will occur.

Data from NGED suggests that most secondary (11 kV/LV) substations have significant spare capacity

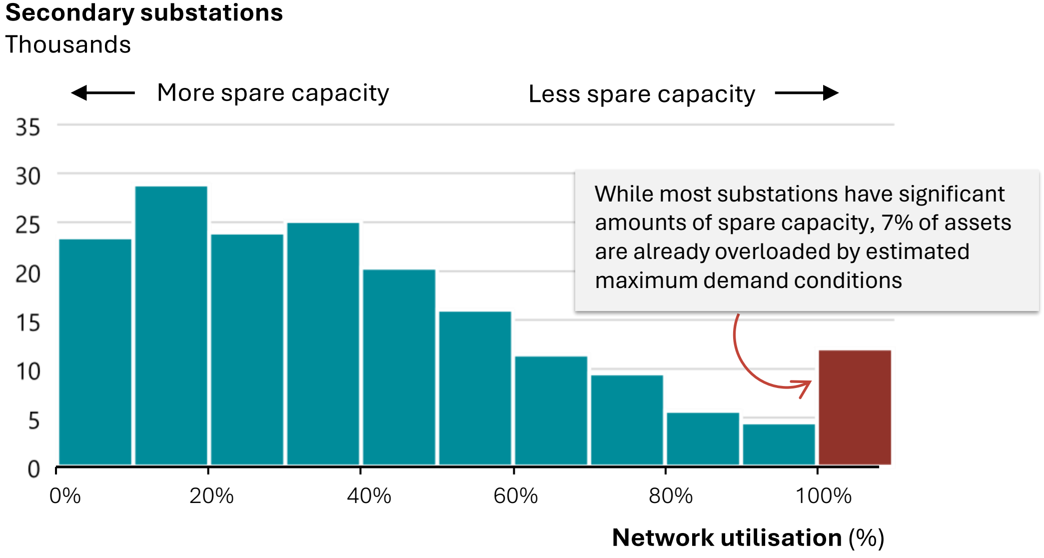
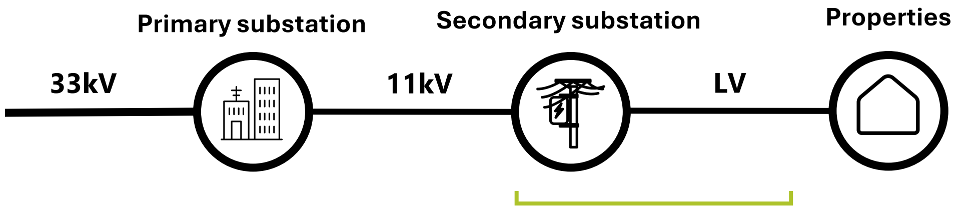


Figure 8: Current thermal utilisation of secondary (11 kV/LV) substations for National Grid (NGED). NGED has 181,000 secondary substations.

regen

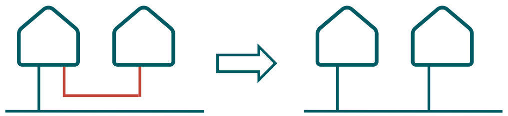


Many properties will also require fuse and service cable upgrades

As well as upgrades to the local high-voltage and low-voltage networks, the equipment that connects directly to peoples' homes may also need replacing. The LV network is connected to households by service cables and cut-outs (containing a fuse), located inside properties, which avoid overloads.

DNOs do not yet know exactly which properties need service cables replacing and cut-outs upgrading. Without this information, it will be difficult for them to deliver the upgrades needed ahead of customers wishing to connect their EVs and heat pumps.

While fuse replacements are straightforward, replacing service cables will require more planning as it can involve intrusive work such as digging cable trenches across roads and gardens. Some DNOs are moving towards a more proactive approach where customers are informed of their property's readiness for a connection ahead of the point of LCT purchase, creating the opportunity for works to be carried out in advance.



Looped services

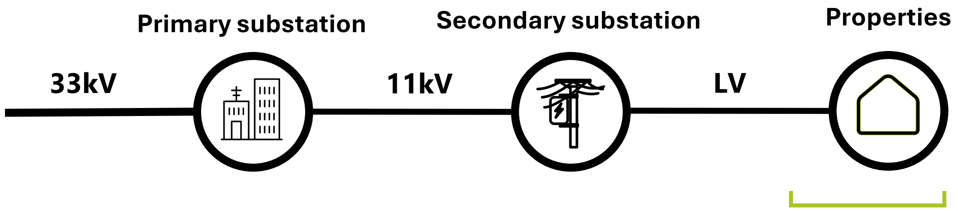
In some areas, up to 20% of service cables are shared with neighbouring properties (known as looped services). In many cases these will need to be replaced to avoid overloads of these shared cables. Under the current price control, there is a dedicated Uncertainty Mechanism to fund service unlooping.

SP Energy Networks estimates that it will need to unloop fifty times as many service cables from 2023-2028 as it did in the previous five-year price control. ENWL estimates that half a million (20%) of the 2.4 million homes in its licence area require unlooping.

Fuse upgrades

When installing low-carbon technologies, installers assess a property's fuse rating. Most DNOs (though not all, as explored in Section 5) will provide an upgrade to up to 100 A on a single-phase connection free of charge.

This equates to a load of 23 kW, which will be sufficient for most properties with an EV charge point and a heat pump. Load balancing equipment can allow customers to keep their power consumption under this limit – such as by turning down EV charging for a few minutes when using an electric shower.



2

Section summary: **When will upgrades be needed?**

- **Demand from low-carbon technologies will cause a range of network constraints across all voltage levels**.
- **Network operators model when and where to expect demand increases** – the Distribution Future Energy Scenarios allow DNOs to forecast when and where changes in demand will occur.
- **Network constraint projections show that 45% of primary substations could run out of headroom by 2035 without interventions.**
- **Networks have little visibility of demand and generation on the local low voltage networks** – monitoring is being installed in the current 2023-2028 price control period.
- **Upgrades are not just required on networks** – many consumers will require fuse and service cable upgrades within their properties to install low-carbon technologies.

Recommendations ▶ ▶ ▶

Network Operators should commit to producing and publishing data on capacity and constraints on their secondary networks as a key priority.

