Mallard Pass
Solar Farm

Mallard Pass Solar Farm

Future Energy Scenarios Report - 10 July 2023

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Future Energy Scenarios

ESO

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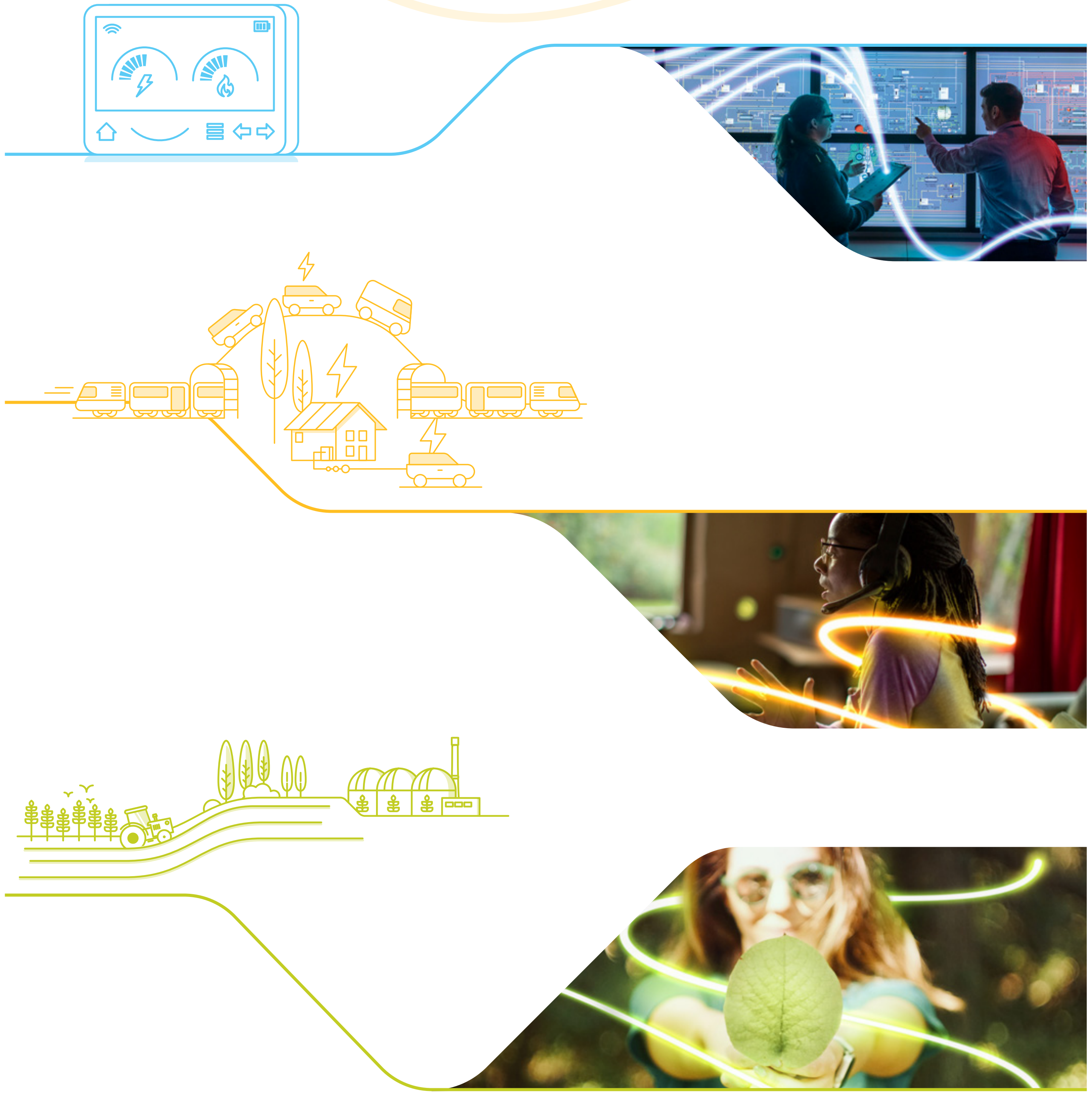


Foreword

[redacted] Two years ago, the Government announced its intention for the electricity system to be fully decarbonised by 2035. This ambitious target reinforced Great global leadership in enabling low carbon electricity generation. The 2035 target gives us just over a decade to deliver a world-first, but it requires a major transition across industry, regulation and government policy – a challenge that we need to meet head on.

Great Britain also continues to take strides towards the 2050 net zero target. Businesses of the net zero economy are driving productivity, contributing over £70bn to Great Britain every year. Regions and local authorities are seeing evidence of the growth opportunity that decarbonisation presents. Maintaining this growth relies on clean energy being available – energy is part of almost every product or service that the British economy relies on. As the Electricity System Operator (ESO), we are driving the changes needed to achieve the 2035 and 2050 targets and now operate one of the fastest decarbonising electricity systems in the world.

But the decarbonisation of the energy system is only one of the challenges that we face. The devastation caused by the illegal Russian invasion of Ukraine has created global uncertainty in energy markets. It has depleted supply chains, restricted access to fossil fuels and exacerbated a cost-of-living crisis which continues to impact everyone across Great Britain.

The scale and significance of these parallel challenges highlights the ongoing challenge of balancing the opportunities of decarbonisation with the requirement for energy security and access to affordable power for consumers and businesses. What is clear is that Great Britain cannot address this trilemma without sustained, collaborative action.

Last winter, working with the Government, Ofgem and industry, we led the development of a world first Demand Flexibility Service. Over a million households were signed up to the scheme through their electricity supplier, with eligible consumers receiving payments to reduce electricity consumption during tighter periods on the electricity system – demonstrating the impact that innovation can have as we decarbonise.

This year's Future Energy Scenarios continue to set out credible ways that the UK can achieve net zero by 2050, as well as the UK Government's commitment to a decarbonised electricity system by 2035. Based on extensive stakeholder engagement, research and modelling, each scenario considers how much energy we might need, where it could come from and how we continue to maintain outstanding levels of system reliability.

Our 2023 Future Energy Scenarios highlight one key overall theme – we must act now to achieve a clean, secure and fair energy system for all. If we don't, a once in a lifetime opportunity will pass us by.

Over the coming 12-18 months the ESO will transition into the Future System Operator – taking a broader, whole system view on how Great Britain can deliver on its net zero ambitions while maintaining a reliable and affordable energy supply. We look forward to working with the Government, Ofgem and industry during this period to ensure the Future System Operator is set up for success and the effective delivery of this critical role for society and the economy.

FES 2023 / Foreword 04

Executive Summary

Introduction

Our Future Energy Scenarios (FES) outline four different pathways for the future of the whole energy system out to 2050. Each one considers how much energy we might need and where it could come from, to build a picture of the ways in which Great Britain could reach net zero.

FES is widely used by the ESO and our stakeholders across the energy industry to:

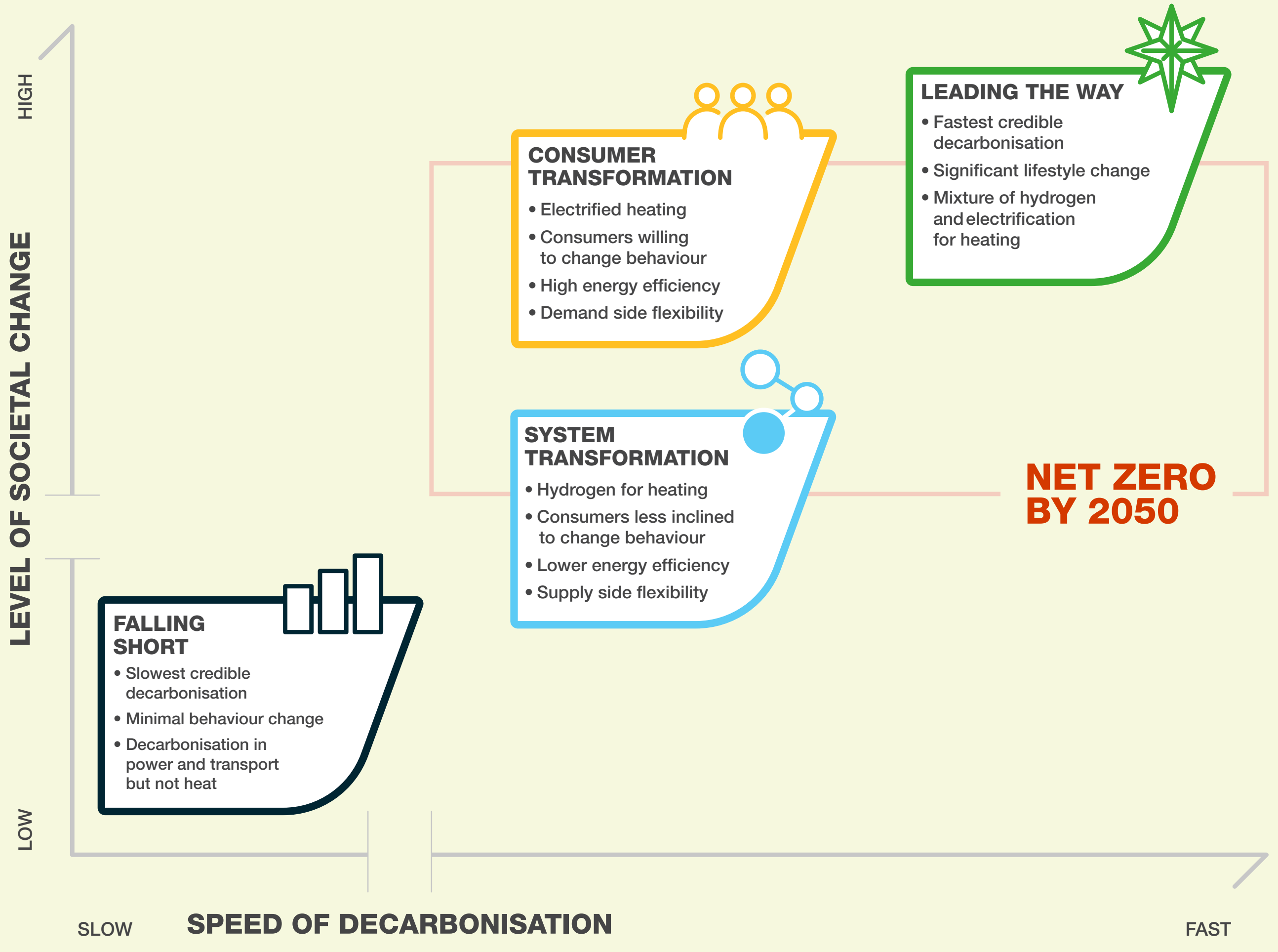
- Underpin energy network investment
- Support financial investment decisions for net zero technologies
- Inform national and regional policy
- Carry out academic research and innovation

Stakeholder feedback is collected as part of our comprehensive engagement work and incorporated alongside our own analysis and research to ensure that our data and insights remain robust and up to date. We also endeavour to make our data publicly available.

FES in Five provides you with the Key Messages and statistics from the full FES report, which can be found here.

Recent events have sparked recognition of the importance of a faster transition to net zero. This can support energy security and reduce exposure to volatile international fossil fuel prices, by harnessing abundant renewable and low carbon resources.

The Scenario Framework



In line with stakeholder feedback, the scenario framework remains the same as in FES 2022. All scenarios meet the relevant security of supply standards across the different fuels in every year.

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More on the Future Energy Scenarios

Consumer Transformation

The net zero target is met in 2050 with measures that have a greater impact on consumers and is driven by higher levels of consumer engagement. They will have made extensive changes to improve their home's energy efficiency and most of their electricity demand will be smartly controlled to provide flexibility to the system. A typical homeowner will use an electric heat pump with a low temperature heating system and an Electric Vehicle (EV). The system will have higher peak electricity demands managed with flexible technologies including energy storage, Demand Side Response (DSR) and smart energy management.

System Transformation

The net zero target is met in 2050. The typical domestic consumer will experience less change than in Consumer Transformation as more of the significant changes in the energy system happen on the supply side. A typical consumer will use a hydrogen boiler with a mostly unchanged heating system and an Electric Vehicle or a fuel cell vehicle. They will have had fewer energy efficiency improvements to their home and will be less likely to provide flexibility to the system. Total hydrogen demand is high, mostly produced from natural gas with Carbon Capture, Usage and Storage (CCUS).

Leading the Way

The net zero target is met by 2046. We assume that GB decarbonises rapidly with high levels of investment in world-leading decarbonisation technologies. Our assumptions in different areas of decarbonisation are pushed to the earliest credible dates. Consumers are highly engaged in reducing and managing their own energy consumption. This scenario includes more energy efficiency improvements to drive down energy demand, with homes retrofitted with measures such as triple glazing and external wall insulation, and a steep increase in smart energy services. Hydrogen is used to decarbonise some of the most challenging areas such as some industrial processes, produced mostly from electrolysis powered by renewable electricity.

Falling Short

This scenario does not meet the net zero by 2050 target. There is still progress on decarbonisation compared to today, however it is slower than in the other scenarios. While home insulation improves, there is still heavy reliance on natural gas, particularly for domestic heating. Electric Vehicle take-up grows more slowly, displacing petrol and diesel vehicles for domestic use. Decarbonisation of other vehicles is slower still with continued reliance on diesel for Heavy Goods Vehicles (HGVs). In 2050 this scenario still has significant annual carbon emissions, short of the 2050 net zero target.

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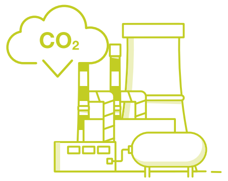
Key Message

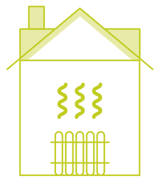
Policy and delivery

Measures to reduce uncertainty are needed to ensure the UK delivers a net zero whole energy system that is affordable and secure.

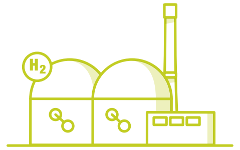
Recent global events have led to high energy prices and concerns over security of supply. Global economic pressure is increasing the need to reduce uncertainty for investors and consumers, and avoid delays in delivery and installation of net zero technologies.



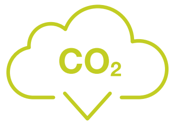
Hydrogen and gas CCUS power generation capacity reaches 12.3 GW by 2035 in System Transformation



Residential heat pump installations range from 0.3 million to 1.5 million per year across all scenarios in 2030

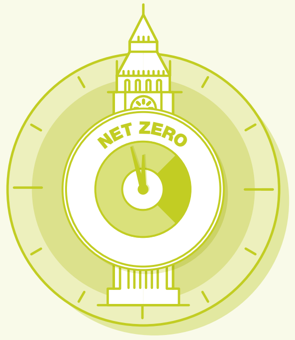


12-56 TWh of inter-seasonal storage is required aross our net zero scenarios in 2050



Removal of BECCS and DACCS from our net zero scenarios leaves residual emissions of 18-49 $MtCO_2e$ annually in 2050

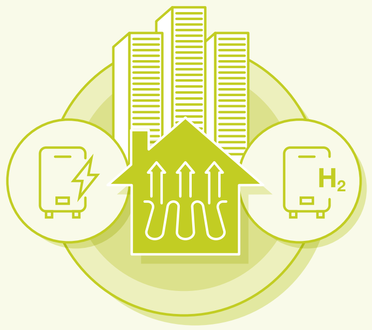
Key recommendations



Net zero policy

The Government must continue to reduce investment uncertainty around the business case for net zero critical technologies such as Long Duration Energy Storage (LDES), transport and storage of hydrogen and CO_2, low carbon dispatchable power and negative emissions technologies.

A clear plan is needed for the funding and development of hydrogen and Carbon Capture, Use and Storage projects beyond delivery of the first industrial clusters.

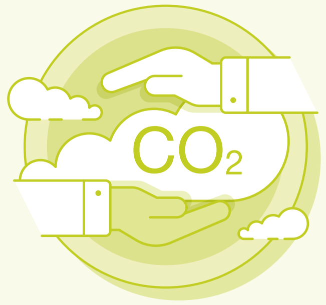


Focus on heat

There is a need to accelerate both the uptake of heat pumps and the decision on whether hydrogen will be used for large scale heating.

