# Growing the Supply Chain for a Net Zero Energy System

March 2022

Powered by: CATAPULT Energy Systems

# Foreword

This work represents the absolute focus of the UK manufacturers of electrical equipment on the delivery of Net Zero energy systems. Our work is about delivering rapid progress to decarbonise the UK, support the delivery of key technologies for a Net Zero compatible Energy System, and grow jobs and prosperity across the UK.

The industry has experienced a significant lack of focus on our supply chain from Government and some key stakeholders to date.  Emphasis is more commonly drawn to the obvious contributors to Net Zero (e.g. wind generation, hydrogen), but the electricity system components our members manufacturer will enable integration of offshore wind, flexibility on the system and electrification of heat and transport. Without the investments outlined in this report, the prospect of Electric Vehicles not being changed, heat pumps not having sufficient power, or renewable generation not connecting are real possibilities.

The demand for the electrical infrastructure products needed in the UK will be global.  We are seeing manufacturers already deciding between the UK and other countries for investment in key manufacturing capacity of vital products for the energy transition. BEAMA wants to ensure we have done everything we can to facilitate investment in the UK and keep business close to home and a central part of the UK supply chain.  We will always be dependent on international trade of raw material and components for these products and with our exit from the EU and negotiation of key Free Trade Agreements now is the time to focus in on the important aspects affecting trade and investment.

This research carried out by the Energy Systems Catapult has really shone a light on the scale of investment needed in our supply chain, the skills and training needs. While we talk a lot about cost, the rewards are great and the job creation from facilitated action to support key supply chains will be a significant contributor to the UK economy and our transition away from high carbon industry. I want to see new manufacturing plants around the UK producing the low carbon, digital products and systems of the future, delivering our low carbon future and exporting to the world.

BEAMA want to ensure we can create a robust, world leading, industrial sector to deliver the needs of Net Zero in the UK. I hope this report prompts a more robust stance from UK Government on the future infrastructure investment plans and provide further market certainty for our supply chain specifically.

Dr Howard Porter
CEO, BEAMA

# Foreword

The critical urgency of changing the types of energy we use and how we use it has never been more stark. If the increasing occurrence of severe weather events, each bearing human, social and economic costs, and the succession of increasingly bleak reports from IPCC and other expert bodies were not enough, the volatility in global fossil fuel markets – with immediate economic consequences forcing remarkably difficult choices on an increasing number of people – surely makes the case for accelerating the pace of energy transition. The urgency of change driven by the growing climate crisis is now compounded by the drive for energy independence and energy resilience.

The United Kingdom, yet again, has demonstrated leadership and realism by adopting the 6th Carbon Budget, a crucial milestone that should catalyse action, now. The timeliness of this report commissioned by BEAMA is clear.

The report reminds us that supply chains count. It reminds us that supply chains are the driver of sustainable economic benefits, once the financial engineers have moved on. We cannot ignore the importance of the supply chains BEAMA represents, constructing the end-to-end connected energy system and adding £13bn to UK turnover. Government's focus on supply chains has been more drawn to key renewable technologies (e.g. offshore wind, solar) but much less consideration has been given to the supply chains that makes up the rest of our Energy System and how much this could be worth to the UK –including designing, manufacturing and installing cables, transformers, switchgear, EV chargers, smart heating systems, energy storage and control devices as well as the intelligence that brings this all together to work seamlessly in helping consumers.

Crucially, and for the first time, the report provides a focused analysis of the infrastructure and componentry requirements of the energy transition. In so doing it sends a strong signal about the markets that will be grown, and the opportunities for UK economic growth and competitive advantage that this can deliver – if we act fast, and act decisively. We need to unleash investment and start building our skills base for the future now. If we do, we will win three times over – first by leading the world in transforming our society and our economy to a sustainable, lower cost and lower carbon energy base, second by reinforcing the existing strengths the UK supply chain can already claim, building jobs, levelling up and creating broad-based prosperity in the process, and third by building a springboard for global competitiveness and national economic advantage.

A great example of this opportunity is flexibility. Developing stronger flexibility markets can not only reduce consumer costs and increase system efficiency. It also sends the price signals that incentivise investment in smarter flexible technologies and innovation in product design and integration and launch new business models and consumer propositions.

Other practical steps that can be taken include supporting the supply chain council in enabling capital investment in the manufacturing supply chain for electrical products, as well as supporting the skills council to grow the capabilities across the workforce to design, make and fit the incredible new products that the future energy world needs.

The energy transition is a necessity. It is also an opportunity, and I am delighted to see BEAMA, and its members show the vision and ambition we need from industry as we confront these opportunities and these imperatives.

Philip New
CEO, Energy Systems Catapult

# Contents



This report has been powered by the Energy Systems Catapult. This means that it has been informed by analysis undertaken using the Energy Systems Catapult's whole system modelling capabilities and subsequent engagement with BEAMA and its members. The recommendations in this report are those defined by BEAMA and its Members.

# DISCLAIMER

# 1. Executive Summary

## INTRODUCTION

**The 6th Carbon Budget necessitates early action and the next 5 -10 years will be a crucial period of investment in manufacturing capacity for electrical products to support the energy transformation. The scale of change required by 2050 is unprecedented:**

**Electricity demand could grow by over 70% owing to the rapid increase in electrification of heat, transport and industry, along with a substantial production of hydrogen for use across the energy system.  Without active mitigation this may result in:**

- **A requirement for millions of heat pumps coupled with thermal storage installed each year by the early 2030s**
- **Over 300,000 km of additional distribution cable installations and an increase of grid and bulk substations by as much as 50%**
- **Connection upgrades required for many domestic properties, unless there are sufficient energy efficiency measures and flexible solutions employed**

**This report presents scenarios that could require a tenfold increase in existing manufacturing volumes for key products. Manufacturers agree that they can make the investments needed to achieve this in the UK, but not under current market conditions.  Getting the market conditions right will unlock huge opportunities to leverage UK capability as part of the new Green Industrial Revolution.**

Manufacturers are today making investment decisions: where to build manufacturing capacity and therefore to employ people.  This report shows how fragile this decision making process is, how critical the decisions being made now are in deciding the UK's Net Zero future, and how far we can benefit from this change.  Already, serious skills and supply shortages mean that the significant targets for UK deployment of low carbon heat, storage and EV charging facing our sector could seriously limit capital investment and progress.

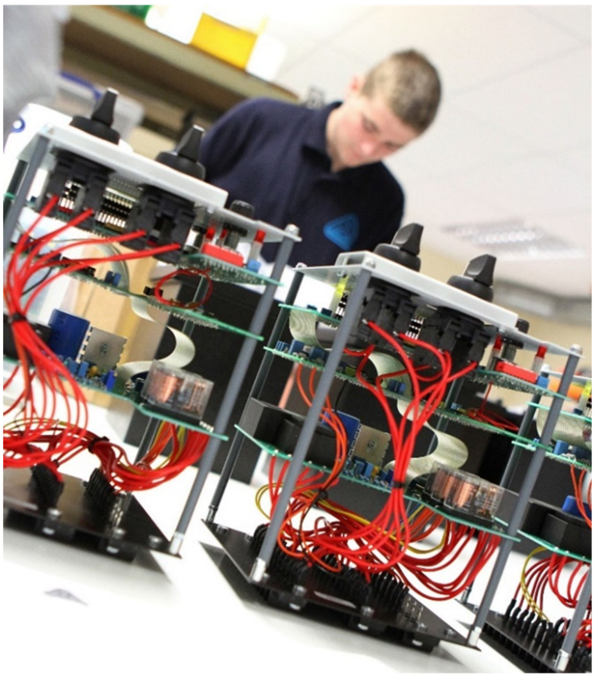
This scale of investment is not business-as-usual, and Government need to acknowledge the dramatic transformation expected within the supply chain.  With sufficient support and planning there is scope to "reshore" parts of the industry suppling key products and raw materials, bringing with it local jobs.  This will aid industrial decarbonisation, the supply of lower emission industrial products and reduce the risks of supply shortages and global competition for materials and skills.

Customers hold significant power in determining the sustainability of the products installed to manage the energy system. Investment in supply chain capacity will be driven by the purchasing decisions of key customers.  As manufacturers invest in their production capacity, they will respond to the market for lower emission products. This is a key factor that will determine where manufacturers base their operations for such a dramatic scale up.

Our energy system modeling tells us a lot about what drives the cost of Net Zero and, importantly, how to reduce it through early action to support innovation in the supply chain, reduce supply chain risks and bring forward capacity for flexibility on the system.  This report, and the work undertaken by BEAMA, provides strong evidence for urgent action to address supply chain risks to ensure a least cost approach to Net Zero.

## TODAY'S UK ELECTRICAL PRODUCT MANUFACTURING SECTOR

BEAMA is the leading UK trade association for manufacturers and providers of energy infrastructure and systems. BEAMA represents a sector currently:



Worth £13 billion

Employing 90,000

With exports worth £5 billion

**The products covered in this report and by BEAMA's work include electricity transmission and distribution equipment, electrical products and services in buildings including EV chargers, heat pumps and smart meters.**

## WHAT PROBLEM ARE WE SOLVING?

The challenge of meeting the UK's Net Zero target is well established and all sectors will need to decarbonise for the target to be met. The Sixth Carbon Budget necessitates further early action, with 78% reduction in greenhouse gases required by 2035. At a time when volatility of energy prices is very much in the public eye, ensuring cost-effective energy in both the near and long-term is paramount. Recently, the UK Government's Net Zero Strategy has presented options to assist system transformation, providing targets and indicators towards future policy that will help the transition take place.

**Supply chain investment decisions with long-term consequences are being made now**. Manufacturers and providers of electricity system equipment must plan out their activities based on projections around the future needs for their products, and these activities require careful

consideration. **The growth in demand for these products will be global, and companies will need to look at where they base their manufacturing facilities and supporting services to best serve their business and markets**.

To unlock private investment in the UK for the core industries necessary for the delivery of Net Zero, we need to ensure the market and regulatory signals are delivered quickly to incentivise growth in the right place, and to retain and grow key sectors as part of the new green industrial revolution.

Many studies have already explored potential pathways for the UK to reach Net Zero. However, a practical and detailed review of the demands on key sectors and supply chain delivery, with an emphasis on the Sixth Carbon Budget window, is not readily available**.** The resourcing required for this supply chain to deliver what is needed for Net Zero has not previously been explored in depth. As a result, BEAMA, the UK trade association for manufacturers and providers of energy infrastructure technologies and systems, commissioned the Energy Systems Catapult to study these details.

**THE MANUFACTURING OF ELECTRICAL EQUIPMENT SUPPORTING NETWORK AND BUILDING INFRASTRUCTURE – THE "NUTS AND BOLTS" OF NET ZERO – WILL BE CENTRAL TO THE DELIVERY OF A ZERO EMISSIONS SYSTEM.**

Modelling of the whole UK energy system has been completed, combined with a qualitative study of the impact on the supporting supply chain. The modelling provides consistency across national and regional scales within its whole system modelling phase, and subsequent consultation with manufacturers has assessed what the supply chain will need to deliver Net Zero. This research is the first of its kind, analysing the extent of infrastructure investment needed and the demands specifically on the UK electrical product manufacturing sector. It presents an insight into the reality of market deployment to 2050 whilst acknowledging the near-term requirements of the Sixth Carbon Budget.

## THE ENERGY SYSTEM SCENARIO WE EXPLORED

An energy system scenario was developed for this study which presents a pathway consistent with the Sixth Carbon Budget and an ultimate target of Net Zero emissions. In this scenario, consumers take up new end-use technologies readily to meet the needs of the system, without radical changes to living and working practices. Supply chains across the economy are assumed to be well prepared and can deliver these technologies when required. Conversely, infrastructure is assumed to be replaced, reinforced and upgraded using existing, established technologies and processes. It does not rely on emerging electrical infrastructure innovations; thus this modelling provides a deliberately conservative, upper limit on the investment required for infrastructure to deliver Net Zero should innovations in distribution networks and end-use technologies not be realised.