Major strides have been made in improving secondary substation and low-voltage network visibility with network monitoring and smart meter data. However, most DNOs do not publish the relevant data on their Open Data platforms. Without this information it is not possible to reliably predict the volume and cost of network upgrades that will be needed.

3

How can upgrades be minimised?

"Achieving the government's net zero commitments will require households and businesses to be more flexible with the times they use electricity."

"A Flexible Future", Citizens Advice

DNOs are using flexibility to manage network constraints and to defer reinforcement

Traditionally, network operators avoid local network constraints by upgrading physical network infrastructure to meet increases in demand. As an alternative, network operators can procure flexibility to defer reinforcement, either temporarily or indefinitely.

This can involve paying for distribution-connected generation to turn up at peak demand times. It can also involve energy consumers agreeing to adjust their demand patterns to avoid a constraint.

Ofgem requires network operators to consider whether constraints can be met by flexibility (known in the industry as 'flex first'). Distribution System Operators have well-developed flexibility markets for their HV and EHV networks, with almost 2 GW of flexibility capacity contracted over the 2022/23 year.

DSOs are now launching flexibility tenders to alleviate network constraints on their low-voltage networks. National Grid recently announced plans to extend flexibility to over 1,400 locations on its low-voltage distribution network for next winter.

Distribution System Operators have rapidly expanded their flexibility procurement (but demand is a small component)

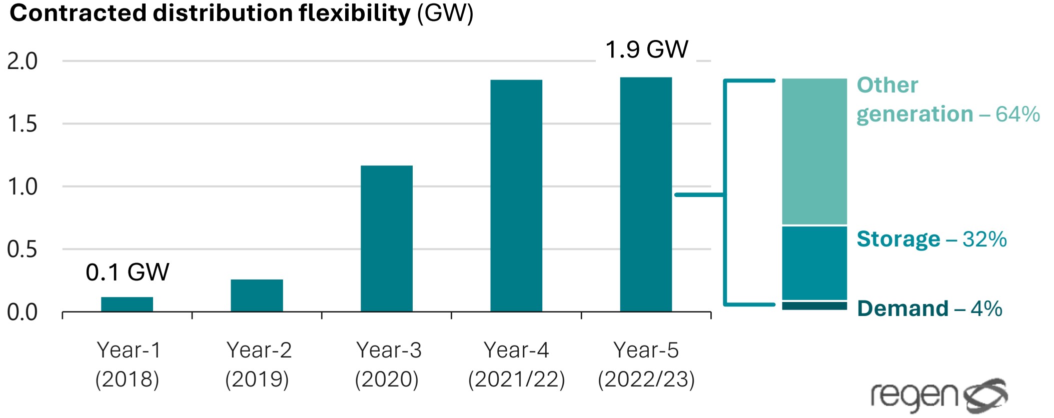


Figure 9: Contracted flexibility capacity across all distribution networks. Source: ENA Open Networks Flexibility Figures 2023.

"In Power-ups, your electricity is free at specific, super-green times. [It] is only open to customers in certain areas in South East & East England for now, because we're launching this cutting-edge project directly with the local network operator there, UK Power Networks."

Octopus Energy

Minimising peak winter load is a key challenge

With a high uptake of electrified heat, cold winter conditions will present a challenge for the local networks. This is because:

1. There is little diversity in electric heating demand – if a local area experiences a cold morning, it is likely that most households in that area will simultaneously require heat.

2. Lower ambient temperatures increase the amount of heat required to maintain properties at room temperature whilst also reducing heat pump efficiencies. Combined, these lead to significantly higher electrical loads.

3. The extent to which heat pumps can be used flexibly is still uncertain. A key question is whether households with low thermal efficiency will be able to pre-heat their homes (to avoid drawing from the grid at peak times) without affecting comfort.

Improving building thermal efficiency is not a prerequisite for electrified heating. Still, it can enable the use of properties as thermal stores, making it easier for customers to turn down their heating systems at peak times. It also enables the use of smaller (cheaper) heat pumps and higher-efficiency low-temperature systems.

Trials are ongoing, such as EQUINOX and HeatFlex, which aim to understand to what extent customers can shift their electric heating load to help the grid. Heatflex found that "participants were generally comfortable... during flexibility windows," while EQUINOX found that more than half of participants sometimes felt discomfort during turn-down events.

Networks will need to be ready for high localised peak loads from electric heating during cold winter days. Getting the most out of electric heating flexibility will be important, but it is unlikely to be a panacea for avoiding network upgrades.

British homes' poor thermal efficiency is a challenge for heat flexibility

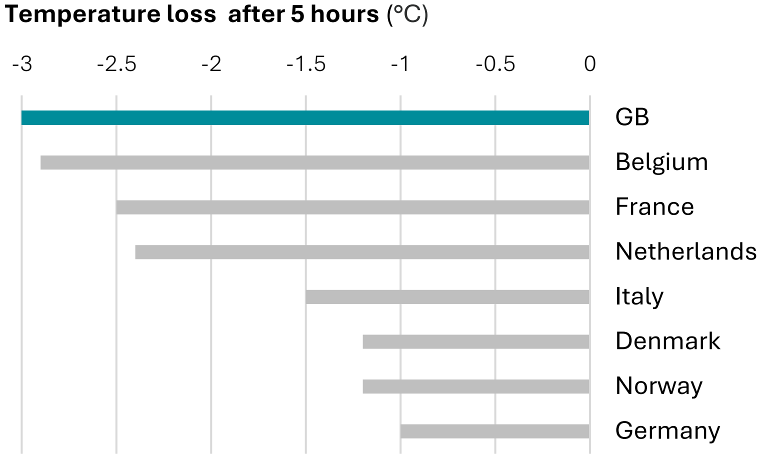


Figure 10: Home temperature loss after five hours with a starting temperature of 20°C inside and 0°C outside. Based on sample of 80,000 homes. Source: Tado.

Flexibility is powerful, but new solutions will be needed to maintain load diversity on local networks

As set out on page 10, diversity of customer demand profiles is a key enabler of an economical distribution network.

'Smart' tariffs reward households for charging their EVs and heating their homes at times of plentiful renewable generation, when electricity prices are low. These signals can be very effective in supporting an efficient electricity system.

However, periods of high generation and low prices (which could be determined by the current national market or a switch to zonal pricing) may lead to clusters of customers charging their EVs and running their heat pump at the same time, reducing load diversity.