Further policy support and incentives are needed to increase uptake rates of heat pumps.

A clear decision on hydrogen for heating should be accelerated and heat pump targets and incentives reviewed accordingly.



Negative emissions

Negative emissions technology is required to enable a net zero whole energy system.

Robust emissions accounting standards are needed to ensure both investor and public confidence in a negative emissions market.

Further demonstration of innovative emissions reduction technologies is required to reduce uncertainties over technology and commercial readiness.

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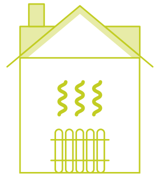
Key Message

2 Consumer and digitalisation

Consumer behaviour and digitalisation are pivotal to achieving net zero but easy access to information and the right incentives are critical.

Consumer engagement plays a crucial role in the transition towards a sustainable and secure whole energy system, while reducing energy costs. Provision of information and incentives enables consumers to become an active partner in the delivery of net zero.

A 9.5 TWh drop in electricity demand was seen between 2021 and 2022 in response to the cost of living crisis



Heat demand reduction of 127 TWh is achieved in Leading the Way in 2050 through higher building standards and behavioural change

The Demand Flexibility Service event on 23rd January 2023 delivered a 324 MW reduction in demand over a half hour period

Residential demand for lighting and appliances reduces to 47 TWh in Leading the Way in 2050

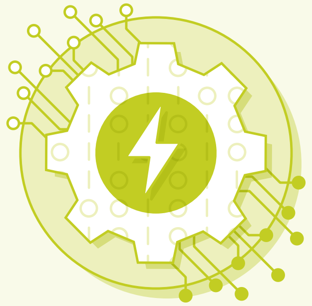
Key recommendations

Empowering change

There is a need to instil trust for consumers in energy markets and emerging technologies and services. Consumers must be guided on how they can best engage in the energy transition. This could be delivered through an information campaign, supported by a national advice service.

Ensuring transparent, comparable and simple information about products and services would enable consumers to benefit from cost savings and maximise the system benefits.

Consumers will be further incentivised to greater levels of demand reduction through market changes that simplify the consumer journey and reward flexible energy use.

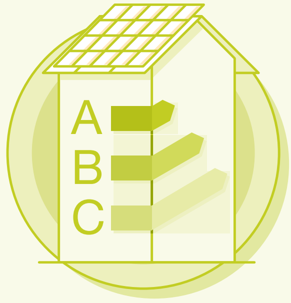


Digitalisation and innovation

Innovation and smart digital solutions are required to enable consumers to further benefit from energy savings at times when they are not able to manually adjust their demand. Key to this will be developing consumer trust in data privacy.

Smart digital solutions will enable effortless consumer participation in the delivery of a net zero whole energy system. Mandating technology manufacturers to include smart capability in their products is key to the delivery of smart homes.

Successful delivery of Market-wide Half Hourly Settlement will enable consumers to participate more readily in demand flexibility.



Energy efficiency

Further emphasis is needed to harness the potential of efficiency improvements in reducing energy demand. Energy efficiency improvements to the construction and technology within our homes must be accelerated.

Radical overhaul is required to achieve this both in new build and existing housing stock. Targets for minimum energy efficiency standards should extend beyond the private rented sector.

Additional incentives and grants must be considered to ensure energy efficiency improvements are available for more consumers.

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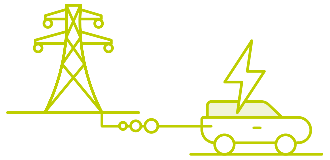
3 Key Message

Markets and flexibility

Improved market signals and new distributed flexibility solutions are key to managing a secure, net zero whole energy system at lowest cost to the consumer.

Delivery of the required growth in flexibility will depend on key enablers such as market reform, digitalisation and innovation.

47 GW of electricity storage is operating by 2050 in Consumer Transformation, with 18 GW connected at distribution level

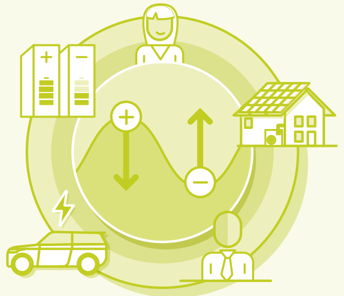


After the 2030s, V2G could contribute 20 GW of Demand Side Response in Leading the Way

Demand Side Response from residential, industrial and commercial consumers reaches over 13 GW in Consumer Transformation in 2050

Smart charging of EVs contributes a 60% reduction in peak demand in Leading the Way in 2050

Key recommendations

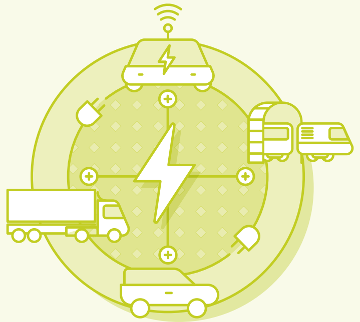


Distributed flexibility

The growth of distributed flexibility (flexible energy demand resources, such as storage, EVs, heat pumps and thermal storage, connected at distribution level) is a key enabler of net zero.

A market-wide strategy, including government targets, policy support and market reform is required to facilitate the significant growth in distributed flexibility.

This can also provide incentives for consumers to provide Demand Side Response, such as smart charging of EVs.



Transport flexibility

Across all future scenarios, cars are primarily electrified, increasing electricity demand and requiring strategies to manage how they are charged and how system costs are recovered.

Increasing implementation of smart EV charging is a low-regret action to help reduce the impact on peak demand and reduce curtailment of renewables.

Commercial trials of Vehicle-to-Grid (V2G) business models are required to explore their viability and contribution to system services. It also requires current challenges to be addressed, such as the slow rollout of charging infrastructure.

Locational signals

Market reform is needed to provide the real-time locational signals required to optimise decisions on when and where flexible energy sources are used.

Improving locational signals has the potential to deliver significant cost savings to consumers and support the delivery of decarbonisation targets.

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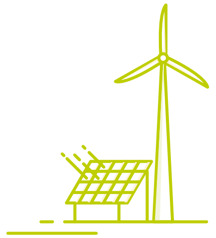
Key Message

4 Infrastructure and whole energy system

Benefits to the whole energy system must be considered to optimise the cost of delivering net zero technology and infrastructure.

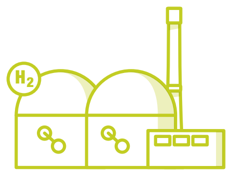
Strategic coordination and whole energy system thinking across all sectors is required to achieve decarbonisation targets and avoid unmanageable network constraints and potential curtailment.



Across the net zero scenarios, at least 89 GW of wind and solar is connected in 2030, with 119 GW in Leading the Way

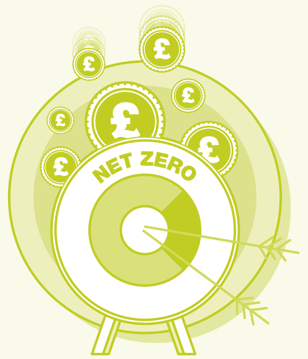
Between 7.6 and 21.3 TWh of electricity is curtailed in the net zero scenarios in 2030

There are over 38 GW of network-connected electrolysers in 2050 in Leading the Way



56 TWh of hydrogen storage is required in System Transformation by 2050

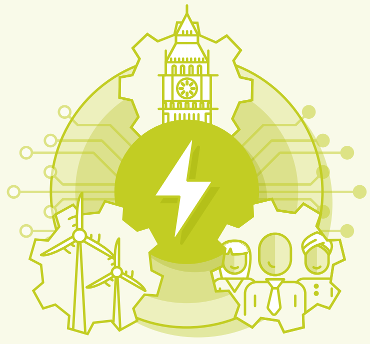
Key recommendations



Strategic network investment

Strategic and timely investment across the whole energy system is critical to achieving decarbonisation targets and minimising network constraints.

Accelerated coordinated planning and delivery of strategic, whole energy system investment through Centralised Strategic Network Planning (CSNP) will require continued collaboration and engagement with the Government, Ofgem, local communities, industry and the supply chain. Strategic network investment should be enabled through reforms to the planning system, while also balancing social and environmental impacts.