A substantial scale-up of low-carbon energy is critical to realising Net Zero. Electrification of transport and heating means that our scenario presents a rapid increase in electricity demand. **This is projected to grow by 70%, to circa 500 TWh by 2050. This scale-up needs industry to supply high volumes of their products: as many as 30 million electric vehicle chargers and 20 million heat pumps or hybrid systems could be required by 2050**. At the same time, new hydrogen networks play a key role in decarbonisation, supplying over 200 TWh in the long-term. Low carbon sources of these vectors are progressed at pace to ensure lifecycle emissions remain low across the timeframe, with a portfolio of generation options as outlined in the Net Zero Strategy.

**The scenario developed for this project is described in Chapter 4 of the full report.**

## SCALE UP OF ENERGY INFRASTRUCTURE

Investments in the supply chain are influenced heavily by the investment trajectory of the energy system. Electricity distribution network operators already expect to invest £5bn per year under RIIO ED2, and this includes crucial investment for our path to Net Zero. There are many factors that influence the longer-term network investment costs, and these must be carefully considered when modelling future energy systems. These include assumed states of headroom in existing infrastructure, projections of network flexibility, representation of diversity, asset aging and replacement strategies and network scope and granularity. Within the conservative modelling approach utilised in this project, a substantial investment in energy distribution networks would be required. **Without the critical network innovations outlined already, this investment could reach as high as £7bn/year, averaged over the next 15 years, and as much as £15bn/year**

**subsequently**. These estimates are broadly in line with projections for the 2023-2028 RIIO-2 price control period but indicate a significant overall uplift on historic investment and a sizeable increase for future RIIO-3 periods and beyond.

To transport and distribute the increased volumes of low carbon electricity, early and extensive network reinforcement is needed. **Electricity lines, cables and substations are increased in quantity by roughly 20-50% by 2050. More than 300,000 km of additional distribution network cable could be required by 2050, and much of this would need to be in place by 2035.** However, neither these large quantities of infrastructure nor these absolute requirements for investment are inevitable: innovative network solutions can help reduce network volumes.

**Projected infrastructure and product volumes are described in Chapter 5 of the full report.**

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**NETWORK INNOVATIONS ARE CRUCIAL FOR COST-EFFECTIVE ENERGY SUPPLY FOR THE POPULATION. WITHOUT INNOVATION THE RISK OF FAILING TO DELIVER NET ZERO OBJECTIVES DUE TO PRACTICAL INVESTMENT CHALLENGES IS SUBSTANTIAL.**

**The tight Sixth Carbon Budget targets require that much of this investment takes place in the 2030s, after the RIIO-2 price control period has concluded**. However, due to lead times for the supply chain to build up capacity, preparation for this period needs to take place immediately, and appropriate steps should be taken now to ensure delivery and to reduce future costs. As noted in the Heat and Buildings Strategy, ensuring that distribution network operators can anticipate demand growth and invest ahead of need is crucial. This preparation includes scale-up of UK assembly and manufacturing facilities and of component sourcing, with a much larger, well-trained, and up-skilled workforce required for the installation and servicing of equipment.

## A SUPPLY CHAIN FOR END USE TECHNOLOGIES

Over the next fifteen years, investment in end-use technologies for vehicle charging, heating and, perhaps, domestic solar power is critically important, with this investment averaging £3bn/year over 30 years in the scenario developed. As highlighted in the Heat and Buildings Strategy, the transition to low-carbon buildings could add £6bn gross value added by 2030 and support hundreds of thousands of skilled green jobs.

In our Net Zero scenario, increased electrification occurs across the whole economy. Transport, heating and industry all see increases in demand for electricity and there is need to reinforce both transmission and distribution networks. Accordingly, the scenario draws on flexible systems for the end-user at all scales; at a local level, key operational sources of flexibility are managed vehicle charging, smart electric heating systems (supported by thermal storage) and domestic batteries. Timelines for deployment of such sources of flexibility are key[1].

**WITHOUT SOURCES OF FLEXIBILITY, THE TRANSITION WILL BE CONSIDERABLY MORE DISRUPTIVE AND EXPENSIVE FOR CONSUMERS, AND MANAGEMENT OF SUPPLY AND DEMAND WILL BE EVEN MORE CHALLENGING**


In broad agreement with the Government's Net Zero Strategy, we see flexible systems as essential for a cost-competitive transition to Net Zero. We highlight the need for market and policy support that adequately incentivises flexibility that will help deliver a secure energy system.

In parallel, evolving technologies such as smart network management also have the potential to offer substantial investment cost reductions and should be pursued alongside flexibility support.

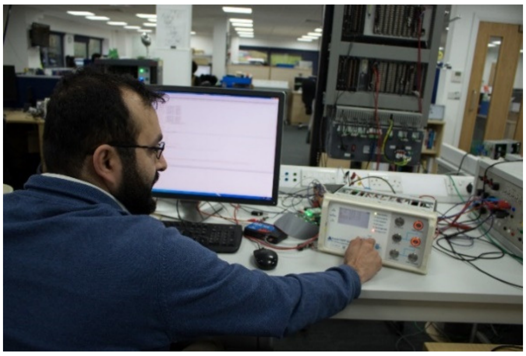
[1] National Grid ESO, Bridging the Gap (March 2022), https://www.nationalgrideso.com/future-energy/future-energy-scenarios/bridging-the-gap-to-net-zero

## WHAT DOES THE SUPPLY CHAIN NEED?

Our structured consultation with BEAMA members from across the electricity system supply chain affirms that industry sees decarbonisation as a real opportunity to resource and deliver greater volumes of product into the UK market and more widely. **Chapter 6 of the full report summarises the findings from this consultation.**

Overall, industry considers the required growth in volumes to be achievable under the right market conditions, with scale-up already having been demonstrated in some markets and for some products that have robust enough demand growth projections. Over 85% of organisations surveyed expect to scale up their production by over 20%, and some are preparing for as much as a tenfold increase in UK market size.

**HOWEVER, MARKET CONDITIONS AND ADEQUATE CERTAINTY FOR INVESTMENT NEED TO BE IN PLACE BEFORE INDUSTRY IS IN POSITION TO SCALE UP ITS OPERATIONS.**



### How can we facilitate capital investment in the supply chain?

- **Availability of a skilled workforce**. Clean Growth offers prospects for more and better jobs in the UK. Industry agree areas such as innovation in delivery models, artificial intelligence and system integration are all critical skills we could be exploiting in the UK. However, the supply chain currently faces significant skills shortages in many key areas. Most notable is product installation for network infrastructure and end use technologies.
- **Manufacturers need clarity on likely volumes of technologies to develop robust business cases for investment in the supply chain – this cannot be avoided**. Uncertainty stalls investment, which in combination with low consumer confidence and awareness inhibits the pace and scale of uptake needed. There is broad concern across industry of which pathway the UK will take to reach Net Zero, despite the recent strategy publication. While manufacturers support flexible innovation over prescribed technologies, more clarity could be provided on the near-term pathway for key technologies. An over-reliance on short term subsidy funding and grants means that there is an expectation that top-down government policy will ultimately drive technology choices and uptake by consumers. This is considered to be a barrier to innovation, and many respondents suggested that a more outcome-based policy framework with long-term demand pull, backed by legislation, could create more favourable market conditions to address this barrier.

- **Financial stability through policy over the long term can help increase confidence in zero and low carbon solutions.**Support in the form of tax breaks, longer term subsidies, new standards and better enforcement of existing standards were all cited as potential methods which would give industry stronger grounding on which to accelerate investment.

## NEXT STEPS

BEAMA's membership is ready and prepared to invest in both manufacturing and its UK workforce but the uncertainties presented within this report and current market conditions make this difficult. The Government's Net Zero Strategy helps alleviate some of this uncertainty and is considered likely to aid private investment, but there are still significant market limitations.

BEAMA calls for Government to take a leadership role in establishing a clear strategy for infrastructure deployment between now and 2035.

## KEY RECOMMENDATION

BEAMA calls for the formation of a UK Electricity Supply Chain Council, backed by Government, tasked with the development of a five to ten year roadmap to support capital investment in the supply chain for electrical products, ensuring the delivery of the Government's Ten Point Plan.

## PROJECT OVERVIEW

| BEAMA members say they can meet the needs from the electricity sector for a least cost Net Zero future by 2050… | …but before they can invest, there are several risks and constraints faced by the sector that need to be addressed… | …that can be overcome through a number of recommendations from BEAMA members: |
|---|---|---|
| £3bn per annum investment into domestic technologies such as heat pumps, chargers and storage prior to 2035 | The electricity system supply chain is internationally competitive and complex | Beyond the UK Net Zero Strategy, develop further plans on longer-term infrastructure deployment with more detailed supply chain needs |
| £7bn per annum investment into electricity distribution networks prior to 2035 – including 20-40% increase in lines, cables and substations | Uncertainty on direction in UK policy has stalled investment | Form an industrial electricity supply chain council, backed by Government, which will develop a 5-year plan to support capital investment |
| 85% BEAMA members surveyed expect to scale up by 20-100% to meet future needs, with some expecting to scale by 10x | There is typically an approximate five year lag time between investment and the resultant scale up | Near-term finance to adequately stimulate the market<br>Review of the regulatory and planning system to enable investment ahead of need |
| The installer base for low carbon heating could need to be increased by a factor of 20 | Skills shortages in key sectors are throttling demand | Plan to urgently tackle scarcity of apprentices and support transfer of skills from high carbon sectors |

## 2. BEAMA’s sector

BEAMA is the UK trade association for manufacturers and providers of energy infrastructure and systems.

BEAMA represents more than 200 companies: from start-ups, to SMEs, to large multinationals. BEAMA’s members provide heating, ventilation and air conditioning products, electric vehicle infrastructure, electrical transmission and distribution equipment, and energy storage and flexibility assets in networks and the built environment, to support a safe and secure low carbon energy system.

**BEAMA’s VISION**

As an industry trade association, BEAMA’s vision is to ensure and establish:

- A market for safe, secure and compliant products
- A prosperous export market for our members
- A strong investment environment for new technologies
- A low carbon smart flexible energy system

**BEAMA’s TECHNOLOGIES**

BEAMA’s sector represents a wide range of technologies and sub sectors, including:

- Transmission and distribution equipment for the electricity grid
- Smart IoT devices for buildings
- Heating, hot water and ventilation products
- Electrical installation products for the built environment
- Storage – thermal, phase change, battery
- Electric vehicle charging infrastructure
- Smart metering

# 3. Introduction

The energy system will need to transform for the UK's Net Zero obligations to be met. All sectors will be required to substantially decarbonize, and incumbent fossil fueled technologies used in industry, heating and transportation must be phased out. The recent adoption of the Sixth Carbon Budget[2] further hastens this transformation, with an 80% reduction in emissions by the mid-2030s now mandated. Publication of the Net Zero Strategy[3] and the Heat and Buildings Strategy[4] provides an indication of targets, key technologies and policies required to deliver on these obligations but there is still uncertainty around how the coming decades will develop. At a time when volatility of energy prices is very much in the public eye, ensuring that development in both the near and long-term delivers cost-effective energy for the population is paramount.

Many studies have already shown plausible routes to Net Zero. To date most have focused on critical issues such as the choice of heating technology, the power generating mix and the role of society and behaviour in enabling or hindering decarbonisation. However, there has been less emphasis on how the future energy system will be delivered practically. Within the electricity sector, it is business and industry who will need to supply and maintain network infrastructure to support a higher electricity demand. Companies will need to scale up manpower, manufacturing facilities and distribution, whilst managing uncertainty around the speed of transition and the preferences of consumers. Decisions related to this scale-up, including location of manufacturing facilities, investment avenues and training, need to be made with confidence.

In Sizing the Market, we explore these practicalities. Firstly, we describe an ambitious scenario that meets the Sixth Carbon Budget, using the Energy Systems Catapult's established Energy System Modelling Environment (ESME) tool. We then analyse the potential electricity network reinforcement required for this scenario to be realised, using the Catapult's Infrastructure Transitions Analysis Model (ITAM). This analysis establishes a projected investment upper limit, excluding specific network innovations that could reduce or defer local network reinforcement. The modelling has been supplemented through consultation with stakeholders from the electricity supply industry, to assess the real-world feasibility of delivering the modelled energy system and to identify opportunities and barriers. We outline what industry must do, when, and how, in support of the transition to Net Zero.