Distribution System Operators are considering how to manage this issue with new flexibility markets that maintain load diversity on the local networks. SSEN has outlined two market concepts to avoid clusters of customers responding with high levels of demand that could cause local network constraints. It will be important to understand the effectiveness of these new diversification markets when trials get underway.

Developing and trialling these market-based solutions will be important for enabling flexible demand to help the overall system without causing issues at a local level.

Until we know how effective these solutions are, network operators will need to consider reduced diversity in their planning assumptions to ensure they have the capacity required for high levels of flexible demand.

"When flexibility is well established... a single event, such as a dip in the wholesale price, can destroy diversity, overloading networks and risking loss of supply"

SSEN Flexibility Strategy Webinar

Dynamic tariffs provide very strong signals to shift demand

Price on 23 July 2023 (pence/kWh)

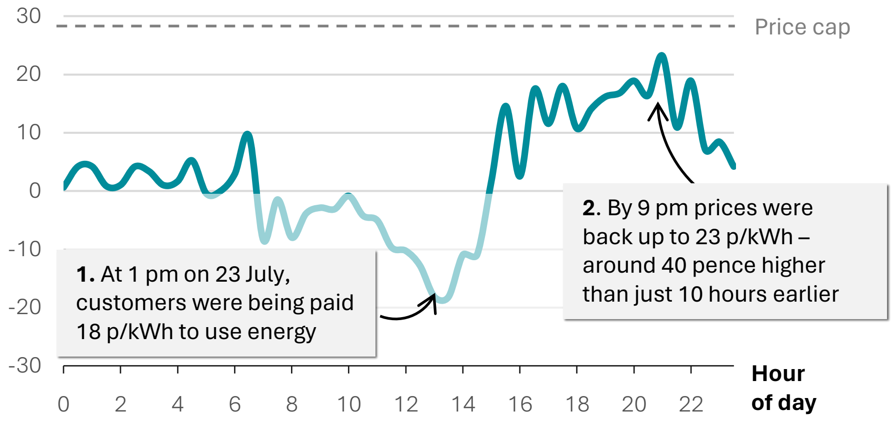


Figure 11: Regen analysis of Octopus Energy Agile Tariff (Jan to Dec 2023). Over 2023 the average daily difference between max and min half hour price periods was £0.24/kWh.

3

Section summary: **How can upgrades be minimised?**

- **Consumer devices will provide critical national energy system flexibility** – dominated by home heat and electric vehicle charging connected to the local distribution network.
- **Networks need to be ready for people to use the energy in their EV** – either for other devices in the home or possibly to export to the grid.
- **Load shifting also presents an opportunity to mitigate local reinforcement** – DSOs are using flexibility tenders to alleviate network constraints on their low-voltage networks.
- **The extent to which households can load-shift their heating during peak winter events is uncertain** – low building thermal efficiency hampers the use of properties as thermal stores, making it difficult to turn down heating at peak times without affecting comfort.
- **New solutions will be needed to maintain diversity on local networks** – if lots of us use heat pumps or EV chargers when wholesale prices are low, that will reduce the diversity of our power use, and networks will need to plan for this.

Recommendations ▶ ▶ ▶

3.1 Government and Ofgem should ensure local and national arrangements for flexibility are coordinated to optimise the whole electricity system

Price signals that benefit one part of the energy system, e.g. alleviating transmission constraints, could cause problems for low-voltage networks unless they are coordinated.

3.2 DNOs should accelerate development and roll-out of local flexibility markets

Managing local constraints with demand-side response will be challenging, so DNOs need to rapidly determine which market structures are effective and roll them out.

3.3 DNO should ensure local network planning is prepared for a reduction in diversity of demand due to stronger wholesale pricing signals and electrification of heat

Diversity of demand is key to local network planning. More work is needed to understand how smart tariffs will reduce this diversity and to ensure this is built into local network planning assumptions.

4

How should networks plan and invest in upgrades?

"If the networks are not sufficiently developed, there will be no net zero. If they are slightly over-invested, the costs across the whole customer base are small, and in any event the assets will in due course probably be needed"

Dieter Helm, Professor of Economic Policy at the University of Oxford. Energy network regulation failures and net zero.

The rate of local network interventions needs to increase to enable net zero

As demand from electric vehicle chargers and heat pumps increases, primary substations across the country will reach thermal capacity (see analysis on pages 17 and 18).

Regen's analysis of substation capacity data indicates that DNOs will need to intervene at over 350 primary substations per year on average over the 2030-2035 period to enable electrification at the rate needed to meet our carbon reduction targets.

While no projections have yet been published, extensive interventions will likely also be required for secondary substations and low-voltage feeders.

It will be important to take a smart, data-driven approach to maximise the value network assets can deliver. In some cases, reinforcement can be deferred or avoided through procurement of flexibility. However, flexibility will not be a panacea, particularly on the secondary networks (see section 3).

The pace of network upgrades will need to increase significantly in all scenarios where we meet our carbon budgets.

Annual intervention rates at primary substations could more than triple by the 2030s

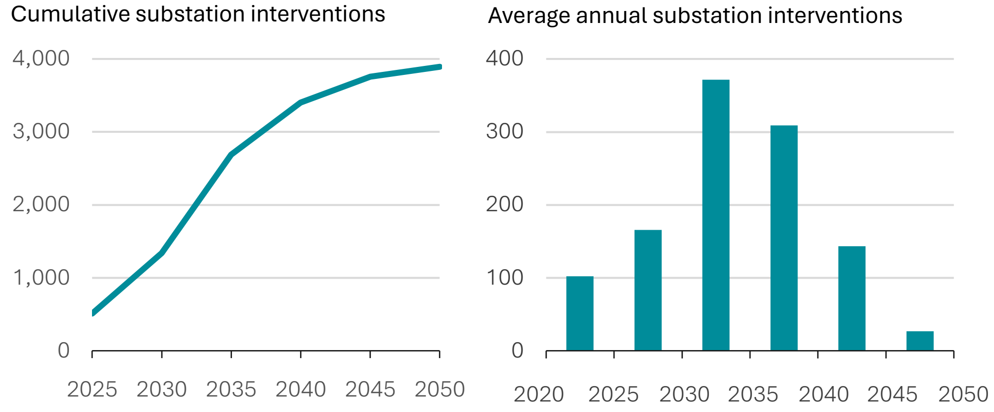


Figure 12: The left chart shows cumulative interventions required at primary (33 kV to 11 kV) substations across all DNOs. The right chart shows the annualised intervention rate for each five-year period. Source: Regen analysis of DNO primary substation headroom data under an accelerated electrification scenario (DFES Consumer Transformation).