Connections reform

Connections reform is required to facilitate quicker, more coordinated and efficient connection to the GB electricity system to deliver net zero.

Continued collaboration between Government, Ofgem and industry is critical.

The process must be future-proofed to facilitate potential prioritisation of connections for delivery of whole energy system benefits and net zero in line with strategic network planning.

Location of large electricity demands

New large electricity demands, including electrolysers to convert electricity to hydrogen, will be required for net zero. This demand has significant potential to deliver whole energy system flexibility and reduced network constraints alongside decarbonisation.

A coherent strategy is required to ensure large electricity demands are located where they provide the biggest benefit to consumers and the whole energy system.

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The routes to net zero

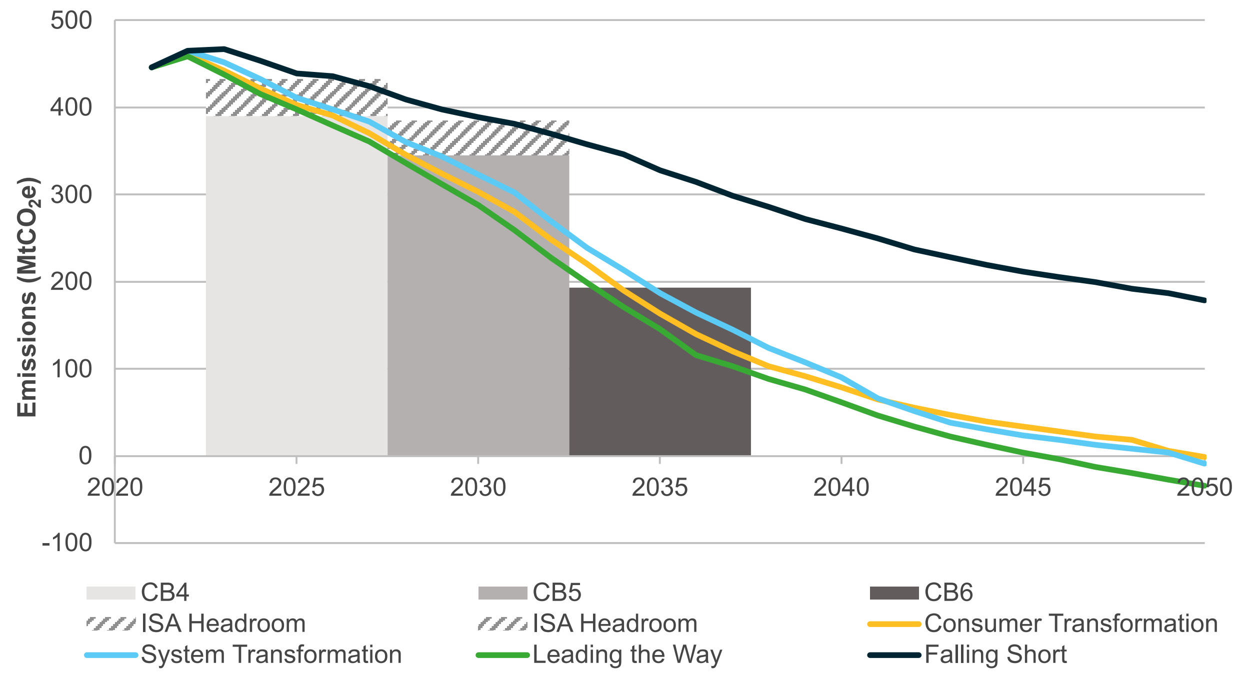
Our net zero scenarios show that it is possible to reach net zero before 2050. However, significant uncertainty remains in the delivery of key net zero technologies out to 2050, so it is critical to address these in the short-term. Bringing forward the decarbonisation of key levers to the transition, like the decarbonisation of heat, and acting now on no regret options, such as V2G, will reduce the risk of falling short.

Leading the Way reaches net zero by 2046 and achieves annual net emissions of -34 $MtCO_2e$ by 2050, which amounts to removal of Greenhouse Gas (GHG) emissions from the atmosphere. Consumer Transformation and System Transformation reach net zero by 2050. Falling Short does not get to net zero by 2050, resulting in 179 Mt of residual emissions.

Net zero power sector emissions are reached in 2034 for Leading the Way and Consumer Transformation: one year earlier than the 2035 target. System Transformation reaches net zero power sector emissions by 2035 and Falling Short in 2046.

It is important also to look at short-term progress, decisions, and policy implementation alongside long-term potential to get a view of current progress towards any one of our net zero scenarios. This varies across sectors and fuels but allows for additional commentary on what is needed for net zero. This informed the recommendations we set out in our Key Messages.

Figure 1. Total net GHG emissions including carbon budgets



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Key statistics

	2022	2030				2035				2050				
Emissions		CT	ST	LW	FS	CT	ST	LW	FS	CT	ST	LW	FS	**Emissions**
Annual average carbon intensity of electricity (g CO_2/kWh)	183	66	68	38	104	-14	0	-7	50	-41	-40	-13	-10	Annual average carbon intensity of electricity (g CO_2/kWh)
Net annual emissions ($MtCO_2e$)	463	303	323	288	389	164	187	145	328	-1	-9	-34	178	Net annual emissions ($MtCO_2e$)
Electricity														**Electricity**
Annual demand (TWh)[1]	286	344	325	369	326	467	400	479	373	726	678	671	570	Annual demand (TWh)[1]
Electricity demand for heat (TWh)	19	27	21	28	24	43	21	45	30	80	60	65	69	Electricity demand for heat (TWh)
Peak demand (GW)[2]	58	69	63	63	67	87	73	82	78	113	101	98	114	Peak demand (GW)[2]
Total installed capacity (GW)[3]	112	187	172	207	159	266	225	287	189	386	344	387	285	Total installed capacity (GW)[3]
Wind and solar capacity (GW)	35	102	89	119	70	158	134	178	94	239	213	249	149	Wind and solar capacity (GW)
Interconnector capacity (GW)	7	12	12	17	12	19	16	24	15	21	16	27	16	Interconnector capacity (GW)
Total storage capacity (GW)[4]	3	21	17	31	13	37	20	52	15	64	41	72	26	Total storage capacity (GW)[4]
Total storage capacity (GWh)[5]	29	60	51	118	44	116	59	149	47	166	116	197	62	Total storage capacity (GWh)[5]
Total vehicle-to-grid capacity (GW)[6]	0	2	0	3	0	14	1	28	0	34	16	39	8	Total vehicle-to-grid capacity (GW)[6]
Natural Gas														**Natural Gas**
Annual demand (TWh)[7]	986	571	671	533	828	384	581	331	700	29	364	74	513	Annual demand (TWh)[7]
1-in-20 peak demand (GWh/day)	5550	3985	4823	3368	5331	2593	3858	1987	4950	282	2086	509	3962	1-in-20 peak demand (GWh/day)
Residential demand (TWh)[8]	311	240	276	227	325	151	204	117	294	0	1	0	147	Residential demand (TWh)[8]
Imports (TWh)	598	411	460	353	559	285	422	227	436	25	358	55	356	Imports (TWh)
Hydrogen														**Hydrogen**
Annual demand (TWh)	0	3	38	40	1	19	151	80	3	120	446	242	14	Annual demand (TWh)
Residential hydrogen demand for heat (TWh)	0	0	0	5	0	0	49	14	0	0	119	29	0	Residential hydrogen demand for heat (TWh)
CCS enabled hydrogen production (TWh)[9]	0	0	25	7	0	1	104	26	1	1	218	26	6	Blue hydrogen production (TWh)[9]
Electrolytic hydrogen production (TWh)[10]	0	3	11	32	1	17	26	48	2	111	175	177	8	Green hydrogen production (TWh)[10]
Bioresources														**Bioresources**
Bioresource demand (TWh)	127	103	113	147	130	169	156	139	137	219	228	160	148	Bioresource demand (TWh)

1. Customer demand plus on-grid electrolysis meeting GB hydrogen demand only, plus losses, equivalent to GBFES System Demand Total in ED1 of data workbook.
2. Refer to data workbook for further information on winter average cold spell (ACS) peak demand.
3. Includes all networked generation as well as total interconnector and storage capacity (including vehicle-to-grid available at winter peak).
4. Includes vehicle-to-grid capacity available at winter peak.
5. Excludes vehicle-to-grid.
6. Less capacity will be available during winter peak 5-6pm due to vehicle usage.
7. Includes shrinkage, exports, biomethane and natural gas for methane reformation.
8. Residential demand made up of biomethane and natural gas.
9. Blue hydrogen is created using natural gas as an input, with CCUS.
10. Green hydrogen is created via electrolysis using zero carbon electricity (this figure does not include hydrogen produced directly from nuclear or bioenergy).