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[2] Committee on Climate Change, Sixth Carbon Budget, https://www.theccc.org.uk/publication/sixth-carbon-budget (accessed November 2021)

[3] HM Government, Net Zero Strategy: Build Back Greener, October 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1028157/net-zero-strategy.pdf (accessed November 2021)

[4] HM Government, Heat and Buildings Strategy, October 2021, https://www.gov.uk/government/publications/heat-and-buildings-strategy (accessed November 2021)

### Box 1: A whole system modelling approach to support infrastructure analysis

Taking a whole system approach is integral to the Energy System Catapult (ESC) mission. ESC's capabilities include coverage of consumer insights, end-use and infrastructure technologies, data and digitalisation, systems integration and markets, policy and regulation.

Reflecting this approach, ESC has developed a set of modelling assets for every level of the energy system, from top-down, economy-wide energy system models, to models of the physics of individual housing types. Within this project, ESC utilised its Energy System Modelling Environment (ESME) and complementary Infrastructure Transition Analysis Model (ITAM).

#### UK pathway modelling: Energy System Modelling Environment (ESME)

ESME was developed to evaluate the role of innovation in UK energy system decarbonisation, from energy resources and conversion through to end use in buildings, transport and industry. It has historically been used by ESC, Government, industry, the Committee on Climate Change and academia.

ESME is an optimisation model and finds the least-cost combination of energy resources and technologies that satisfy UK energy service demands along the pathway to 2050. Constraints include emissions targets, resource availability and technology deployment rates, as well as operational factors that ensure adequate system capacity and flexibility. Importantly, ESME includes a multi-regional UK representation and can, at a high level, assess the infrastructure needed to join up resources, technologies and demands across the country. This includes transmission and distribution networks for electricity and gas, and pipelines and storage for $CO_2$.

ESME is designed to be neutral in its market, policy and regulatory assumptions. Policy analysis can draw upon insights from modelling, but these are typically not imposed on the model except in constructing specific scenarios. This approach first examines the cost and engineering challenges of meeting consumer needs before considering how to drive such outcomes.

#### Infrastructure deep dive: Infrastructure Transitions Analysis Model (ITAM)

ITAM takes least cost net zero whole energy system designs from ESME and translates these to form indicative national infrastructure requirements, based upon local characteristics, that allow those energy systems to be realised. It has three fundamental steps:

1. Translation of model outputs at regional level and distribution of demands (e.g. boilers, heat pumps, electric vehicles, industry, power generation etc.) at a fine granularity within that region – defining peak energy demands from each demand sector within each area.
2. Definition of indicative infrastructure networks needed to meet those peak demands – including electricity, hydrogen, gas, district heat and $CO_2$ networks. Comparison of how these networks are different to existing network infrastructure and what transitional steps are needed (e.g. decommission, reinforce, build new). Aggregation of these infrastructure specifications into bills of quantities at local government scale.

3. Passing of these bills of quantities through cost analysis that accounts for contextual factors and deployment rates to develop whole system infrastructure costs associated with the ESME scenario.

The bill of quantities derived within ITAM includes elements that are not typically modelled directly in coarse-grained whole energy system models. These include electricity and gas connections, network abandonment costs and repurposing interventions. Costs quoted include contingency, profits, contractor overheads, preliminaries, project management and engineering.

### How does this analysis add value?

This study adds to the knowledge base in two clear areas:

- Emphasis on the Sixth Carbon Budget, with additional perspective of innovators

With the Sixth Carbon Budget necessitating a 78% emissions reduction by 2035, action that previously could be avoided until the 2040s must now be accelerated. This study models these challenging interim carbon budgets directly alongside the established Net Zero target for 2050.

- Direct linking up of UK-level strategic plans with more granular modelling of energy infrastructure

We are not aware of any alternative modelling suite that links together national Net Zero scenarios and local details around infrastructure so directly, allowing a consistent strategic and practical picture to be natively developed.

### Methodological assumptions underpinning infrastructure modelling

Scenario planning for the UK energy system has been established over many years, with whole energy systems models offering a powerful means of constructing such scenarios[5]. Insights from such coarse-grained models are typically at a strategic level rather than offering detailed transition pathways for specific technological interventions.

With regards to energy infrastructure planning, though, no single known approach is able include all the complexities of the energy networks. Accordingly, common simplified modelling methodologies are:

- **Archetype-based models**: a finite set of typical networks is used to represent a simplified UK electricity system and network. Within such models, reinforcement of networks is done at an archetype level
- **Local area energy planning**: considering a spatially limited energy system, it is possible to integrate power systems and planning models to explore requirements for upgrade
- **Data-driven models**: such models combine spatially granular datasets with algorithms that specify how network components will evolve over time alongside demand changes
- **Power systems models**: for evaluation of the operational characteristics of energy networks, power systems models focusing on flow of energy are appropriate. These don’t typically intrinsically construct systems but act as a test of the operational viability of a network solution

The ITAM model utilised in this study is an example of a data-driven modelling methodology.

[5] E.g. Hughes and Strachan, Methodological review of UK and international low carbon scenarios, Energy Policy 38 (10), 2010, https://doi.org/10.1016/j.enpol.2010.05.061

### Technical details relating to infrastructure models

Infrastructure reinforcement is highly location-dependent, with existing physical and network topology strongly influencing realistic upgrade paths for electricity distribution. There are also many uncertainties around existing network loads and future intervention options, which are both challenging to address at a whole UK level.

Key assumptions that affect the projected scale and cost of network reinforcements are:

- Assumed headroom in existing networks: this is network-specific and uncertain.
- Projected innovation in cable addition, removal and reinforcement (mitigating costs incurred in upgrading networks).
- Availability of smart solutions for network deferral (delaying reinforcement activity).
- Network component and installation costs and their granularity, including spatial / contextual factors.
- Assumptions on current and future load diversity; notably as the share of the electricity load arising from electrical heating and vehicles increases.

All of these assumptions represent uncertainties in understanding both of the existing electricity system and of its potential future evolution.

To highlight the potential scale of the challenge for the electricity infrastructure supply chain, the modelling carried out within this study presents a scenario with deliberately limited solution innovation.

- ⇨ Extensive measures to defer network investment are not included. While existing flexible technologies are included (such as shifting of heat demand and managed vehicle charging), there are a variety of expected and unproven technologies that could have significant benefits but are not included in this analysis.
- ⇨ Advancements in reinforcement approaches and operational innovations (e.g. Advanced Network Management) are out of scope.
- ⇨ Innovations that could substantially help reduce the quantities of infrastructure required (e.g. via higher capacity cables) are not included.
- ⇨ Conservative levels of assumed headroom.

As a result, the quantities of network reinforced, and the overall costs presented in this study, should be thought of as an upper limit, indicative of the requirements should further innovations not be pursued or prove to fail.

# 4. An energy system fit for the future

The energy system envisioned in this study is broadly consistent with Energy Systems Catapult's established Clockwork scenario[6]. Clockwork reflects a UK where the energy transition is ambitious but also well-planned and coordinated. It is not a prediction but rather an illustration of how the future energy system might evolve. Investment in strategic infrastructure is supported by policies that enable supply chains to deliver a rapid scale-up in the speed and extent of transformation.

The scenario developed for this study has been updated to be consistent with the Sixth Carbon Budget. Early action is necessary for the UK to meet its obligations; 2035 is now indicated as a critical point, with 78% emissions reduction required by this point.

Three energy vectors are key to successful decarbonisation in this scenario: electricity, hydrogen and district heat. Many different technologies can supply these energy vectors, but within our scenario there is a fairly balanced mixture of technologies including wind and solar energy, nuclear power, carbon capture and storage, methane reformation and electrolysis.

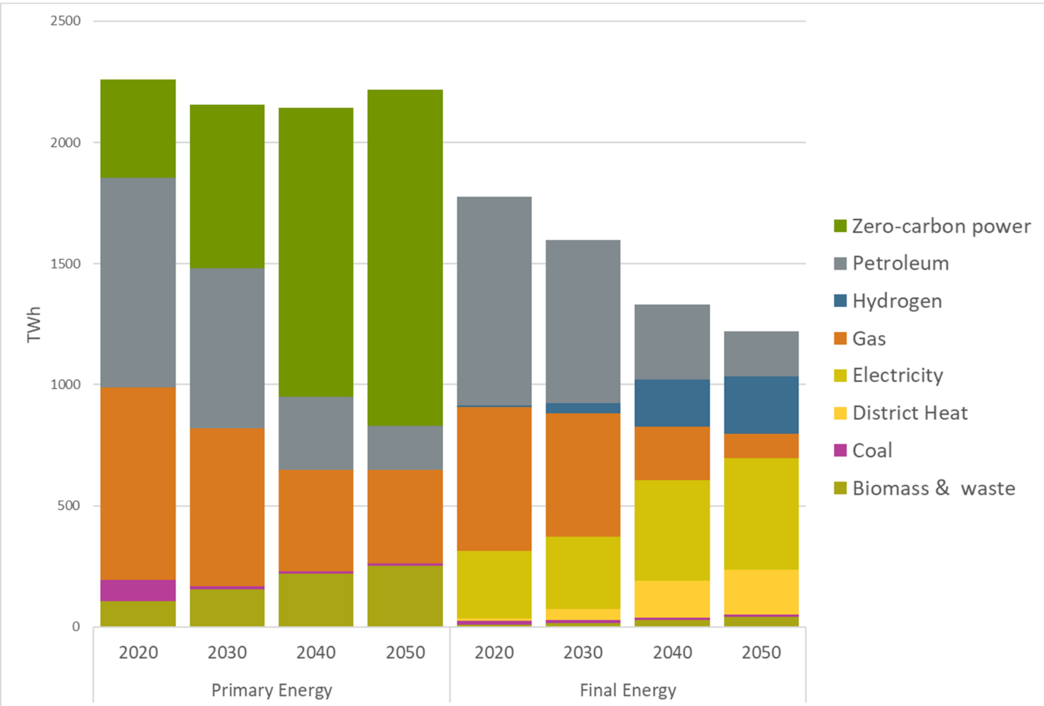


*Figure 1: Primary fuel consumption and final (end-user) energy consumption in modelled scenario*

Electrification of both transport and heating underpins the pathway, but this is enabled by extensive management of consumer demand. A transition to a 100% electric private transport fleet emerges, reflecting both direct policy and recent market trends. This full fleet will require at least 28 million vehicle chargers to be installed in homes, public streets and workplaces. Smart charging is key to the deliverability of this, with aggregate peak demands managed down to less than 0.5 kW at properties that have electric vehicles. Electrification of road freight is also prioritised where feasible, meaning that commercial-scale supply or charging infrastructure will be required alongside that developed for personal transport.

[6] Energy Systems Catapult, Innovating to Net Zero, March 2020, https://es.catapult.org.uk/report/innovating-to-net-zero/ (accessed November 2021)

**Box 2: Alternative perspectives**

Over many years, organisations such as National Grid ESO, the Committee on Climate Change and the UK Government have built scenarios to explore possible pathways for meeting carbon budgets and achieving Net Zero emissions. These scenarios are often developed with the support of modelling tools, such as ESME, UK TIMES or sector-specific models. In each case these modelled pathways constitute the starting point from which to conduct analysis of the energy system.

As well as utilising different modelling tools, organisations may adopt different assumptions about future uncertain characteristics of the energy system: for example, energy service demand, technology costs and resource availability. They may model policy instruments directly or may deliberately avoid doing so. These assumptions may differ within a single study: for example, the pathways presented within National Grid's Future Energy Scenarios are markedly different to each other and reflect different views on technology preference, innovation success and coordination.

ESME and ITAM typically represent a predominantly optimistic view of the world: future end-use technologies become available at timelines and costs underpinned by engineering analysis. First-of-a-kind premiums are overcome for technologies. This neutrality in technology and policy aligns to the well-planned philosophy adopted in the Clockwork scenario. However, the Clockwork scenario is not a prediction of the future. Many alternative routes to Net Zero are viable, and planning action to be taken should reflect on the range of possible futures that could emerge.