Increasing demand

When will upgrades be needed?

How can upgrades be minimised?

How should networks plan and invest in upgrades?

How can customers get connected quickly and easily?

'Touching the network once' when upgrades are done can minimise costs

Much of the cost of upgrading the local network is in civil works, such as digging up the road. Therefore, it makes sense to ensure that the upgrade is sufficient to meet the level of demand expected in 2050 rather than having to go back again, causing more cost and disruption.

Analysis carried out by the Department for Energy Security and Net Zero has shown that greater levels of investment foresight significantly reduce the number of separate network interventions needed and reduce costs (on an undiscounted basis).

The Department for Energy Security and Net Zero "Draft Strategy and Policy Statement for Energy Policy in Great Britain states that 'investment ahead of need' in networks is government policy.

In projects Regen has been involved with (such as the network innovation project 'EPIC'), a future-proof investment strategy is almost always optimal. These strategies also reduce wider societal costs, such as road closures and service disruption. Industry reports also support this conclusion.

> "On an undiscounted basis, the analysis suggests that increased levels of foresight almost always lead to more efficient investments."
>
> Electricity networks strategic framework

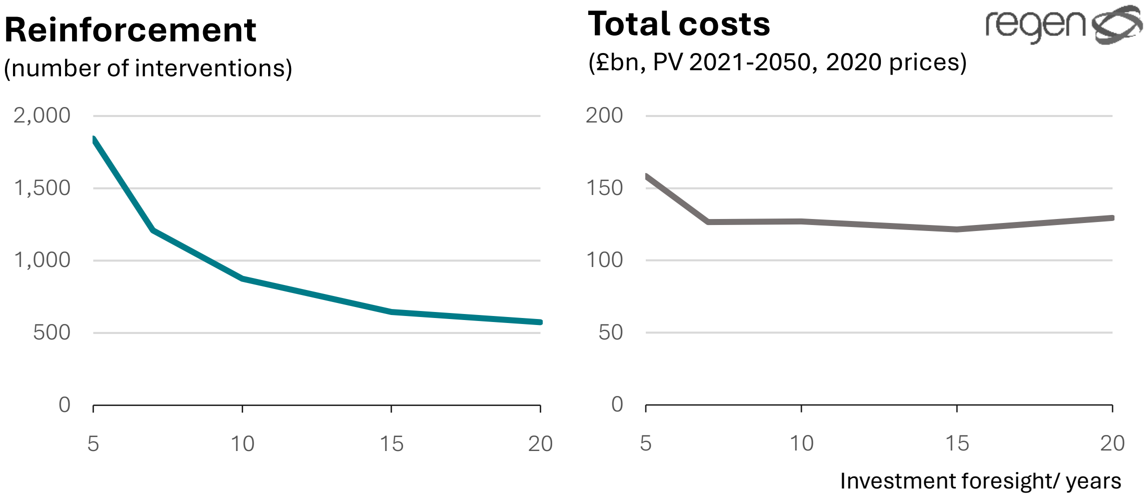


Figure 13: DNO network interventions and associated costs (combined network and social disruption costs such as road works) in DESNZ's Net Zero Higher Demand scenario (averaged, two levels of assumed remaining network capacity). Costs are discounted; costs that occur earlier are discounted less, reducing the cost savings from early strategic investment. Source: Electricity networks strategic framework.

Upgrades will be more complex and costly in urban areas where cables need to be underground

Network upgrades in urban and semi-urban areas, where cables are more likely to be buried underground, will inevitably incur higher civil works costs from excavation and roadworks and cause greater disruption.

Urban and semi-urban networks represent less than 20% of the total network, but underground cables could make up over 80% of cable reinforcement costs.

It is particularly important in our cities and towns that networks take the opportunity to 'touch the network once' by ensuring cable replacements and upgrades provide the capacity required to meet our 2050 net-zero targets.

Underground cables are significantly more expensive to replace than overhead lines

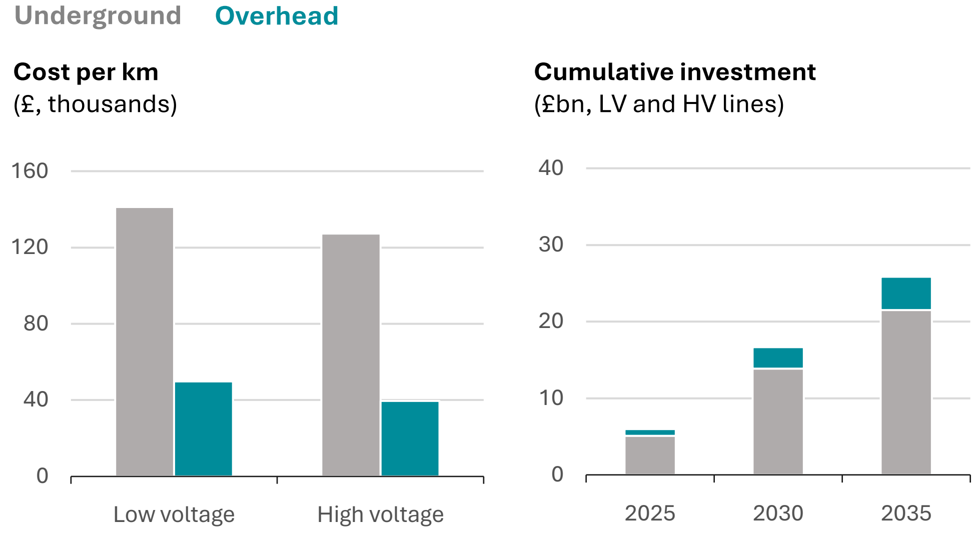


Figure 14: Left chart shows unit costs DNOs can recover from network charges under Ofgem RIIO-ED2 final determinations. LV costs are higher per km than HV due to the complexity of reinforcements (shorter cable runs, road crossings, etc). Right chart shows investment in a central pathway modelled for the CCC.

regen

Many distribution network assets are due for replacement anyway because of their age

Many distribution assets still in operation today were installed during the post-war housebuilding boom during the 1950s and 1960s. These assets are now due for condition-based replacement, which provides DNOs with the opportunity to increase capacity while replacing assets due to age.