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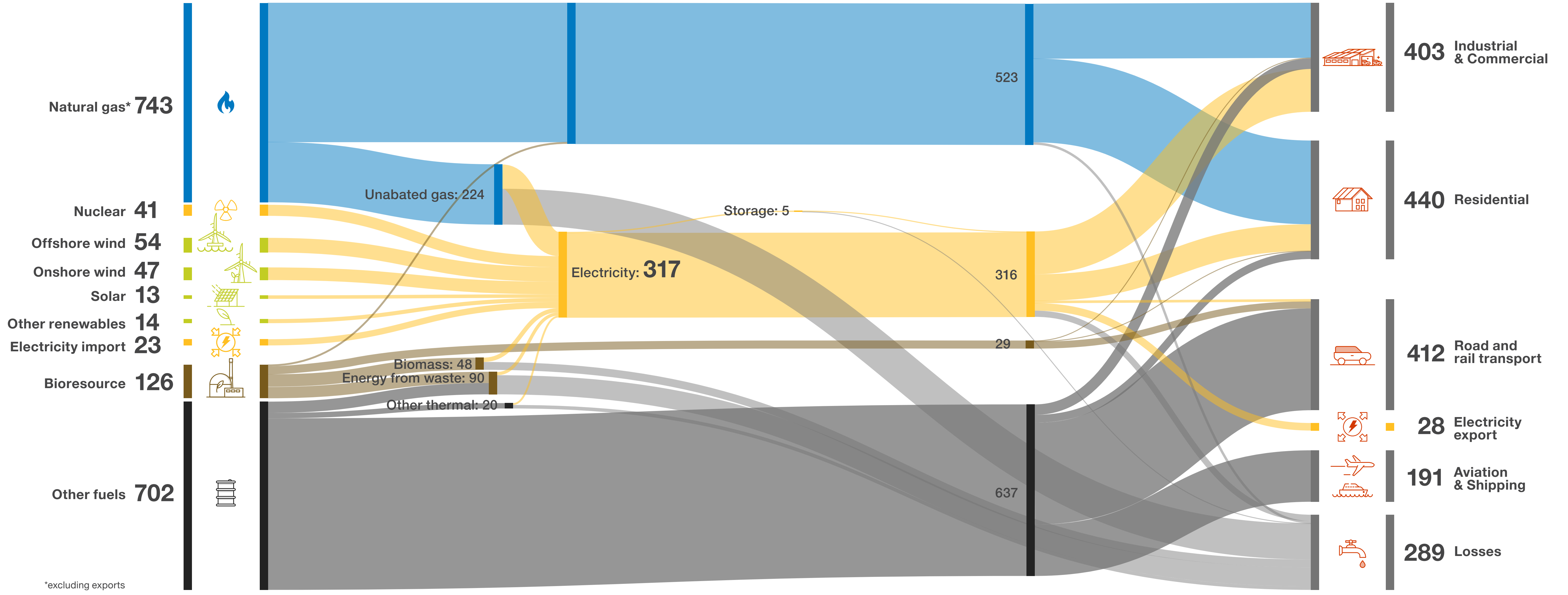
Energy supply and demand

2022 (1763 TWh)

- Fossil fuels make up 82% of total energy supply in 2022
- Petroleum supplies 93% of road transport demand and 100% of aviation and shipping demand
- Interactions between different fuels are low, demonstrating limited whole system thinking



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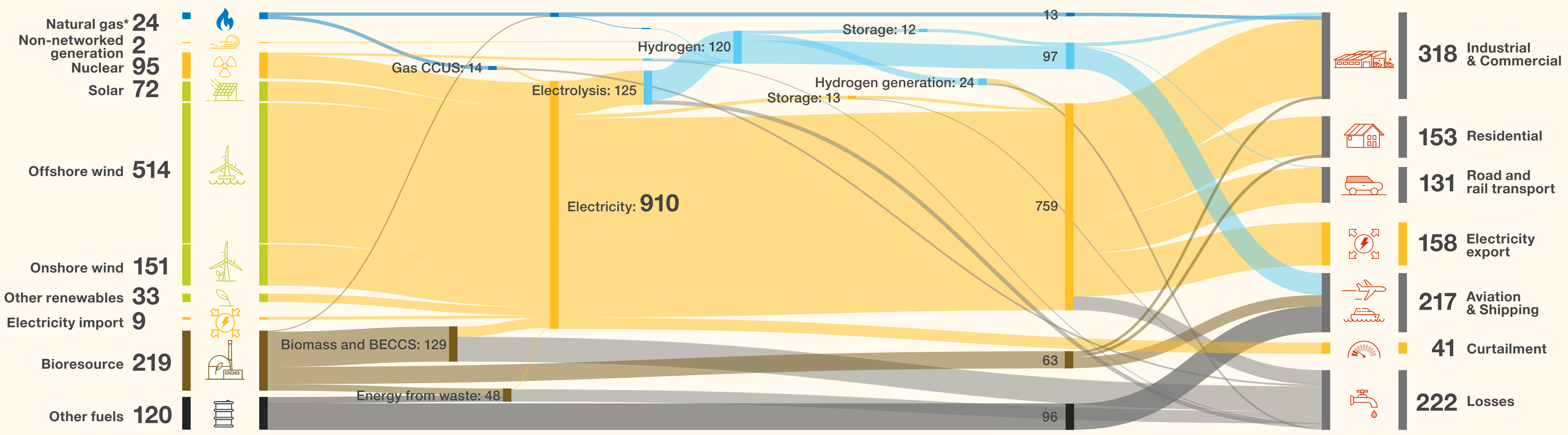
Energy supply and demand in 2050

Consumer Transformation (1239 TWh)

- Home heating, transport and industry largely electrified
- High levels of energy efficiency combined with large-scale electrification lead to lowest consumer energy demands across the scenarios excluding aviation
- High levels of renewable generation with low hydrogen production leads to the highest levels of electricity curtailment and export of any of the scenarios
- Two thirds of hydrogen produced is used in aviation, with another 20% used for electricity generation, to help meet security of supply



*excluding exports

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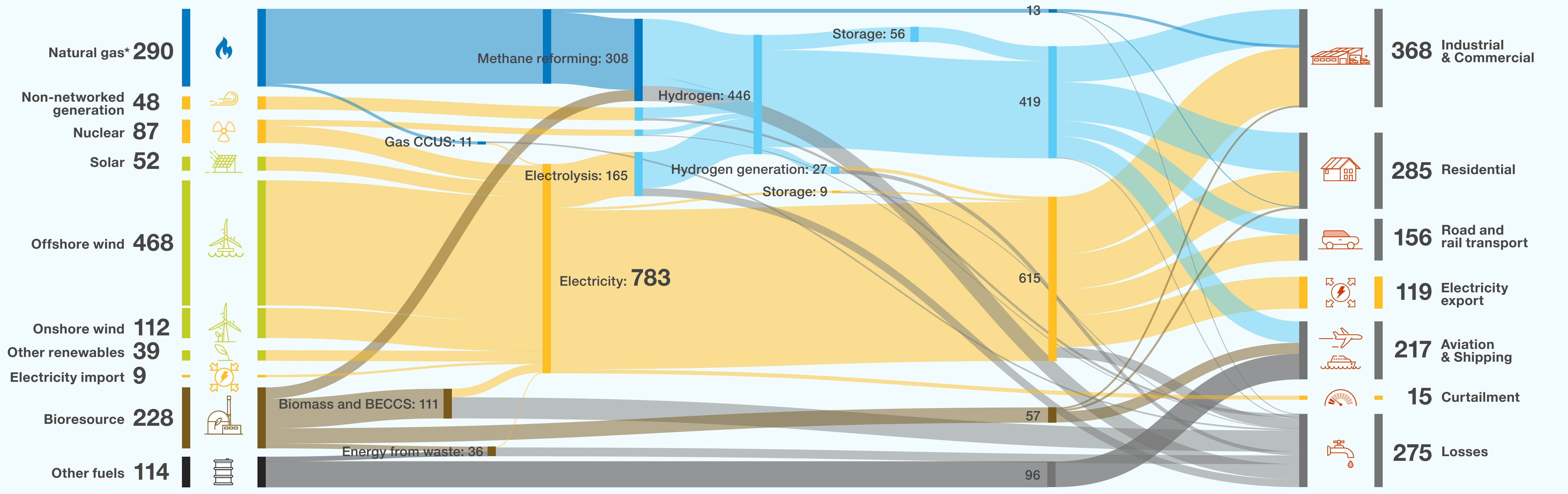
Energy supply and demand in 2050