Flexible heat pump and hybrid heat pump systems, coupled with thermal storage, provide much of the space heat supply for homes and businesses in the long-term. These technologies need to be deployed at rates in excess of one million units per year by the early 2030s to ensure compliance with the Sixth Carbon Budget. For these rates to be realised, consumers need to consider the technologies appealing enough to choose over fossil fuelled boilers. There are some early signs of an acceleration in deployment of low carbon heating systems, with the Microgeneration Certification Scheme (MCS) Service Company indicating over 20,000 heat pump installations in the ten months to October 2021[7]. This represents growth of 120% on 2019, which is substantial but further growth is required to achieve the millions of installations per year required in this scenario by the early 2030s. In addition, the installer base, which is estimated to be running at less than 2,000 trained installers at present[8], needs to increase at least tenfold to deliver the projected deployment rates.

[7] MCS, https://mcscertified.com/what-the-heat-and-buildings-strategy-means-for-mcs-certified-installers/ (accessed November 2021)

[8] BEAMA, Electrification of Heat, October 2021, https://www.beama.org.uk/resourceLibrary/electrification-of-heat-.html (accessed November 2021)

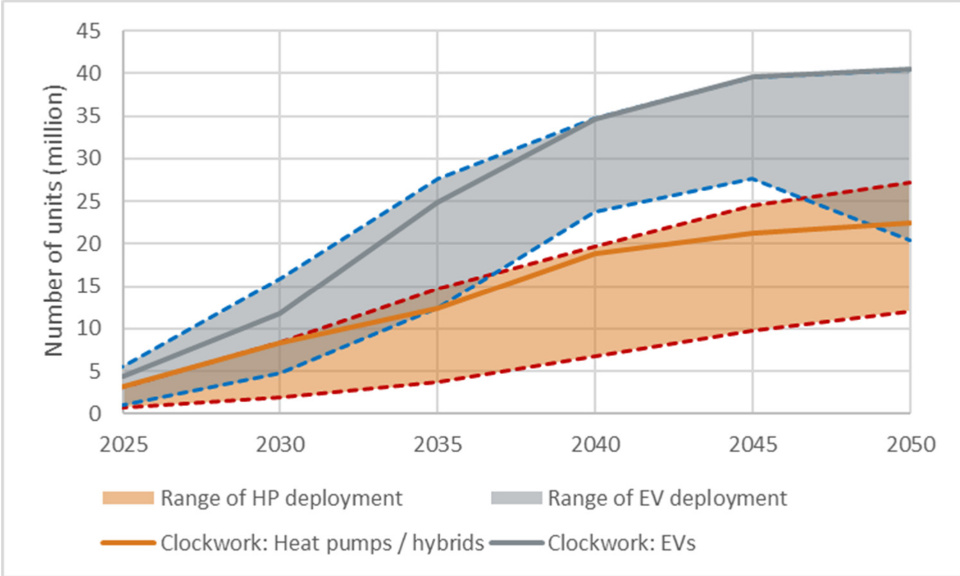


*Figure 2: Heat pump (including hybrid) and electric vehicle deployment in modelled scenario, compared with range in National Grid Future Energy Scenarios and Committee on Climate Change scenarios*

Eight million domestic retrofits are applied to homes that have an Energy Performance Certificate of grade E or lower. As well as reducing thermal loss, these retrofit packages also prepare properties for installation of a cost-effective zero-carbon heating system. This requires careful planning to ensure actions taken are cost-effective, appealing to residents, minimise disruption and future-proof. In reality, these retrofits may be made more attractive and further enable demand-side flexibility by installing technologies that are out of scope of this study but key products for BEAMA members; for example, mechanical ventilation and heat recovery to improve ventilation and internal air quality, or products offering security, comfort and control. Ensuring readiness of homes for Net Zero is critical[9].

Although electric systems contribute almost half of all space heat in this scenario, hydrogen also plays an important role in its application through hybrid heat pumps. The use of hybrid systems avoids the requirement to produce huge volumes of hydrogen for combination boilers annually and mitigates electricity network reinforcement. By repurposing portions of the existing gas network to allow it to supply hydrogen in the coldest periods, the electricity network avoids being systematically sized for heat supply in rare, extreme weather events. Developers of electricity-based systems must be aware of the uncertainties relating to the choices that affect these systems. As repurposing of gas networks to carry hydrogen affects multiple energy consumers, there are likely to be decision points at a regional and local level wherein a choice between investing in hydrogen infrastructure versus supporting alternative systems for domestic heating must be made.

[9] BEAMA, Net Zero By Design, October 2021, https://www.beama.org.uk/resourceLibrary/net-zero-by-design----our-vision-of-a-zero-carbon-home-and-how-we-get-there.html (accessed November 2021)

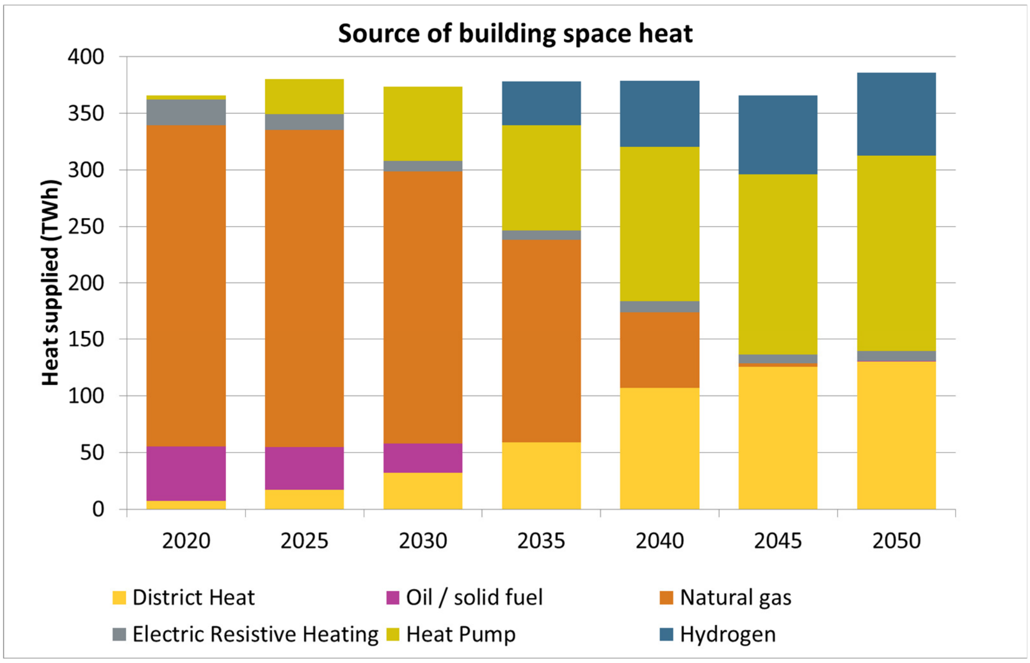


*Figure 3: Supply of domestic, commercial and public sector space heat in modelled scenario. Heat supply from hydrogen and heat pumps includes supply from boilers and individual heat pumps and also energy consumption from hybrid systems*

**Box 3: Modelling of electricity system flexibility**

In broad terms, flexibility is needed to ensure that the electricity system operator can balance supply and demand. This requires the following:

- The ability to quickly ramp supply or demand up or down to meet immediate needs caused by supply / demand imbalance or intermittency in renewable generation (maximising use of intermittent generation)
- The ability to hold the right technologies in a state of readiness should ramping or de-load be required in the future (i.e. reserve services)
- Preparedness for long-duration system challenges, such as winter anticyclones
- The ability to deploy and manage technologies to avoid network problems, such as circuit overloads

Historically, power stations powered by natural gas have been able to provide a substantial proportion of system flexibility. However, a Net Zero target is likely to prohibit operation of unabated fossil fuel plant even occasionally. Alternative technologies will be required to deliver and guarantee a stable electricity system.

Within this study many of the key requirements and supply options for a flexible system have been considered, including:

- Ramping of technologies – enough supply or demand that can be ramped or de-loaded must be available to meet likely near-term needs
- Reserve margin – the ability to supply a quantity of power greater than the maximum demand (both locally and nationally) is mandated. This also includes operation in an extreme (1 in 20) cold winter day
- Storage and smart dispatch – technologies that decouple timing of supply and demand can be deployed at local or national scale, and utilized in a cost-optimal way
- Energy carrier integration – it is possible to convert energy from one vector to another to solve balancing issues
- Managed vehicle charging – flattening of vehicle electricity demands, rather than charging at peak, is required
- Extreme weather event management – holding of sufficient flexible technologies to enable the electricity system to operate in a multi-day low wind period

This study has not undertaken detailed dispatch analysis that considers the minute-by-minute operational challenges of balancing supply and demand, including control strategies and communication. However, the modelling is able to identify and exploit many key sources of flexibility that will be required to deliver on the requirements for the Sixth Carbon Budget and for Net Zero. These key sources include:

- **Smart vehicle charging**: avoiding peak charging of an entire fleet of electric vehicles

- **Hybrid electrification coupled with thermal storage:** over 200 GWh of building thermal storage is deployed, charging when electricity is plentiful and allowing capacity of heat supply systems to be reduced
- **Seasonal hydrogen storage** and deployment of turbines fired by hydrogen
- **Interconnection**: utilising imports of electricity from outside the UK to help meet demands
- **Plant with flexible output**: for example, nuclear plant where electricity can be diverted to supply heat or hydrogen for networks

Without exploiting these sources, management of intermittent generation and peak demands would be challenging. Additional flexible generation and grid reinforcement at local and national scale would be required, and the resulting system would be costly.

A parallel question to that of flexibility is that of electricity network innovation. Within the ITAM model we do not assume any advancement in operation of electricity networks, which could reduce costs of reinforcement for future networks. For example, an increase in peak demand in a region to slightly above the maximum carrying capacity of a cable necessitates installation of a second parallel cable. Reduction in peak capacity requirements originate wholly from the flexibility sources outlined above.

# 5. Investment in and scale-up of energy infrastructure

Within the modelled pathway, networks at all scales must transform, particularly to support growth in electric transport and heating and to integrate greater levels of generation.

In this section we focus on the growth of electricity infrastructure, but it should be noted that other energy carriers must also grow in consort. For example, an interconnected hydrogen network capable of carrying and balancing hundreds of TWh of energy by 2050 is required in this scenario, and the costs of developing this network are substantial, requiring effective planning, coordination and investment.

These scenario projections are based on a conservative perspective of future electricity infrastructure development. Technologies to specifically defer or eliminate local network reinforcement activities – often dubbed "smart network solutions" – are broadly excluded from the analysis. Similarly, specific innovations that could assist with network line / cable upgrades, such as advanced meshing solutions, are not included. Finally, with conclusive data on low voltage network headroom not available in the public domain, conservative assumptions on headroom are assumed. The infrastructure characteristics presented in this work therefore comprise an upper limit both in terms of line and substation upgrade requirements and investment cost and should be interpreted in this spirit.

### Transmission networks

At the transmission level, the network will be required to move electricity from new large onshore and offshore wind farms, nuclear plant and carbon capture-equipped generators to where it is needed. New lines and cables enable this: the total transmission cable length grows by roughly 10% by 2035 and by 30% by 2050. This increased length of network is also able to carry greater capacity: in 2035, 16% of installed transmission lines and cables are upgraded to double their existing capacity whereas in 2050 this rises to 36%.