Higher levels of demand on older assets may lead to increasing rates of condition-based replacement.

While the retirement of aging assets poses an additional challenge for network operators, the rates of installation managed in the 20th century illustrate that very high rates of infrastructure delivery can be achieved.

Ensuring that work on the network to replace ageing assets is coordinated with the need to increase network capacity will require the DNOs to have the right digital tools, data sharing and coordination between asset management and system planning teams.

DNOs have been capable of extraordinary build rates in the past

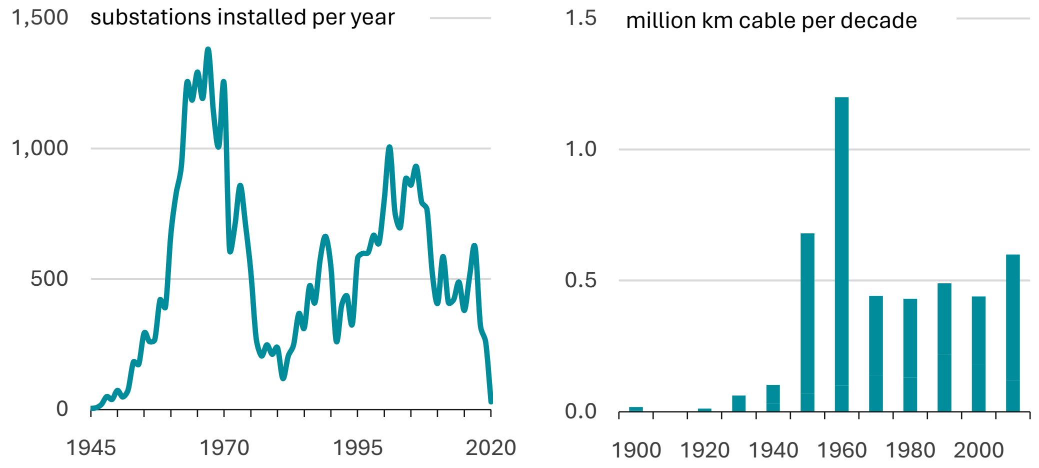


Figure 15: Left chart shows the number of secondary (11 kV/LV) transformers in operation in 2022 by installation year across both SSEN licence areas. Right chart shows the length of LV service cable in operation in 2022 by decade of installation for SSEN. Actual installation rates are even higher than shown as the charts show installation dates from assets in 2022. Source: SSEN ED2 Engineering Justification Papers.

regen

Significant investment is needed whether we achieve net zero or not

Modelling by DESNZ has found that distribution network costs to deliver net zero would increase by between £10bn and £20bn (discounted) by 2050 above a baseline scenario where net zero is not delivered.

There is uncertainty around the level of capacity on the LV networks, as explained on page 19. If those networks are assumed to have 50% less capacity than the DNOs currently anticipate, then investment will need to increase by between £20bn and £60bn by 2050.

Even in the most pessimistic view of the amount of network capacity available, most of the investment required in distribution networks will be needed whether or not we electrify transport and heat.

Distribution network investment is more sensitive to levels of existing capacity than extent of electrification

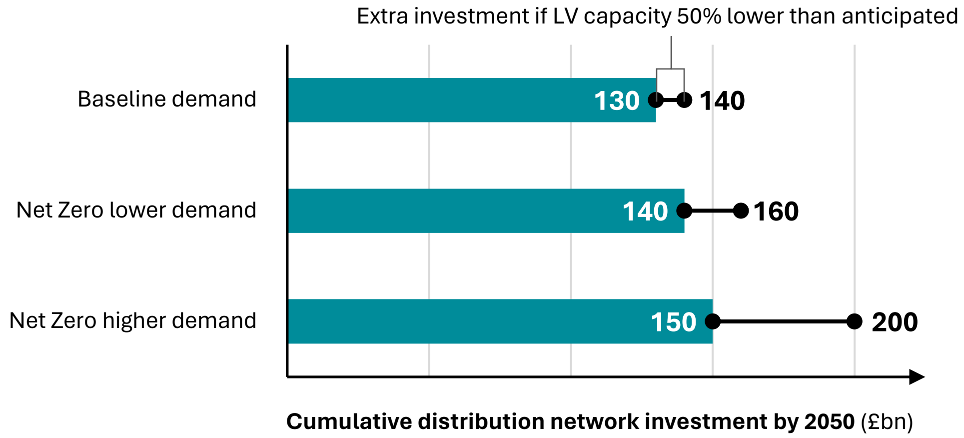


Figure 16: Cumulative distribution network investment required from 2021 to 2050, estimated by DESNZ. Present value, 2020. Source: Table 2, Electricity networks strategic framework Appendix I.

Preparing for net zero is not expected to put up network charges per unit of energy

Network upgrades will require billions of pounds of investment, which will be paid for via network charges to customers. The networks will be delivering more electricity, and so the cost per unit of power delivered may not increase significantly and could even fall over the longer term.

Annual electricity demand under net zero could increase from 275 TWh to around 800 TWh in 2050.

In this high electrification scenario, DESNZ and Ofgem have estimated that, despite increases to total network costs (including transmission and system balancing charges), the cost per unit will stay within a range of around 4-6 pence per kWh of electricity delivered.

As households use more electricity, their overall electricity bill will likely increase, but they will no longer be paying to transport petroleum products to petrol stations or for gas networks to fuel our boilers.

However, there are distributional impacts that need to be considered: network charges could rise in the short term, and the consumers that benefit most may be those who can afford to switch early to low-carbon technologies, charge their EVs at home and take advantage of flexibility offers.

DESNZ estimates that total network charges will stay between £40 to £60 per MWh

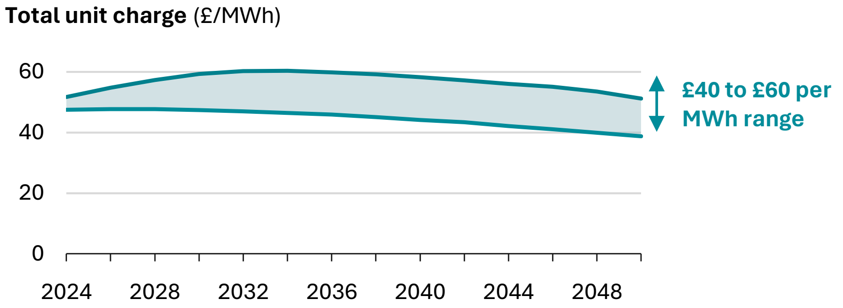


Figure 17: Average per-unit network costs for households (£/MWh, 2020 prices), including both transmission and distribution charges. Source: Figure 13, Electricity networks strategic framework Appendix I.