System Transformation (1447 TWh)

- Highest proportion of hydrogen across the scenarios with widespread use for home heating, industry and HGVs
- High natural gas use for hydrogen production from methane reformation
- Highest level of bioresource use - bioenergy used to produce both hydrogen and electricity, mostly alongside CCUS for negative emissions
- Electricity production more than double that of today, partly to meet highest demand for electrolysis



*excluding exports

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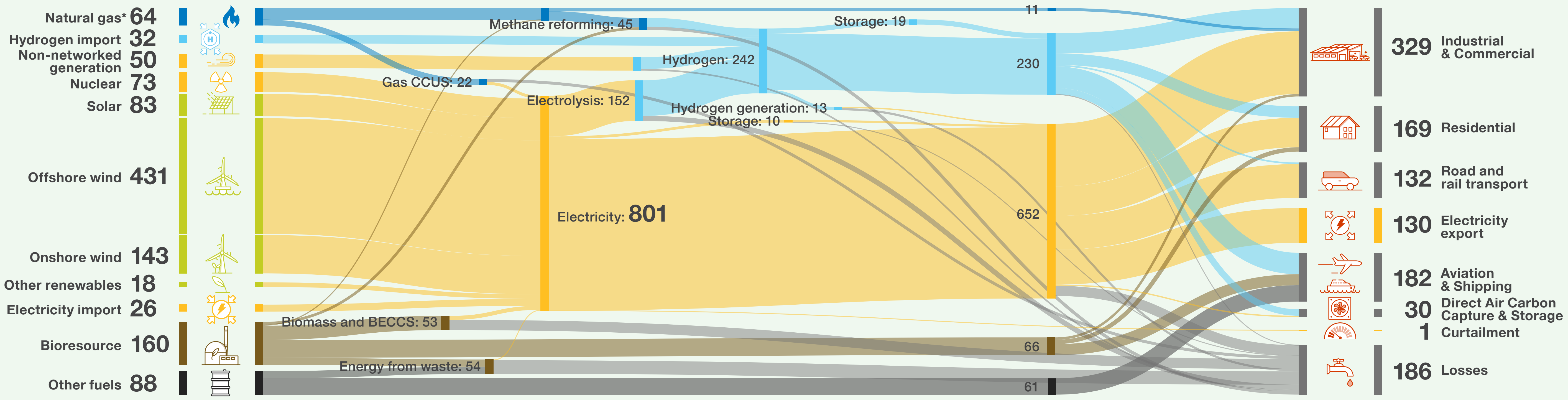
Energy supply and demand in 2050

Leading the Way (1167 TWh)

- Combination of hydrogen and electricity used in industry and to heat homes
- Lowest level of electricity curtailment across the scenarios, due to the highest level of flexibility
- Lower bioresource use for negative emissions due to emissions reduction from land use change and Direct Air Carbon Capture and Storage (DACCS)
- Zero carbon fuels meet two thirds of aviation demand



*excluding exports

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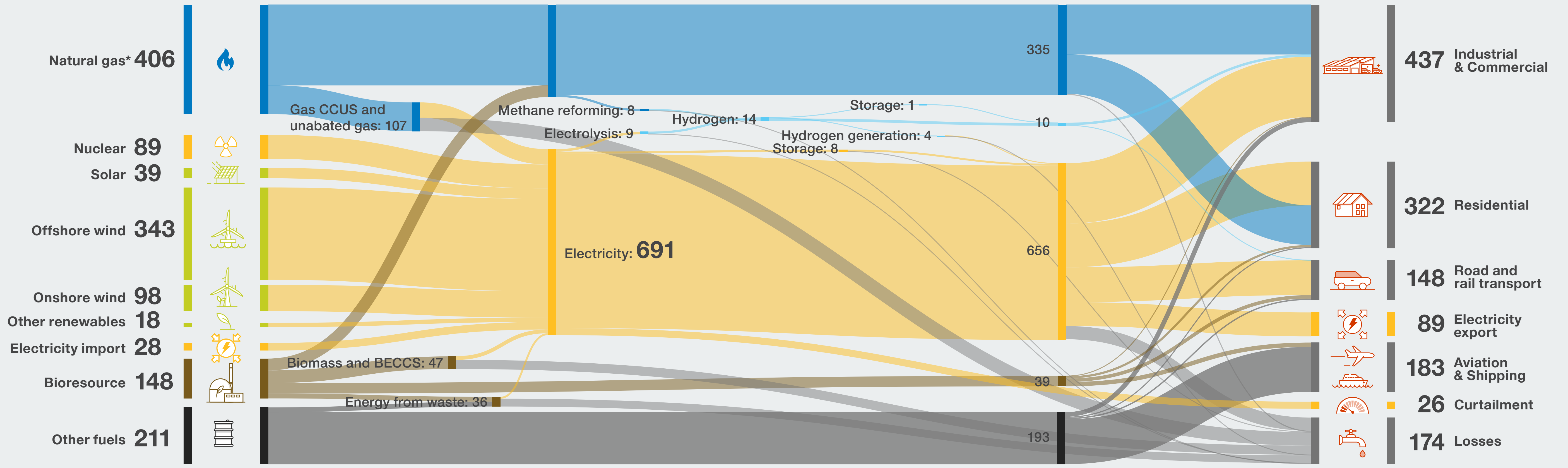
Energy supply and demand in 2050

Falling Short (1380 TWh)

- Continued high usage of natural gas, particularly for domestic heating and industry
- Small private vehicles fully electrified (including some plug-in hybrids) whilst HGVs rely on fossil fuels
- Low use of hydrogen as production isn't decarbonised
- Highest total end-user energy demand due to minimal increase in energy efficiency measures and reliance on inefficient fossil fuels



*excluding exports

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Introduction to the FES

ESO

Introduction

As we live through the uncertainty caused by recent global events, the challenge of tackling climate change remains. This is now viewed against a backdrop of increased gas and oil prices, geopolitical insecurity and a high cost of living.

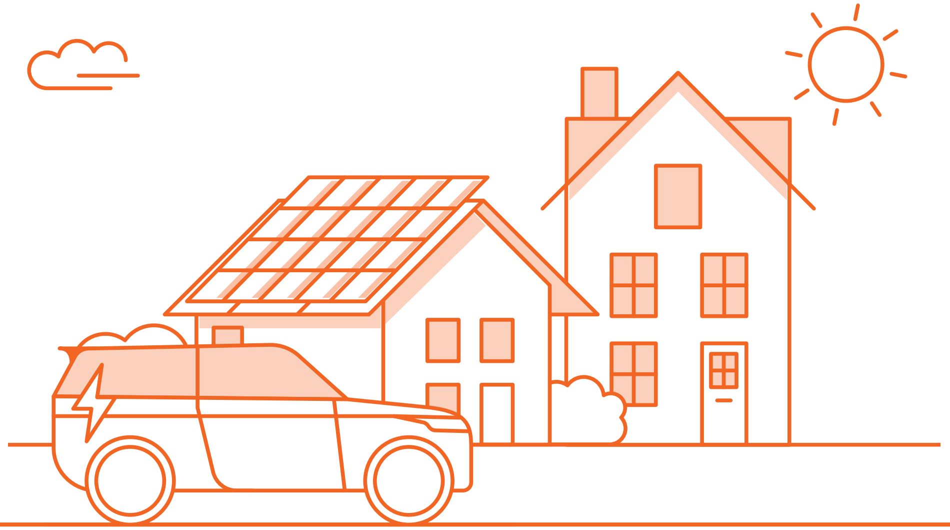
2022 was a critical year, both in the UK and internationally, for climate action, and we are all witnessing the impacts of climate change today. We saw the world come together in Sharm el-Sheikh for COP27 and the conclusion was that all countries are required to make an extra effort to address climate change – starting now.