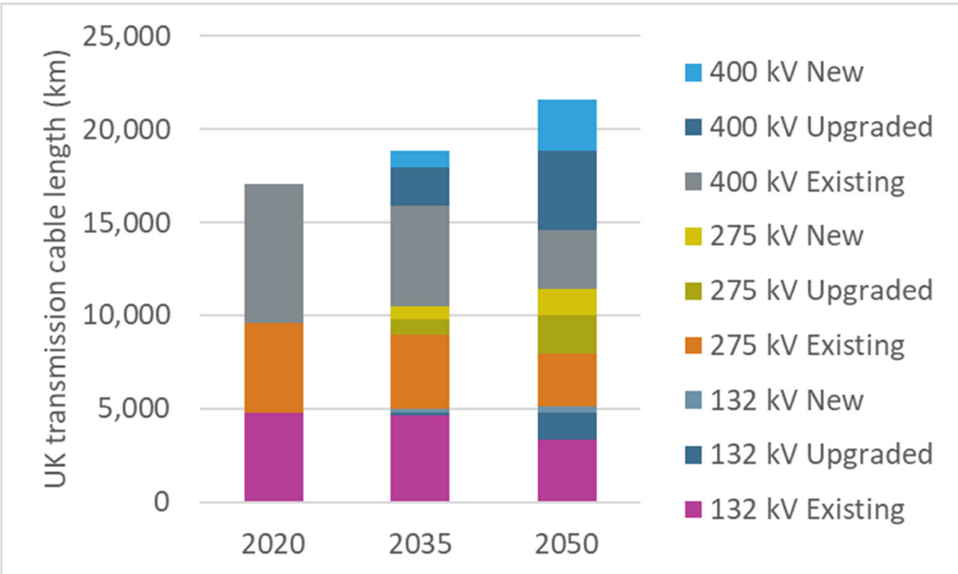


*Figure 4: Growth of transmission network[10] lines / cables in modelled scenario*

[10] Including 132kV infrastructure in Scotland

To support these generation connections, the number of grid and bulk supply substations must increase by over 50% between 2020 and 2050.  An increase in the number of substations means that the need for equipment that makes up the substation will grow.

### Distribution networks

To maintain consistency with the Sixth Carbon Budget, there is a need to rapidly increase the capacity of the distribution network.  Early action in domestic and non-domestic buildings, associated with increased deployment of electrified transport and heating solutions, means that reinforcement takes place earlier at a distribution level than in the transmission network.  Over 1,000,000 km of distribution cable is required, of which more than 300,000 km is additional, corresponding to an increase in overall distribution network length of 25% by 2035.

The lengths of line and cable required in 2050 are similar to 2035 but at higher capacity: in 2035, 41% of the new 11kV network is at a rated capacity of over 9 MVA whereas in 2050 this rises to 46%.  This capacity supports an increase in national peak demand of roughly 20 GW between 2035 and 2050, driven by further electrification in all sectors.  Demand-side flexibility substantially mitigates this increase, with managed vehicle charging and heat storage particularly important at a distribution level.

Primary and secondary substations across the distribution network will need to be upgraded to match future capacity requirements. New substations will be required for new demand and generation connections.  Growth in substations broadly tracks that of lines, with action required relatively early.  A shift towards higher capacity is apparent for distribution substations, with almost 40% of low voltage substations being rated at 1 MVA or higher, compared with 12% at the outset.

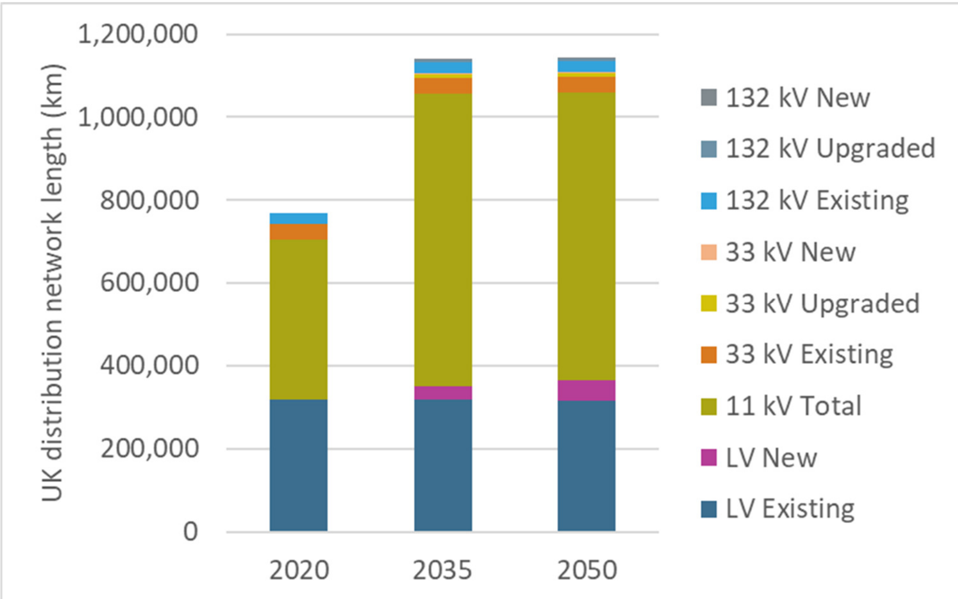


*Figure 5: Growth of distribution network lines / cables in modelled scenario*

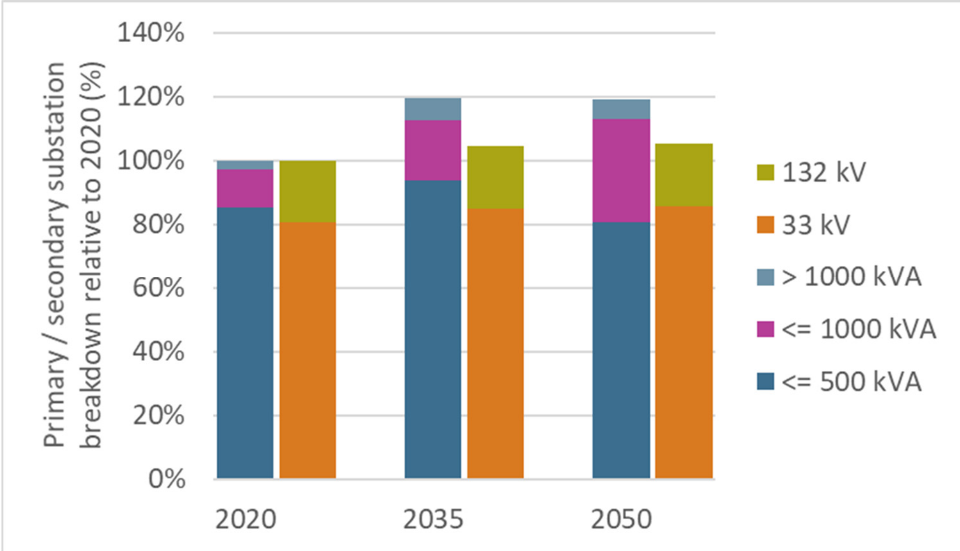


*Figure 6: Distribution substation growth in modelled scenario*

## Electricity system components

Electricity networks are made up of a large variety of components, supplied and installed by organisations such as those represented by BEAMA. Upgrading and installing new substations affects the number of such components needed in future years. At the distribution level, some components are directly linked to or physically integrated within secondary substations. These include ring main units, transformers, distribution boards and remote terminal units. In line with the growth in demand and infrastructure, there would be a requirement for more of these components in the future: circa 30,000 by 2035 and 40,000 by 2050. The scenario envisioned thus offers substantial growth opportunities for a wide variety of organisations within the electrical component supply industry.

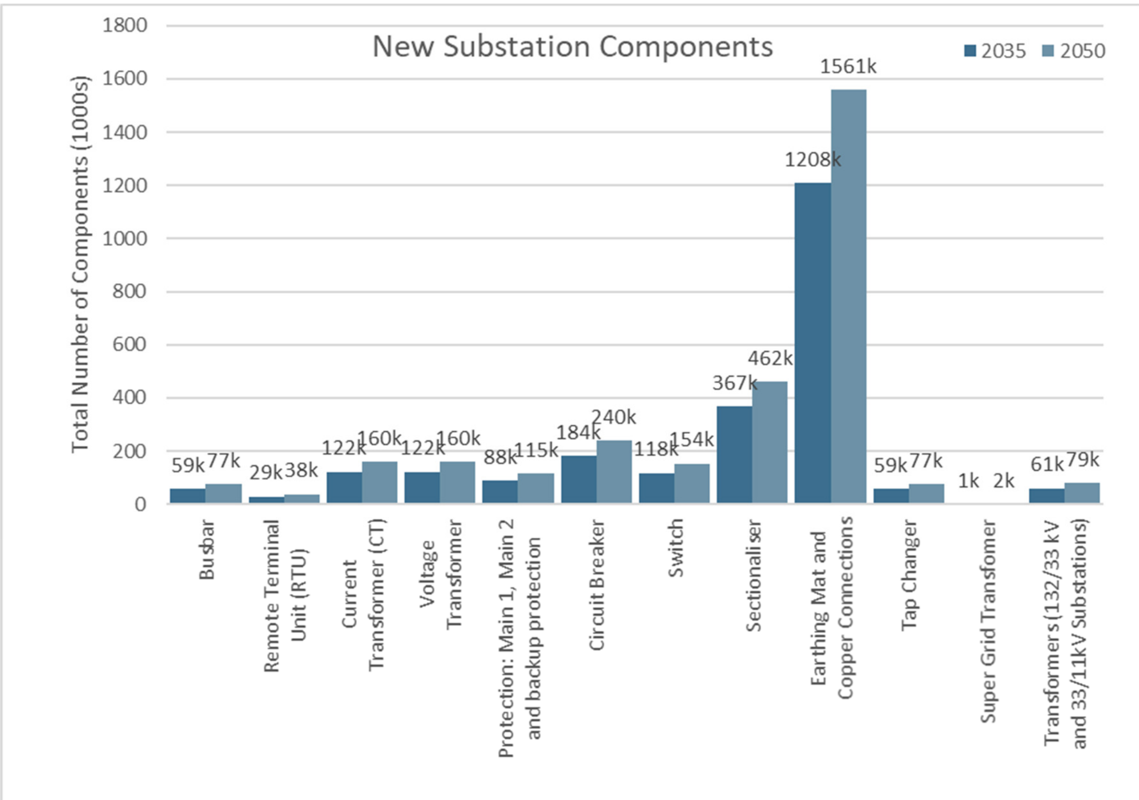


*Figure 7. Growth in substation components required to fulfill demand for new/upgraded substations*

### Timing of reinforcement: anticipatory investment ahead of need

These results indicate that electricity networks will need to be well prepared to be able to support the parallel electrification of heat and transport. This contrasts with current reinforcement strategy: at the distribution level, the network is built to support peak demand with little intervention from the Distribution Network Operator.

The projected increase in lines, length of lines and cable ratings shows that there is a need to substantially increase the capacity of the network at local, distribution and transmission level. For increases in demand of this magnitude, future needs would ideally be considered at the first intervention to increase capacity. An intervention to increase capacity should consider long-term needs beyond typical planning time-horizons; in many cases only a single reinforcement would be needed. This would reduce the need to visit sites to carry out multiple interventions, minimise the number of assets required and minimise early write off of assets or multiple lines / cables being used. The challenges of anticipatory investment are acknowledged, with a need to ensure cost-effectiveness throughout and to recognise local needs and uncertainties; any investment well ahead of need must take account of these challenges.

### Cost of transition

To decarbonise we need substantial investment into the energy system, but exactly who directly contributes the funds required depends on the technology, market structures and any related policy or subsidy. Much of the cost of the future energy system is from construction of centralised power generation and other large energy conversion assets, which are key to the delivery of Net Zero but are not of primary interest in this report. However, end-user technologies and electricity infrastructure investment costs are substantial and relevant to manufacturing and supply industry.

- For domestic, commercial and public sector end-users, a migration from fossil fuel use for heating and transport is projected within this pathway. Installation of replacement technologies will require capital investment, and at least initially the upfront costs for these alternatives are likely to be higher than consumers are used to paying. Although future innovative financing and energy-as-a-service business models may offer alternatives to lump-sum cash investments, consumers and businesses are likely to directly bear the costs in this sector. A longer-term aspiration, as outlined in the Heat and Buildings Strategy, is for cost parity with boilers by the 2030s which places additional pressures on a supply chain in terms of where and how they manufacture their products.
- Electricity infrastructure covers a range of products, from domestic electricity connections up to a gigawatt-scale transmission line connecting an offshore wind farm. As a result, many different investments take place when reinforcing the network. At distribution level and below, key investors are the electricity distribution network operators themselves, although that upfront cost is recovered from the connecting party and from energy consumer bills. Depending on the size and location of a connection the costs incurred can vary depending on the level of reinforcement required. This has led to innovative "flexible connections" that has lowered the cost and delayed the need for reinforcement in many areas. Electrification is likely to lead to a large number of demands for new or reinforced connections, compared with historic connections for single, large consumers or producers of electricity.