"The cost of the network per unit of electricity generated – and therefore the amount paid by consumers for each kilowatt hour – is estimated to stay broadly the same or even decrease given wider efficiencies and the greatly increased supply of electricity."

Electricity networks strategic framework, C.6.2.1

2023-2028 ED2 investment budgets are based on low rates of electrification of heat and transport

Ofgem set DNO investment budgets for 2023-2028 based on the ESO's System Transformation future energy scenario.

The chart shows that under this scenario, two and a half million fewer households have electric heating by the end of 2028 than the Climate Change Committee's Balanced net zero pathway.

Ofgem noted that most consultation responses disagreed with using the System Transformation scenario as the basis of investment it was "too conservative and would hinder the investment needed to match national and local net zero ambitions".

Ofgem has made further funding available if demand for EVs and heat pumps necessitates it via 'uncertainty mechanisms', which can unlock contingency budgets.

However, if we delay network investment until heat pump installations do increase, the grid capacity required will not be there in time.

It will be very hard to deliver widespread local grid upgrades in a short timescale due to skills and supply chain constraints. Lead times for 33 kV transformers have recently risen to 15 months.

There is a balance to be struck in setting investment levels. However, the downsides of investing early with a small risk of regret cost are far lower than the risk of delayed investment, leading to capacity problems which could affect customers, stall the net zero transition and limit economic growth.

Planning to fall short?

Households with heat pumps
(millions, cumulative installed from start of 2023)

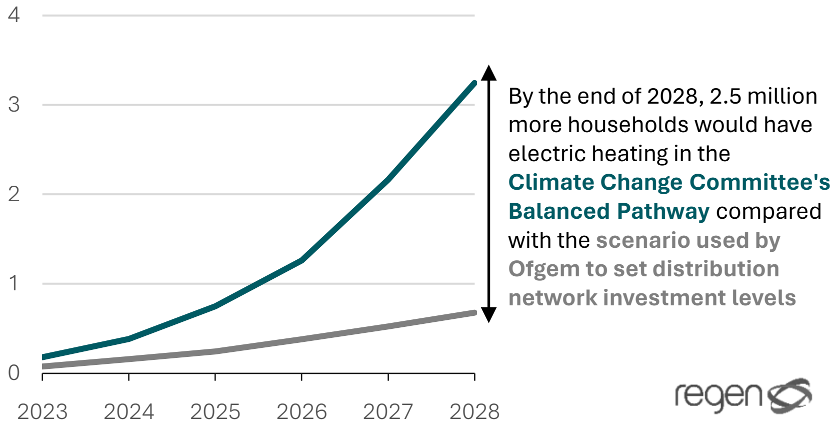


Figure 18: Comparison of the Climate Change Committee's Balanced Pathway scenario and ESO's FES System Transformation scenario. Includes hybrid heat pump systems.

Ofgem's regulatory model needs to adapt to deliver a net zero network upgrade

The network price control process, with reviews every five years setting the network investment, has led to ‘saw-tooth’ fluctuations in investment levels. DNOs ramp up work through each price control and then slow the pace until budgets have been confirmed for the next period.

This pattern is exacerbated by a lack of trust between some network operators and the regulator. Networks can be hesitant to invest for the future in case Ofgem deems investment to have been unnecessary (forecasted demand did not arise) or inefficient (it could have been delivered at a lower cost).

Consequently, network operators are limited in the degree to which they can give their supply chain partners the long-term certainty they need to invest efficiently.

Ofgem’s introduction of Regional Energy Strategic Planners, which will set a long-term pathway of regional energy demand, provides an opportunity for a longer-term approach to network investment.

Setting a long-term upgrade plan for local networks as the basis for price controls would smooth out the current boom-and-bust investment profile, enable DNOs to invest in supply chain capability and lead to a lower risk and more efficient approach to upgrading Britain's local networks for net zero.

Fluctuations in network investment have coincided with price controls

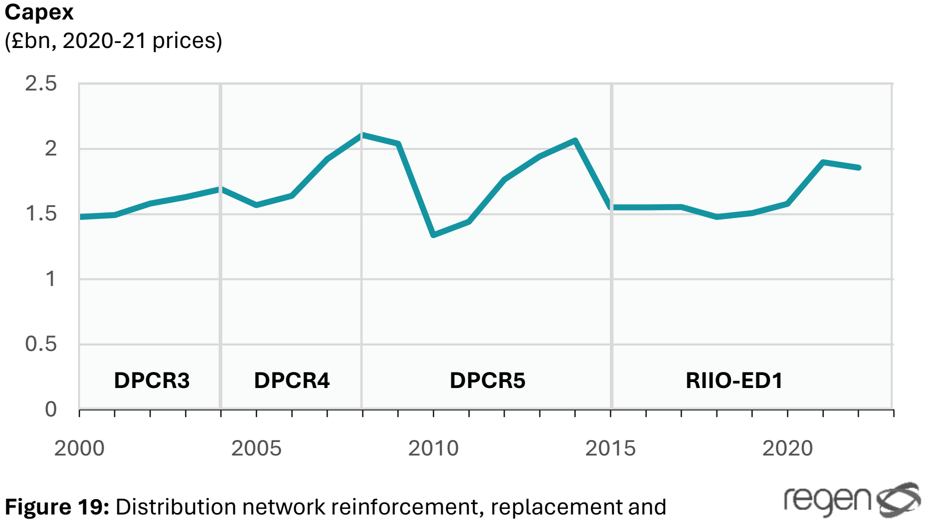


Figure 19: Distribution network reinforcement, replacement and network fault CAPEX (£m, 2020-21 prices). Source: Nera Consulting, Ofgem annual reports.