In March 2023, the United Nation's Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report (AR6 Synthesis Report),[1] as a final warning to the world on climate change. The previous IPCC report, delivered almost a decade prior, warned of the need to keep the global temperature rise under 1.5 °C (from pre-industrial levels) and led to the landmark Paris Agreement at COP21 (December 2015). This latest report is a rallying call to the nations of the world that it is not too late to keep the temperature rise below this critical level, but there has been a lack of progress since the Paris Agreement. To make up for this, the global transition to net zero will now need to be accelerated. UN Secretary-General António Guterres called for developed nations to aim to reach net zero by 2040, at the latest. If this call is heeded, it is critical that we see more ambitious climate plans emerge at the COP28 at the end of this year.

In the UK, the government is taking actions to enable a net zero transition through its policies and regulations but there is still significant progress to be made. In 2023, the Department of Energy Security and Net Zero (DESNZ) was created to strengthen the UK's long-term energy security, and further UK energy independence to help deliver a clean and prosperous future for the country. This will also be further supported by ESO's Net Zero Market Reform (NZMR) programme, which examines holistically the changes required to the current UK electricity market design to achieve net zero.

'Powering Up Britain', recently announced by the UK government, outlines plans to improve energy security, mobilise green investment and deliver net zero commitments.[2] The plans include the vital role that the Future System Operator (FSO) will play to deliver energy security and net zero across the whole energy system. The FSO will play an important role in coordinating and ensuring strategic planning across the sector, with an ambitious long-term vision and independent provision of advice to government and Ofgem. The FSO will adopt a 'whole energy system' approach through responsibilities in operation, strategic network planning, long-term forecasting, and market strategy. Through these roles, the FSO will drive progress towards net zero while maintaining energy security and reducing costs for consumers.

The above initiatives will help provide economic incentives for investment and change in the UK as we transition towards a net zero world, but even more action is needed as set out in the Future Energy Scenarios (FES) Key Messages.



1 ipcc.ch/report/ar6/syr/
2 gov.uk/government/publications/powering-up-britain

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Introduction

In the face of the unprecedented changes seen in the UK and around the world, it has become clearer that the transition to an energy system supplied predominantly by weather dependent sources, and a reformed market to underpin it, will deliver many benefits. High levels of renewables can help deliver net zero while also addressing the cost of living crisis that we see today. For the first time, we saw millions of consumers participating in Demand Side Response (DSR) as a real-service, through the Demand Flexibility Service (DFS), launched by the ESO (Electricity System Operator) during November 2022.

Through analysis and insights from our Future Energy Scenarios, achieving a net zero energy system by 2050 is possible and credible, but urgent actions and change are needed to get there. Through our Future Energy Scenarios, we bring together the latest insights from across the market, stakeholders, and policy announcements, as well as from our own supply and demand modelling, to dive deeper into the transformation required across society and infrastructure. The benefits are already clear – it is increasing momentum on delivery that is critical.

Recent global events have impacted the energy industry significantly and we saw the cost of electricity and gas reach an all-time high in September 2022. This rise in prices led to a reduction in demand which may appear to show more progress towards net zero than is the reality. Considering this, we took a close look at the short-term and include additional commentary around what we see in our scenarios over the next 5 years.

At the ESO, we are dedicated to enabling the transition while continuing to provide the highest levels of reliability and value for our consumers. We believe reaching net zero by 2050 is possible, if we work with government, the regulator, industry and consumers to reduce our emissions and deliver a clean, reliable, and fair energy system for all.

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What are the Future Energy Scenarios?

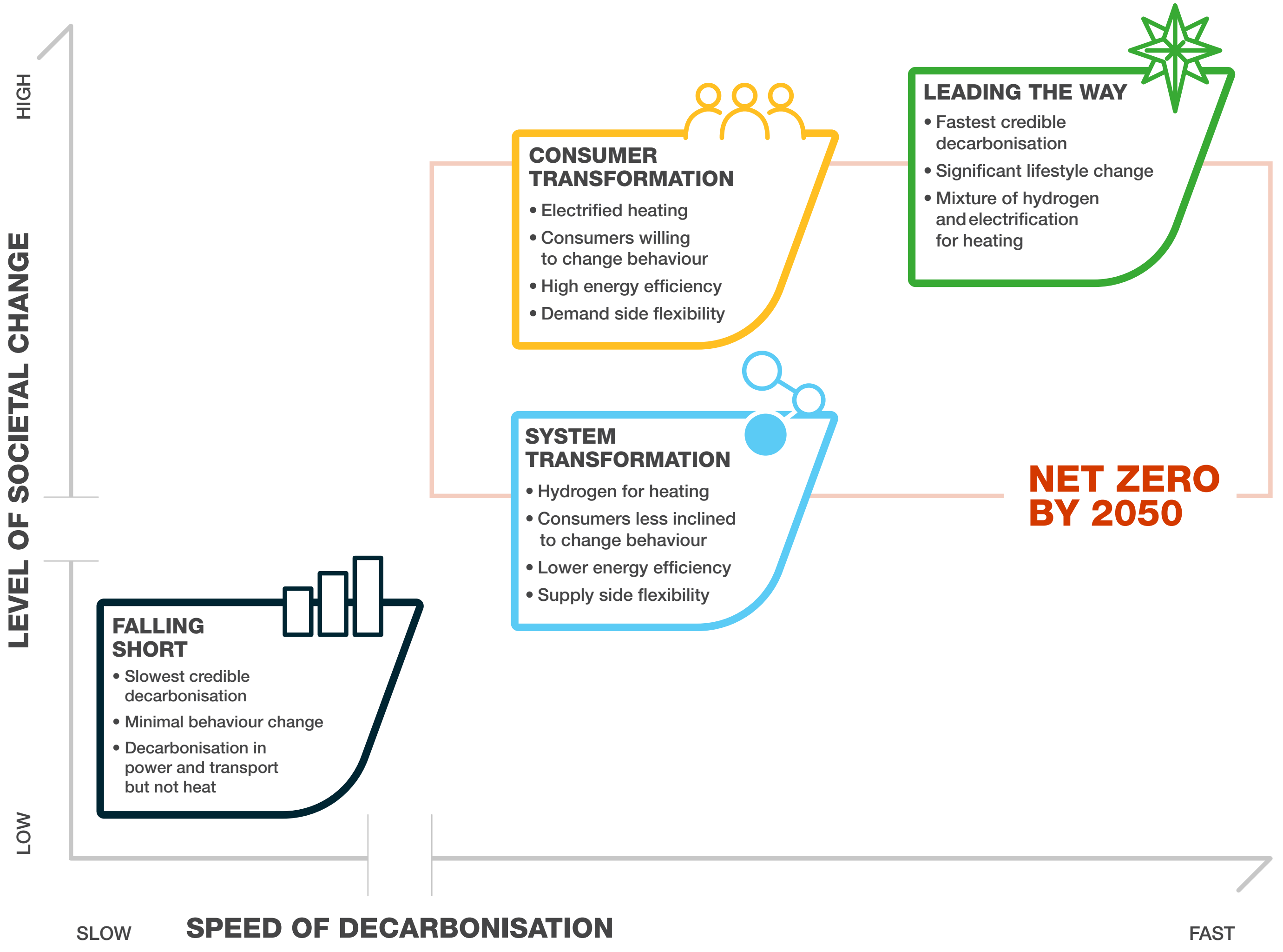
Scenario Framework

Our Future Energy Scenarios explore how the energy system could change between now and 2050. They analyse how the energy system might transform to meet the UK's net zero target, through changes in infrastructure, technology, innovation, and consumer behaviour.

In FES 2023, we use four scenarios to show the credible range of possibilities for the future of energy between now and 2050. The 'societal change' axis combines innovation, engagement, and other possible changes. Due to stakeholder feedback and our own internal analysis, this scenario framework has remained broadly consistent[3] since FES 2020. Recent global events have impacted the energy industry, highlighting the need for a more focused view of the energy system in the short-term based on current progress, policy, and project pipelines.