For domestic technologies (including heat pumps and hybrid systems, resistive heating, heat storage systems, electric vehicle charging, domestic solar power and domestic electricity storage), the required investment between 2020 and 2050 is estimated to total circa £80bn[11], implying an annual average investment of roughly £3bn. The scale-up of heat pumps and hybrid systems in the 2030s is a key source of this investment requirement, consistent with the challenging targets within the Sixth Carbon Budget.

In contrast, the required investment in electricity distribution infrastructure[12] is projected to total circa £330bn[11] between 2020 and 2050. This implies an average investment of £11bn per year. The capital investment profile illustrates that this investment accelerates from the 2030s and particularly around 2035, where the emissions target tightens and electrification ramps up.

The projected investment requirement for the RIIO-ED2 price control period 2023-28 is broadly in line with that estimated in DNO plans; BEAMA analysis of stated RIIO-ED2 plans estimates a total UK distribution network investment of circa £5bn per year over the five-year control period. However, a substantial acceleration in investment in the subsequent price control period is necessary. Planning for this period must start now; delivery affects the whole supply chain, from DNOs to component providers, and adequate scaling up of manufacturing and installation may take years.

As anticipated, the electricity network investment costs presented here are higher than in many existing studies and higher than estimates of recent electricity network investment. Box 2 outlines some of the elements and assumptions considered within this estimate; new connections, contingencies, profits and various other factors are included in this analysis. Some of these costs will be borne whether following the Sixth Carbon Budget or not. As noted earlier, although some types of flexibility are included, business-as-usual approaches to network reinforcement are assumed. There is a clear need for network innovators in particular to help reduce these costs whilst respecting local constraints and ensuring secure supply.

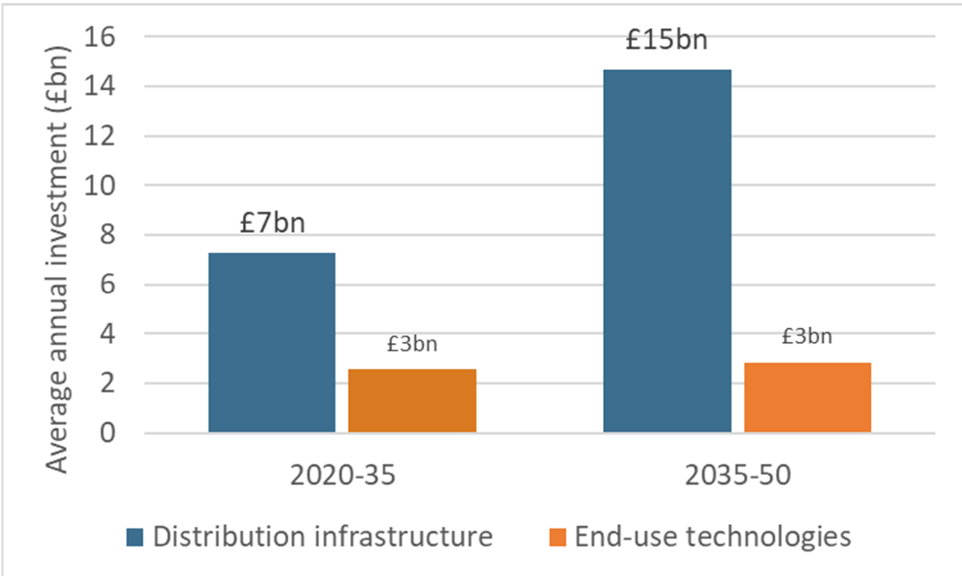


*Figure 8: End-user investment costs for modelled scenario*

### Flexibility: a mitigation for electricity system investment

As described in Box 3, the scenario relies on some key sources of flexibility, arising from several different technologies. In addition to these sources, the scenario exploits the following:

[11] Expressed as NPV (discounted at 3.5%) in £2015

[12] Including new connections, lines / cables and substations

- **Domestic retrofits:** the most inefficient homes are upgraded over time, reducing the peak demand for space heat and hot water
- **Right-sized deployment of residential solar power:** large domestic solar arrays may require an upgraded connection to permit export of large volumes of electricity
- **Deployment of electricity storage systems:** batteries and thermo-mechanical storage systems are deployed, alongside a mixture of generation technologies, to balance supply and demand

These interventions help smooth demand and, as a result, the requirements for energy infrastructure are already mitigated substantially.

Deployment of such flexible systems affects several features of the electricity system:

- Mitigation of electricity connection size upgrades
- Reduction of reinforcement requirements at all scales
- Reduces the requirement for thermal plant to manage intermittency

It should be noted that these levels of flexibility have not yet been proven to be deliverable at scale. They rely upon effective control of distributed assets alongside compliant consumer behaviour in support of the system's needs. In parallel, there are substantial further opportunities for infrastructure innovations to help manage and mitigate the costs of network reinforcement. To deliver such cost savings, a clear pipeline of innovation – with clear and adequate rewards for electricity supply organisations – needs to be in place.

A specific example of how flexibility can affect infrastructure requirements relates to reinforcement of electricity connections. In the domestic sector, the two major contributions to future increases in peak demand are from heating and transport. Without mitigations such as the actions outlined above, the potential uplift in electricity demand is sizeable and – apart from in the smallest or highest efficiency dwellings – could tip peak demand over the limit for a single-phase supply. Additional demand from heating and vehicle charging (over and above that resulting from existing appliance diversity) could be reduced to values as low as a couple of kilowatts if all mitigations are included. Such interventions will therefore, if controlled correctly, reduce or remove connection upgrade requirements within dwellings as well as reducing or deferring local network reinforcement.

The least efficient homes are at most risk of requiring a future connection upgrade should they pursue electric heating solutions. There are roughly 14 million low-efficiency homes in the UK (excluding flats and apartments): without careful planning perhaps as much of half of the UK's dwellings could require an upgrade.

Although this study does not include a detailed assessment of the value of flexibility, one element has been quantified in this study: by modelling the impact of a change in the quantity of domestic heat that can be shifted in time, heating diversity was increased and decreased to represent more and less flexible systems respectively. The impact of this was a 5-10% change in the quantity of distribution substation and cable capacity required. If this source of flexibility can be accessed through improved control and other innovative technologies, then real benefits could be realised in terms of demands on the distribution and transmission network. For the illustrative case this saving was estimated to be as much as £16bn along the pathway to 2050.

Other publications have established the need for flexibility within the future energy system to ensure cost-effective energy. A case study summarising work by National Grid ESO assessing how flexibility can help “bridge the gap” between the current energy system and one reliant on higher volumes of low-carbon inflexible electricity generation is summarised in Box 4. Furthermore, the UK Net Zero Strategy estimates that flexibility across the whole energy system could help reduce system costs by as much as £10bn per year. The potential for flexibility to significantly aid development of a cost-effective Net Zero energy system is therefore supported by the current project.

### Box 4: FES Bridging the Gap to Net Zero – a perspective from National Grid ESO

Since 2019, National Grid ESO has looked in more depth at some of the key messages from its Future Energy Scenarios and tried to understand what needs to be done now to bridge the gap between today and 2050. This year's report, to be published in March 2022, looks at the reality of operating a fully decarbonised power system and how we make sure we have the flexibility we need at our disposal in 2035.

#### Key messages

Through detailed discussions with stakeholders about the flexibility we need in 2035, we've heard some points made again and again. These form the basis of the takeaway messages from FES Bridging the Gap 22. They are the most urgent areas needing to be addressed now to ensure that we're able to deliver a fully decarbonised power system in 2035.

**Flexibility needs broad and large-scale investment now**

- Strategic investment is needed in flexibility related assets, which are digitalised and interoperable. This is alongside the need for urgent market reform and investment in all networks.

**Consumers are part of the solution**

- Unlocking end-consumer flexibility is fundamental to effectively managing a fully decarbonised energy system. Facilitating access to this flexibility is complex and needs to start now.

**Net zero needs cross-sector coordination**

- A whole system approach to coordinating the delivery of net zero across the country is required to prioritise and drive action.

The first key message clearly links to the findings of the Market Sizing report. The scale of investment required for delivering the system needed in 2035 is huge and this is recognised across industry. Investment is needed not just in batteries and long duration storage, but in EV infrastructure and vehicle-to-grid charge points, in hydrogen production and storage, in the networks connecting domestic properties and the digitalised systems needed to deploy flexibility in real time. The supply chains to support all of this need scaling up now to be able to deliver by 2035.

#### Flexibility timeline

National Grid ESO has developed a set of milestones out to 2035, which have been agreed with stakeholders, and represent what they consider to be the most important steps along the way to net zero. To complement this, they have compiled actions from existing plans and strategies to outline what needs to be done, by when and by whom. The full detail of the timeline is in the published Bridging the Gap report here).

This table is a summary of the priority milestones from the different themes identified in discussions.

**The milestones you see here are the priority ones we need to hit to reach 2035. More detailed milestones and associated actions can be found in Part 2.**

| | Investment | Consumers | Roles and responsibilities | Markets | Digitalisation |
|---|---|---|---|---|---|
| **2025** priority milestones | **Strategic flexibility infrastructure projects are underway, e.g. long duration storage, electrolysis.** | **More flexibility enabling, end-consumer products and tariffs are on offer.** | **Clarity on who is doing what in the future, flexible energy system.** | **Revenue streams will be more certain for investment in flexible assets.** | **Interoperability and resilience across the energy system is possible through greater digitalisation.** |
| **2030** priority milestones | Whole energy system approach is used to make strategic decisions about infrastructure. | Consumer facing businesses enable consumers to provide flexibility. | Codes and standards in place to support different net zero roles and responsibilities. | Reformed markets create incentives for flexibility. | System balancing and stability actions are automatically deployed. |
| **2035** end state | Whole system flexibility infrastructure is in place to enable decarbonised system operation. | The majority of consumers are able to deliver the flexibility needed seamlessly via automated products and services. | A coordinated approach to whole energy system operation is achieved through clarity of roles and responsibilities for net zero. | Markets enable flexibility of all durations through the right long-term investment and short-term dispatch signals. | Digitalisation is a fundamental part of the whole energy system as it enables greater market facilitation of flexibility actions. |

# 6. What does the supply chain need?

After developing the scenario outlined previously, ESC engaged with 21 key BEAMA members of varying market shares and areas of activity. These were chosen to be representative of the BEAMA membership, providing coverage from multinationals to SMEs. Deep dive interviews were conducted with selected executive level stakeholders, and a broader sample survey was issued to all members. Whilst there were varying degrees of focus for each organisation, the results can be broadly broken down into a series of key thematic areas as outlined below.

## Upscaling

To meet the UK's ambitious Net Zero targets as outlined in the Sixth Carbon Budget, members suggested they will need to scale up operations significantly. Of those surveyed, **over 85% of members suggested they would need to scale by greater than 20% above current demand** to meet future levels of output, with some members envisioning a doubling or even an order of magnitude increase in demand for their services.

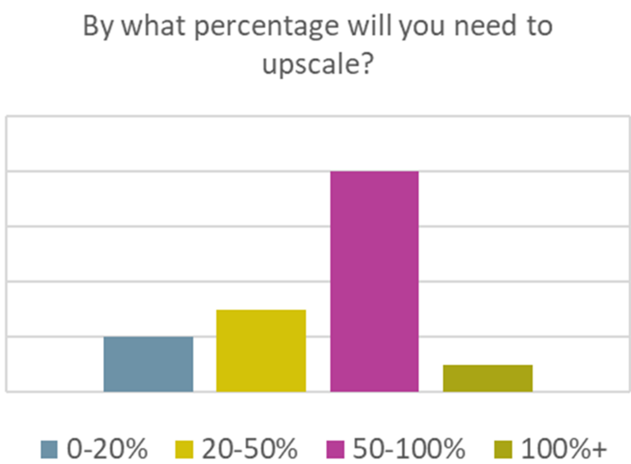


*Figure 9: Breakdown of surveyed responses to question "By what percentage will you need to upscale?"*

*"In terms of new tech and data-centric services there is a significant challenge to scale up to required levels, and we expect at least a 50% increase against current run rates."*

Within a further survey of BEAMA members following the publication of the UK Net Zero strategy, two thirds of the respondents felt that the strategy offers sufficient market certainty needed to justify some further investment. However, comments indicate that it is not likely to be enough to ensure scale-up of supply required to deliver a Net Zero energy system.