4

Section summary: **How should networks plan and invest in upgrades?**

- **Electrification to meet our net zero goals requires an increase in the rate of local network upgrades**
- **Touching the network once will minimise costs** – most of the cost is in the civil works, so it makes sense to install 2050-ready cable and equipment, particularly in urban areas.
- **Many distribution network assets are due for replacement because of their age** – DNOs will need to plan carefully to align this with upgrades for net zero.
- **Significant network investment is needed even without net zero** – but preparing for net zero is not expected to put up network charges per unit of energy.
- **Network budgets for 2023-2028 reflect slower low carbon technology uptake and so did not fund the level of electrification required for net zero** – however, the downsides of investing early with a small risk of regret cost are far lower than the risk of delayed investment leading to problems which could stall the net zero transition and limit economic growth.
- **The regulatory model does not support long-term planning** – as network investment fluctuates, supply chains have to adjust to boom and bust years.

Recommendations ▶▶▶

4.1 Ofgem should reform the price control process to require DNOs to plan and deliver a long-term programme of investment that will ensure the distribution network is ready for demand forecasts set in the upcoming Regional Energy Strategic Plans.

By basing price controls on a pathway of projected energy needs for a region to 2050, Ofgem can enable network operators to make long-term investments in the capability and supply chain capacity required to ensure the network is ready for electrification at the pace required to meet our carbon budgets.

4.2 Network operators should use the mechanisms in their budgets for 2023-2028 to rapidly scale up local network upgrades

All DNOs have committed to investing for net zero in their ED2 business plans. In this price control, they should use the uncertainty mechanisms to scale up local network upgrades to ensure they are ready for increasing demand.

5

How can customers get connected quickly and easily?

"Electric vehicles and heat pumps are coming soon to a street and home near you, and it's our job as the network companies to make the roll-out as quick and simple as possible."

Energy Networks Association, "Slashing red tape on the road to net zero"

Customer services will come under pressure before local network capacity

The rate at which customers connect low-carbon technologies to the distribution networks is going to increase, and DNOs need processes and teams that can handle the increasing number of connections. Under the FES Consumer Transformation scenario, LCT connections will peak in the early 2030s, having more than tripled from current levels.

As adoption increases, households will be more likely to have other LCTs installed, and so a greater share of applications will require assessment by network engineers, which will increase the burden on DNOs.

The seasonal nature of boiler replacements, which currently peak in the winter, will add to concerns around the capacity of connections teams. Some DNOs are moving to a more proactive process, where customers are informed of their “connection readiness” ahead of installing an LCT.

Network operators understand that the volume of work for their connections teams is going to increase. It is crucial that they continue to develop a strong pipeline of connections engineers and a suite of online self-service processes that can handle this.

DNOs will need to handle over 60,000 LCT connections a week

Volume of LCT connections per week

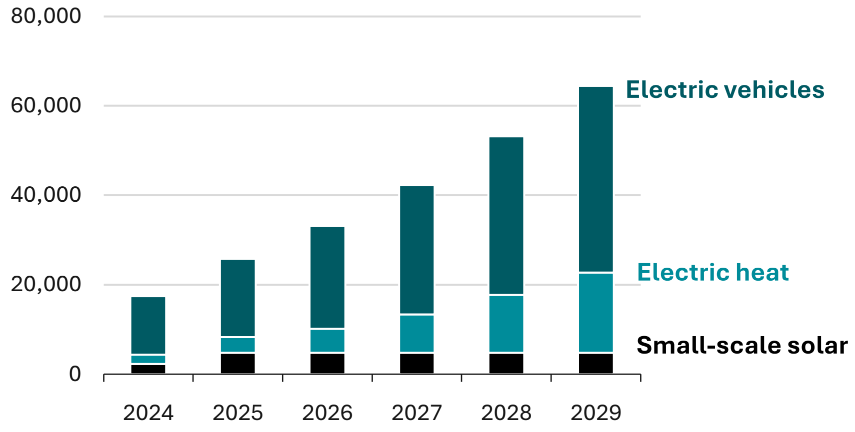


Figure 20: Average weekly projections of low-carbon technologies. Source: Regen analysis of FES 2023 Consumer Transformation scenario.

regen

Connection hassle barriers remain for some householders and installers

As part of this study, Regen engaged with companies and groups involved in the installation of low-carbon technologies to gather feedback on the network-related issues that they face. Several areas were highlighted where DNOs need to continue developing their processes and policies to ensure hassle barriers to LCT installations are minimised:

1. The connections process is still clunky

The networks have made good progress in enabling many households to connect low-carbon technologies without making an application under 'Connect & Notify'. However, the process for 'Apply to Connect' is not yet streamlined for the tens of thousands of weekly applications that DNOs could face in the future. Several DNOs direct customers and installers to fill in a Word document and return it by email – a solution that will inevitably lead to data errors and slower connection lead times. The ENA has announced a standardised digital tool called Connect Direct, which is a positive step.

2. Installers need clear guidance on supply adequacy

An 'adequacy of the supply' assessment is required before any Electric Vehicle Charge Point or Heat Pump installation. Some installers find this challenging to determine. Customers may incur higher costs if installers are overly conservative in their calculations. If they are too liberal, this puts the network at risk.

The ENA website says the IET is responsible for setting this guidance and that installers should contact the IET for further advice. DNOs should take a more proactive role in ensuring the guidance is clearly communicated.

3. Coordinating works between suppliers and DNOs is challenging

Some LCT installations will require coordination between both DNOs and supply companies - for example, to move an electricity meter (meters are owned by the supplier, not the network operator).

DNOs and suppliers should be able to coordinate these works without requiring the customer to coordinate the works of two corporations.

4. Connection policy updates are not always clearly communicated to installers

It is inevitable that connections processes and policies will change over time, and there is a balance between consistency and innovation. However, when changes are made, they need to be clearly communicated.

Currently, some installers find out about policy changes through responses to their connection applications (one major installer carries out dummy connection applications to determine individual DNO policies). This issue has come to a head in relation to the maximum ratings of fuses, which are discussed in more detail on the next page.

Differences in policy at some DNOs have led to confusion

The maximum fuse rating that DNOs install on standard domestic (single-phase) supplies is not consistent across the country. Some network operators install maximum sizes of 100 A, and others only 80 A.

Fuses protect customers from drawing high loads that would cause overheating in incoming cables, reducing the risk of damage or fire. Fuse ratings can be exceeded temporarily before they interrupt the supply of power.