*"We take this as a sign of things to come. It helps the case for investment but falls short of being conclusive."*

## Skills

Members outlined the challenges associated with developing skills for Net Zero given the insufficient quality and quantity of labour in the current marketplace. For example, **the installer base for low carbon heating needs to be increased by a factor of 20** to achieve the deployment rates projected in this scenario. The skills needed to jointly assess, install, and advise on zero carbon technologies are not available at scale, and integration from both a systems perspective and labour perspective are currently missing.

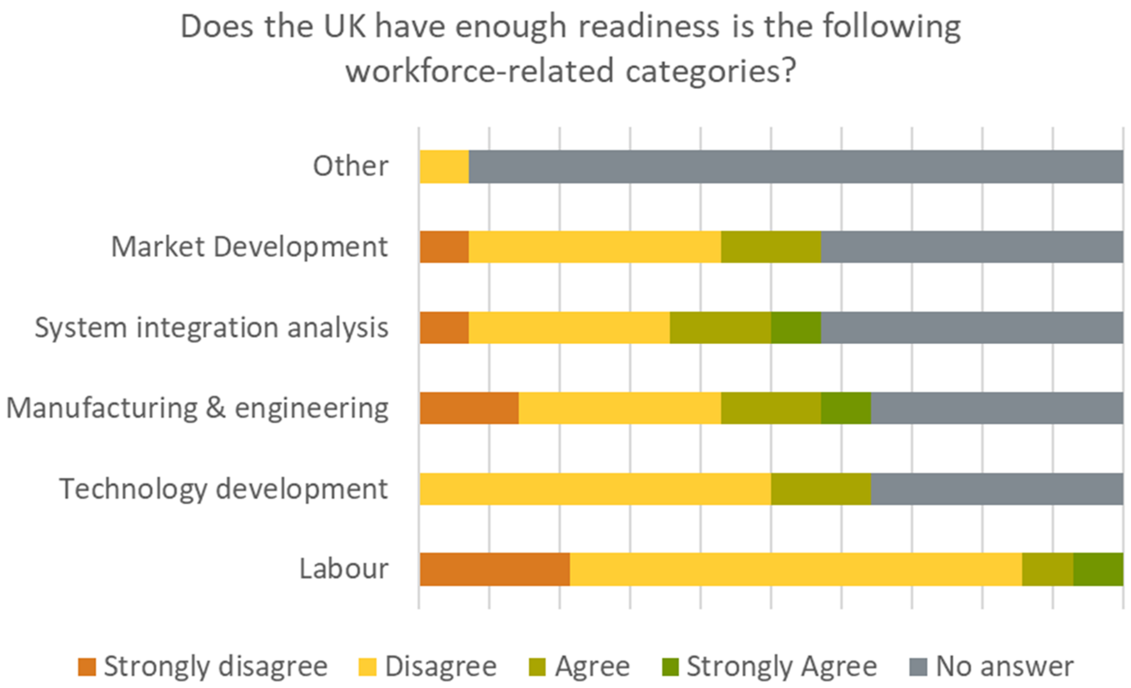


*Figure 10: Breakdown of surveyed responses to question "Does the UK have enough readiness in the following workforce-related categories?"*

However, businesses are adapting regularly – with one representative advising how merger and acquisition activity has stepped up recently, all with a view to adopting more holistic solutions and concepts around integrated solutions and delivering effective system integration.

*"We're building a new energy system where a lot of different parties need to cooperate and interoperate together [...] I see a massive need for cooperation, interoperability, in opening up and sharing of data, and vertical supply chain integration in a way which is in its very early stages today,"*

The Net Zero Strategy outlines several steps to be taken with regards to training and education, such as green apprenticeships. Such interventions are supportive of the requirements for skilled labour indicated by the businesses surveyed. However, additional developments to ensure that specific UK capabilities are leveraged and promoted are likely to be required.

### Uncertainty

There is a broad concern across industry of which pathway the UK will take to reach Net Zero. The consensus is that this **uncertainty stalls investment, which in combination with low consumer confidence and awareness, inhibits the pace and scale of uptake needed**.

An over-reliance on short term subsidy funding and grants means that there is an expectation that top-down government policy and decision-making will ultimately drive technology choices and uptake by consumers. This is thought to be a barrier to innovation and many respondents suggested that a more outcome-based policy framework with long-term demand pull backed by legislation could create more favourable market conditions to address this barrier. Previous experience in reacting to policy and strategy is mixed.

*"The problem is, previous UK Government U-turns have left a bit of a bitter taste in the mouth for manufacturing, where we have invested on a promise of policy direction, but it hasn't manifested itself."*

In response to the UK Heat and Buildings Strategy, all respondents indicated that this strategy alone did not offer the market certainty needed to justify investment in the market, although some specific interventions were noted as promising.

*"HP grant is welcome, but only covers 90000 installations over 3 years. Much clearer stipulation of regulatory drivers would strengthen the case for investment, acknowledging that it is unlikely the Government will subsidise every home on the net zero journey."*

### UK Job Creation / Economic Growth

Investment decisions for years in the future are being made now, meaning that there could be a significant opportunity to drive growth and jobs in the UK if organisations are given market and regulatory signals quickly and the uncertainties outlined above are addressed. **Most companies indicated that many new positions will be created in support of decarbonisation, with a quarter suggesting that they will need to create over 200 new positions in their organisation**.

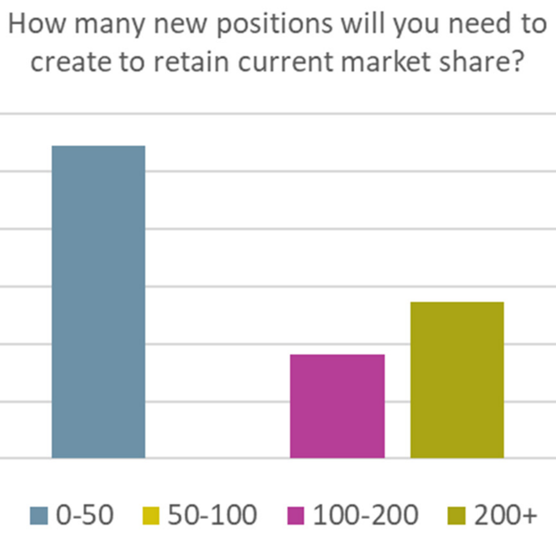


*Figure 11: Breakdown of surveyed responses to question "How many positions will you need to create to retain current market share?"*

Whilst there is considered to be a big opportunity for UK-based manufacturing, which could be encouraged further, some respondents felt the areas of focus should be placed on the "value-add" side of the supply chain, rather than just trying to be cost competitive with other markets.

*"The business is investing in heavily, but the choice for us now is not whether we invest in technologies like grid flexibility or not – the question comes down to which countries we invest the heaviest in, and that again comes back to confidence,"*

As multinational organisations are expected to remain a key source of products required to deliver Net Zero, facilitating an environment wherein the UK becomes an attractive environment for investment is key. Conversely, understanding how best to support innovation by SMEs was flagged as an important requirement.

### Private Investment

There is a general understanding that government can only stimulate markets, however **providing financial stability through policy over the long term can help increase confidence in zero and low carbon solutions**. Support in the form of tax breaks, subsidies, new standards and better enforcement of existing standards were all cited as potential methods which would give industry stronger grounding on which to accelerate investment, however many interviewees still suggested they required greater confidence in the markets they'd like to operate in before moving forward.

*"The finance one is a really fundamental piece. When there is such a large scale of investment required here at a residential level, there is no way that any government scheme is going to do anything other than lead the way,"*

### Policy & Regulation

**Stronger regulatory and financial support in the short term, and legislative market support in the long term** were cited as areas which would give industry confidence to move forward and ramp up investment. The methods outlined above were cited by the interviewees as useful for initiating scale-up and enabling certainty, but with nuances acknowledged. For example, plans and targets can, if not implemented effectively, back-load investment towards the end of a planning period, which hinders industry's ability to mobilise.

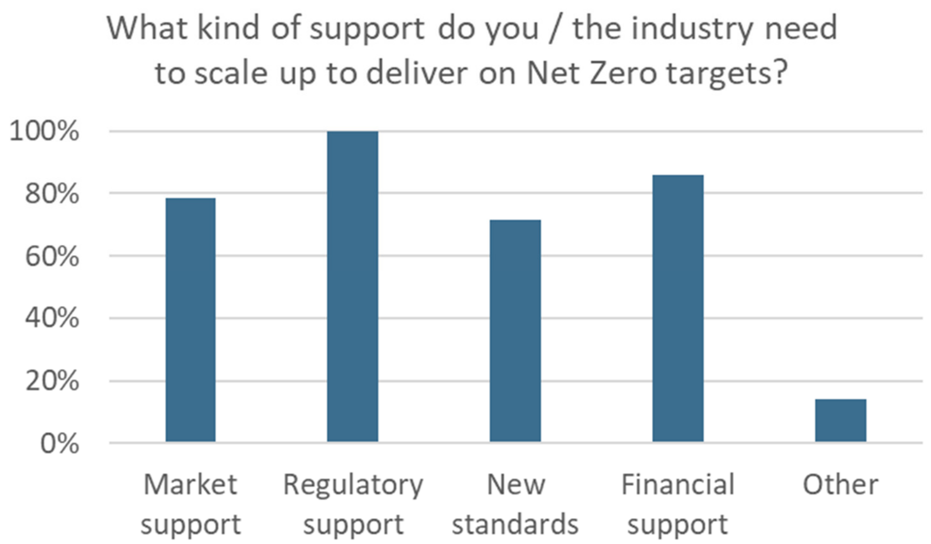


*Figure 12: Breakdown of surveyed responses to question "What kind of support do you/the industry need to scale up to deliver on Net Zero targets?"*

Another example noted by several organisations related to uncertainty of regulation of issues pertaining to flexibility and distributed assets. This uncertainty was noted as a particular barrier towards organisational confidence and ability to deliver on the future energy system's needs.

*"Help those trying to go green! So maybe supporting investments in green/connected/efficient tech/smart tech and support companies to make more sustainable decisions in infrastructure – for example credits for buildings with smart systems or higher energy efficiency,"*

# 7. Key messages and opportunities for innovation

This study outlines an energy system transition pathway that delivers on Net Zero and Sixth Carbon Budget targets.  It has characteristics in line with some known pre-existing scenarios, but the additional detail developed within this study clearly highlights the required contributions from the electricity product sector.  In response to this pathway, industry has outlined its perception of the opportunity and challenges of delivering the projected scale-up over the next few decades.

## Key messages

1. **Meeting Net Zero may be more costly than projections indicate should network innovation not progress adequately**

The modelling work summarised here – deliberately presented from the perspective of a highly "business as usual" approach to network reinforcement – indicates the scale of the investment challenge for energy networks should innovation solutions fail to be proven.  This is not inevitable, but a clear, specific plan to ensure appropriate solutions are brought to fruition at scale is critical. Examples in the Net Zero Strategy, more extensively developed in National Grid ESO's Bridging the Gap project, are promising but these need to be progressed at pace given network investment lead times.

2. **The electricity supply chain expects to scale up in response to the challenges of decarbonisation but risks currently hinder investment**

The scenario demonstrates the need for upscaling of known key technologies. Heat pumps are projected to increase to roughly 8 million installed units, and electric vehicles and related charging infrastructure increase to over 10 million vehicles over the next decade.  This need for scale-up has been demonstrated in several previous studies, most notably in the Committee on Climate Change's scenarios supporting the Sixth Carbon Budget.  Rapid growth in local and distribution lines and cables is required.  An additional 300,000 km of distribution cable is needed, along with 10% to 30% growth in substation numbers.  Demand-side flexibility helps to mitigate this growth.