100 A gives a maximum continuous import capacity of 23 kW (100 A x 230 V), which is sufficient for most properties with an EV charge point, a heat pump and other domestic loads. Households can install low-cost load-balancing equipment (often integrated into EV chargepoints) to ensure they don't draw too much power at once.

The maximum fuse rating is significant because, under Ofgem's 2022 decision on network charging reform, customers do not pay directly for wider network reinforcement when installing a low-carbon technology. However, customers are still required to pay 100% of upgrade costs to 'extension assets' – the cable that connects their property to the wider network.

If a household requires more capacity than available on a single-phase supply, they will need to pay for an upgrade to three-phase, which typically costs £3000-7000 (just for the 'extension assets').

On paper, reducing the limit at which three-phase upgrades are triggered (from 100 A to 80 A) creates a barrier to electrification.

NGED has released a note explaining that an 80 A fuse can be used at 100 A for up to four hours.

There are different policies for connections depending on where in the country you are located – a 'postcode lottery'. It will be much simpler for installers to deal with common standards and processes.

Household headroom for continuous loads is significantly impacted by 80 A fuses

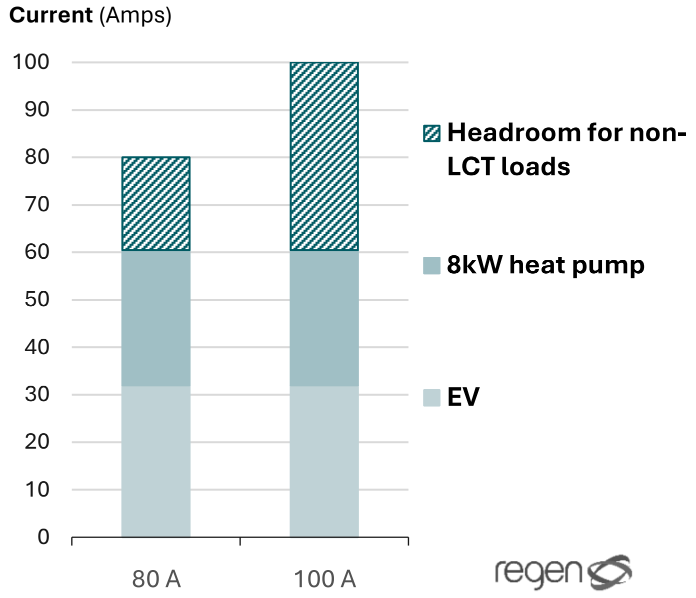


Figure 21: Headroom for a home with a 7 kW EV chargepoint and 8 kW_{th} heat pump for 80 A and 100 A fuses. Assumes both LCTs are running at max demand and the heat pump operating with a very low CoP of 1.2 (coldest day).

5

Section summary: **How can customers get connected quickly and easily?**

- **Networks will need new processes to handle high volumes of connections** – connection applications could exceed 60,000 per week in the next five years, with higher complexity due to multiple LCTs at each property.
- **Several connection hassle barriers remain for some householders and installers.**
- **There is confusion around differences in DNO policies on household fuse capacities** – a single policy across the country would provide clarity for installers.

Recommendations ▶▶▶

5.1 Network operators must deliver a streamlined, digitalised connections process

Installers want consistent policies, clear guidance and streamlined digital tools so that they can get on with the job of supporting their customers to decarbonise.

DNOs will also need to clearly communicate changes in processes and policies as more EV charger and heat pump installers enter the market.

Glossary

Term	Description
CCC	Climate Change Committee
Consumer Transformation	One of the future energy scenarios developed by ESO. This scenario is most aligned with the Climate Change Committee's Balanced Pathway.
Constraint: phase imbalance	Power is transferred via three-phase alternating current. Each phase has a separate cable. Power is then delivered on just one of the three phases to domestic properties. Demand and generation must be roughly equal across phases.
Constraint: thermal	The maximum load the equipment can carry before reaching rated thermal capacity (further load would risk overheating). The amount of spare thermal capacity is often referred to as headroom.
Constraint: voltage	The maximum load a length of cable can carry whilst staying within statutory voltage limits of 216 V and 253 V. Demand causes voltage drop and generation causes voltage rise. Voltage changes increase with cable distances.
DNO	Distribution Network Operator (DNO) companies own, operate and maintain the distribution networks.
ENA	Energy Networks Association, the industry body for the energy networks.
ESO	Electricity System Operator, currently owned by National Grid but operationally independent from the transmission operator.
Extra High Voltage (EHV)	Extra High Voltage (EHV) refers to the extra high voltage infrastructure on distribution networks. These are distribution network assets with nominal voltages of at least 22 kV. Most EHV networks operate at 33 kV and 132 kV (some networks operate at 66 kV and 22 kV).
FES	Future Energy Scenarios developed by the electricity system operator.
Grid Supply Point (GSP)	A Grid Supply Point (GSP) is a Systems Connection Point at which the Transmission System is connected to a Distribution System.
Headroom	Spare capacity. The gap between the rating of the electricity network to supply electrical demand and the actual demand in that part of the network.
High Voltage (HV)	High voltage (HV): Distribution network assets with nominal voltages over 1 kV but less than 22 kV. Most HV networks operate at 11 kV (some networks operate at 6.6 kV).
Low Voltage (LV)	Distribution network assets with nominal voltages below 1 kV. 400 V 3-phase and 230 V single phase.
Ofgem	Energy regulator (office for gas and electricity markets).
Price control	A method of setting the amount of money (allowed revenue) that can be earned by the network companies over a period of time (currently five years).
RIIO	Revenue = Innovation + Incentives + Outputs. This is the current monopoly regulatory regime for electricity transmission and distribution.
RIIO-ED2	Current price control period for distribution
Substation	Substations contain equipment that allows the voltage of electricity to be increased or decreased. Larger substations contain multiple transformers.
Transformer	Electrical equipment used to change the voltage of electricity.

Return to contents

Regen is an independent not for profit centre of energy expertise and market insight whose mission is to transform the world's energy systems for a zero carbon future.

Regen,
Bradninch Court.
Exeter, EX4 3PL

+44 (0)1392 494399
admin@regen.co.uk regen.co.uk
Registered in England No: 04554636

This report was sponsored by	**MCS Foundation**
Prepared by	Frank Hodgson
Reviewed by	Merlin Hyman