The pathway outlined is not the only way to get to Net Zero.  Consumer preferences, innovation success and regulation all affect the practical extent and speed of electrification.  Industry cannot easily anticipate all factors; the risks in investing in manufacturing and skills are high.

3. **There is a need for greater clarity from Government to provide certainty and confidence in the market with short-term (financial signals) and long-term (regulatory / legislative) signals**

Future market conditions and uncertainty around policy are two of the main concerns that affect growth within UK businesses.  Industry currently lacks sufficient long-term confidence in the market to deliver on Government commitments.  Medium to long-term change is needed which goes further than tax breaks, subsidies and grants; for example, new standards, greater enforcement of existing standards and long-term legislation to provide decision makers with the belief to not only keep, but further develop operational activity in the UK.

Specifically, the RIIO framework will need to support an ambitious commitment to ensure compliance with the Sixth Carbon Budget, particularly within the RIIO-3 periods and later.

**Box 5: Policy uncertainties**

Some specific examples highlight the consequences of existing policy providing indirect uncertainty around the speed of transition:

1. DNOs' recovery of investment costs, where first-movers in installing new technology may be required to disproportionally bear the costs of any required network upgrades. This affects the appeal of such technologies to consumers, by uplifting their effective costs. Without addressing such issues, ambitious take-up projections may never be realised.
2. Network planning needs to look some distance into the future, with this and other work noting a specific challenge in the mid-2030s as carbon targets become particularly challenging. The rolling RIIO 5 year framework does not provide a direct motivation to support such longer-term investments – planning well ahead of need – and is not consistent with a "touch once" strategy for upgrade of local networks.
3. The regulatory framework of demand side response, storage and flexibility for instance, is cited as an area which needs clear, long term signals before industry runs the risk of installing vast amounts of legacy equipment.

3. **The UK Net Zero Strategy and UK Heat and Buildings Strategy have gone some way to providing increased confidence to the market.**

The specific policies and targets presented in the Net Zero Strategy offer guidance. They help the case for industry to invest in some sectors, and provide some clarity around subsidies for early adopters, training and specific elements of the supply chain. Conversely, further steps to set out timelines, acknowledging resource requirements to upscale or rebalance manufacturing effort, are required for industry to act decisively.

4. **The skills shortage is a pressing concern, and one which must be addressed to step up supply chain activity.**

Rapid scale-up of installation rates of key technologies requires a sizeable increase in the number of skilled installers. The balance of onshore and offshore manufacturing will influence the amount of skilled labour required in the UK and required overseas. This does not simply indicate that there are likely to be job creation opportunities but also indicates a change in the nature of these jobs. Given the timelines associated with training the workforce and developing new manufacturing facilities, action must be taken now to deliver the size of workforce required to support the projected levels of electrification by the 2030s.

5. **Industry sees this period as both a challenge and opportunity for UK manufacturing. Tackling skills could address job creation, levelling up and regional inequalities.**

The projected scale-up of technologies and infrastructure, although challenging, is seen by industry as achievable. It offers an opportunity for expansion of production and leverage of unique UK capabilities. Industrial forecasts are relatively aligned with current expectations however there are factors which prevent organisations from having the confidence to scale at speed. There is a unique opportunity to leverage private investment which could address wider factors such as the creation of new jobs, economic growth and tackling socioeconomic issues such as fuel poverty.

Rapid scale-up in other regions has already been demonstrated where there is enough certainty for investment. This is a time of opportunity, but there is also a risk that players who operate in international markets may divert investment elsewhere. Various factors influence the lead-time for scaling-up, and organisations must make decisions now to step up their activity within the next 5 years (or less).

6. **If the above points are addressed, and investment is kept within the UK, this could create wider impacts for UK economic growth.**

The cost commitments are challenging but offer opportunities for innovative organisations. The projected growth in electrical components presents expansion potential for incumbent organisations (including onshoring of manufacturing facilities, along with job creation) and scope for new entrants to deliver innovative products into growing local and international markets.

If companies are to invest in the UK, there needs to be an attractive environment to do so. As highlighted, many members operate within other international markets and face similar challenges and issues on the path to net zero. Investment decisions are being made now, and therefore the speed at which markets can create favourable conditions will ultimately dictate where investments end up.

## Opportunities for innovation

BEAMA member forecasts are relatively aligned with current expectations for Net Zero but there are factors which prevent them from having the confidence to scale at speed.

**Heat and Buildings**
Compared with incumbent gas-fired system installations, low-carbon heating installations benefit from a greater level of optimisation to deal with the bespoke nature of the building fabric and the complexity of the relevant systems. This is, in essence, a systems integration challenge, and organisations that can help installers respond to this challenge will be key in delivering the required rates of technology deployment.

These types of engineering and optimisation are areas of UK expertise, so capabilities developed are potentially usable across a wide set of buildings and, critically, exportable for use in other countries.

Targeting of interventions to ensure solutions are accessible to and appropriate for vulnerable consumers is critical. UK targeting and planning capabilities are strong but incentives to find and prioritise different consumers must be in place to use and develop such capabilities to ensure fair access to low carbon solutions for buildings.

**Transport**
There are currently few alternatives to electric vehicles that appear to offer cost-effective routes to decarbonisation for personal transport. As a result, it is paramount to ensure that the overall transport system is deliverable, fits the needs of business and individuals and retains the correct functionality to support the wider system whilst reducing lifecycle emissions. Specifically, the requirement for smart chargers is key. It is likely that smart charging systems will be required to be highly dynamic, predicting and responding to signals that are influenced by intermittent renewable generation. This implies two areas of opportunity:

1. Product manufacture – with tens of millions of smart chargers required over the next couple of decades, there are opportunities for manufacture of products that meet a price point, are interoperable and flexible in their capabilities.
2. Utilisation and optimisation – advanced machine learning or artificial intelligence-based methods to schedule charging in a way that supports locational and national energy requirements will be valuable (if markets permit rewards of such operation).

**Networks**
The growth in network infrastructure implied in the modelling study will require all parties involved in the delivery of upgraded and new networks to adapt. In particular, innovators who are able to develop methods of monitoring, upgrading and installing cable / line (or otherwise intervening) in a more effective and efficient way are likely to see ample demand for their services. Similarly, component manufacturers and installers who can provide products that help minimise the cost of substation infrastructure will be required. Funding avenues such as the Ofgem Strategic Innovation Fund[13] (in particular, innovation challenges relating to system integration and digitalisation) offer opportunities for organisations to demonstrate the benefits of adopting innovative approaches to network upgrades.

Sophistication of network solutions, rather than chasing the bottom-line, is likely to be a more productive approach for these organisations, which prompts consideration of use of a skilled UK workforce. Thus investment in networks will be supported by job creation in some areas, and a requirement for skilled manufacturing or R&D workforce elsewhere.

[13] Ofgem, https://www.ofgem.gov.uk/publications/strategic-innovation-fund-innovation-challenges (accessed November 2021)

# 8. BEAMA's recommendations

BEAMA's membership is ready and prepared to invest in both manufacturing and its UK workforce but the uncertainties presented within this report make this difficult at the moment. The Government's Net Zero Strategy helps alleviate some of this uncertainty and is considered likely to aid investment but there is still need for further conclusive action. A longer-term strategy, with a transition from subsidy to regulation is likely to be necessary over the coming years, with suggestions such as minimum product quality standards being quoted as appealing.

### Recommendation

BEAMA calls for the formation of a UK Electricity Supply Chain Council, backed by the Government, tasked with the development of a five- to ten-year roadmap to support capital investment in the supply chain, ensuring the delivery of the Government's Ten Point Plan.

Content of this roadmap will drive action in the following areas:

- Further modelling analysis to understand variables that influence the energy system transformation to 2035 and 2050. Following engagement with a range of stakeholders, we've identified that further work within this sector is needed to address existing gaps in knowledge. Specifically, further exploration into which of the known uncertainties are most impactful – such as existing low voltage cable headroom, future diversity representation, and the impact of innovative flexible technologies.
- Inform the UK Critical Minerals Strategy. This should be expanded to look at critical supply over all relevant materials, metals and non-metals, and to identify at risk supplies.
- Advise the supply chain of the nature of the challenges in meeting net zero targets and influence their innovation and skills plans.
- Urgently address the skills shortages working with the Green Skills Taskforce.
- Input supply chain considerations to the early work of RIIO-3.
- Establish a stronger connection between domestic policy delivery for Net Zero and trade.
- Determine sector (electrical products) demand side policies to drive the uptake of lower emission industrial products that incentivise clean growth in the UK and industrial decarbonisation.

Key investment barriers to consider will be:

- **Financing options for end use technologies, beyond the existing grant provision**. With end use technology investment of circa £3bn a year, the finance solutions and market incentives are key. Industry agree reliance on grants alone won't achieve this - we need to address regulation to drive uptake and re-distribute fuel levies and subsidy to ensure low carbon fuel costs less. Service options like 'energy as a service' will play an important role in financing home retrofit programs. The current gas crisis should be seen as an opportunity to address urgent action needed to reduce energy bills today through energy efficiency measures, which will in turn lay the groundwork for future low carbon heat retrofit and financing.

- **A review of the regulatory and planning system** that underpins the investment cycles for electricity networks, to allow for more investment ahead of need, which is proven here to reduce the cost of Net Zero.  With up to £7bn/year projected for electricity distribution networks alone, stepping up during RIIO-3, provisions in the regulatory investment cycles to accommodate this will ensure the supply chain will be ready to deliver. This is already being considered at transmission level for offshore wind. This conversation needs to start now to ensure supply chain planning for RIIO-3 delivery.
- **A plan to urgently tackle the scarcity of apprentices** to ensure sufficient skills and capacity for delivery of Net Zero.  This should focus on the transferable skills available also from other industries, specifically those from high carbon sectors.
- **Bringing forward innovation for flexibility markets**, including decisions on regulatory mechanisms such as half hourly settlements which will ensure greater capacity to bring forward additional flexibility on the energy system.  Bringing forward investment and reform of flexibility markets will be a key driver to reducing the cost of Net Zero on the energy system.

For a UK supply chain to support growth following a pathway to the 6th Carbon Budget, decisions and planning on infrastructure deployment need to be made urgently to bring in the private investment needed. Without this urgent action, we risk losing out on the opportunity to capitalise on the growth on clean technology markets.

Further analysis will be needed, but this work clearly demonstrates the implications for supply chains in the delivery of Net Zero.  BEAMA intend to take forward work to further expand on this and inform the effective delivery of Net Zero across our supply chain.

# 9. Appendix 1: Glossary and acronyms

| | |
|---|---|
| **ASHP** | Air-source heat pump |
| **BEAMA** | (Formerly) British Electrotechnical and Allied Manufacturer's Association |
| **BECCS** | Bioenergy with carbon capture and storage |
| **BTM** | Behind the meter |
| **CCC** | Committee on Climate Change |
| **CCS** | Carbon capture and storage |
| **COP** | Coefficient of performance (of heat pump) |
| **DACC** | Direct Air Capture of $CO_2$ |
| **DH(N)** | District heat (network) |
| **DNO** | Distribution network operator |
| **ESC** | Energy Systems Catapult |
| **ESME** | Energy System Modelling Environment |
| **ETI** | Energy Technologies Institute |
| **GHG** | Greenhouse gas(es) |
| **GSHP** | Ground-source heat pump |
| **GSS** | Grid substation |
| **ITAM** | Infrastructure Transitions Analysis Model |
| **ITNZ** | Innovating to Net Zero (ESC report) |
| **LCOE** | Levelised cost of energy |
| **LSHP** | Large-scale heat pump |
| **NOAK** | Nth of a Kind |
| **OHL** | Overhead line |
| **PSS** | Primary substation |
| **RES** | Renewable energy source(s) |
| **RMU** | Ring main unit |
| **RTU** | Remote terminal unit |
| **SMR (Hydrogen)** | Steam methane reformation/reformer |
| **SMR (Nuclear)** | Small modular reactor |
| **SSS** | Secondary substation |
| **TMS** | Thermo-mechanical storage |
| **UGC** | Underground Cable |
| **V2G** | Vehicle-to-grid |

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