Consumer Transformation and System Transformation represent two different ways to reach net zero by 2050 – either by changing the way we use energy or by changing the way in which we generate and supply it. Leading the Way describes our fastest credible decarbonisation journey, achieved through a combination of high consumer engagement with world leading technology and investment – allowing Great Britain (GB) to reach net zero before 2050.

Three scenarios (System Transformation, Consumer Transformation and Leading the Way) reach net zero by 2050. Falling Short represents our slowest credible speed of decarbonisation and does not reach net zero by 2050. Falling Short has residual emissions of 179 $MtCO_2e$ annually in 2050. While this is significant against 1990 levels, it is far from reaching net zero.[4]



3 This year the main changes against FES 2022 are presented in the subsequent sections and chapters, rather than in a standalone document
4 An 80% reduction was the UK's emission target prior to net zero being legislated in 2019 and highlights how decarbonisation ambition has progressed in recent years

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More on the Future Energy Scenarios

Consumer Transformation

The net zero target is met in 2050 with measures that have a greater impact on consumers and is driven by higher levels of consumer engagement. They will have made extensive changes to improve their home's energy efficiency and most of their electricity demand will be smartly controlled to provide flexibility to the system. A typical homeowner will use an electric heat pump with a low temperature heating system and an Electric Vehicle (EV). The system will have higher peak electricity demands managed with flexible technologies including energy storage, Demand Side Response (DSR) and smart energy management.

System Transformation

The net zero target is met in 2050. The typical domestic consumer will experience less change than in Consumer Transformation as more of the significant changes in the energy system happen on the supply side. A typical consumer will use a hydrogen boiler with a mostly unchanged heating system and an Electric Vehicle or a fuel cell vehicle. They will have had fewer energy efficiency improvements to their home and will be less likely to provide flexibility to the system. Total hydrogen demand is high, mostly produced from natural gas with Carbon Capture, Usage and Storage (CCUS).

Leading the Way

The net zero target is met by 2046. We assume that GB decarbonises rapidly with high levels of investment in world-leading decarbonisation technologies. Our assumptions in different areas of decarbonisation are pushed to the earliest credible dates. Consumers are highly engaged in reducing and managing their own energy consumption. This scenario includes more energy efficiency improvements to drive down energy demand, with homes retrofitted with measures such as triple glazing and external wall insulation, and a steep increase in smart energy services. Hydrogen is used to decarbonise some of the most challenging areas such as some industrial processes, produced mostly from electrolysis powered by renewable electricity.

Falling Short

This scenario does not meet the net zero by 2050 target. There is still progress on decarbonisation compared to today, however it is slower than in the other scenarios. While home insulation improves, there is still heavy reliance on natural gas, particularly for domestic heating. Electric Vehicle take-up grows more slowly, displacing petrol and diesel vehicles for domestic use. Decarbonisation of other vehicles is slower still with continued reliance on diesel for Heavy Goods Vehicles (HGVs). In 2050 this scenario still has significant annual carbon emissions, short of the 2050 net zero target.

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FES in the short-term

It is important to consider the ongoing challenges in the energy landscape to understand the actions that need to happen in the next critical decade to achieve the net zero transition.

Recent global events have impacted the energy industry significantly and we saw the cost of electricity and gas reach an all-time high in September 2022. This rise in prices led to a reduction in demand which may appear to show more progress towards net zero than in reality.

Energy prices

The cost of living crisis, rising inflation and the spike in energy bills seen in 2022 have put added pressure on consumer budgets, pushing more people into fuel poverty. Commercial businesses and industry are also affected. This limits the investment in smart technologies, which are crucial to deliver a resilient, reliable, and decarbonised energy system.

From a modelling perspective, the higher energy prices do not change our long-term projections significantly, as high gas prices were already modelled based on increases in energy prices through to last autumn. We use price forecasts from third party experts combined with stakeholder feedback to understand the impacts of these price changes on energy demand and supply. While the data used in our demand modelling reflected potential increasing prices, the situation continued to change during our modelling process. We will continue to consider the implications of significant price changes and associated demand impacts in our future publications.

Changes in behaviour

Consumers being enabled to engage with the energy system is crucial to unlocking flexible supply and demand and achieving net zero in the most cost-effective way. Investment in digitalisation, automation and the right market signals is vital for this engagement to happen, and needs to happen in the next decade. The extent to which consumers are willing and able to change their behaviour and lifestyle to enable the net zero transition still has a high level of uncertainty. Our scenario framework considers what levels of societal change might be possible. This year we explain further factors which enable or inhibit change in the short-term, and how they may evolve over time.

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Long-term policy and funding

We have taken a deeper look at the main long-term policy plans, including technology and funding, and their impact on our scenarios.

Government policy

The Climate Change Committee (CCC) publication on a resilient, reliable, and decarbonised electricity supply system[5] by 2035 highlights the need for investment in low carbon flexible solutions now, so that they can deliver and contribute to addressing the system needs in the 2030s. This will also gradually reduce the UK's dependence on imported oil and gas, reducing, in turn, the exposure to volatile international prices. Attention was also paid to the need for development of new business models for hydrogen transportation and storage infrastructure in the short-term, so that the options are ready for larger scale hydrogen use by 2030.

In March 2023 the government published the 'Powering Up Britain' strategy, a new plan for delivering net zero. The plan builds on the ambitions set out in the British Energy Security Strategy and the Net Zero Strategy to deliver a secure, reliable, and clean transition.

These policies and publications inform our scenario assumptions and, as discussed in the chapter overviews, compare progress against policy timelines for each of the scenarios. If a policy milestone is not met, this does not mean it is unfeasible but may indicate that policy and market dynamics within that scenario do not fully support it.

Technology and funding

Rising inflation has increased uncertainty for project developers and for manufacturers of technologies, such as Electric Vehicles, heat pumps and solar panels. This offsets some of the capital cost reductions that have been seen in these technologies in recent years and has also put additional pressure on developers to proceed with financial investment decisions. In addition, the cost of living crisis has put added pressure on consumer affordability of smart technologies, despite them being crucial to deliver a resilient, reliable, and decarbonised energy system.

We continue to see advances in existing technology, but also in some which have the potential to be part of the whole energy system in the future. We consider which technologies to include in FES based on both technical and commercial readiness level, where they are now, and where we expect them to be in future. Political appetite is also one of the factors accounted for through the 'level of societal change' axis of the scenario framework.

5 theccc.org.uk/publication/delivering-a-reliable-decarbonised-powersystem/

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Continuous improvements

The role of FES

FES is widely used by the ESO and our stakeholders across the energy industry to:

- Underpin energy network investment
- Support financial investment decisions for net zero technologies
- Inform national and regional policy
- Carry out academic research and innovation

Stakeholder Engagement

We continue to engage with a broad range of stakeholders, ensuring a rich and varied input to our modelling.

For FES 23 we engaged with **1,516 stakeholders** including bilateral meetings, our new Topic Table Talks event and our Call for Evidence (CfE).[6]

Stakeholder categories included communities, consumers and consumer groups, energy industry, innovators, Non-Governmental Organisation (NGO), academia, policy makers, the regulator and network operators.

Modelling and Insight

We continue to improve our regional insights by providing more regional spotlights in FES 2023.

We also provide additional insights, such as tipping points between hydrogen and electrification of heat, and system response during an extreme weather period.

We took a deeper look into the short-term and include additional commentary on where we are heading alongside our four scenarios.

Publication

Alongside this document, we have published further supporting documents on the ESO website:

- FES 2023
- FES in Five
- NEW: Energy Background Document (EBD)[7]
- Data Workbook
- Scenario Assumptions
- Modelling Methods

6 nationalgrideso.com/document/277071/download
7 The main purpose of the Energy Background Document is to provide supplementary content and background to support the main FES 2023 document

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Who is using FES?

Our Future Energy Scenarios are used for a number of regulated activities and referenced by a wide range of energy industry participants and stakeholders

How & Where FUTURE ENERGY SCENARIOS are used

REGULATED ENERGY SYSTEM ACTIVITIES

OPERABILITY
- Distribution System Operability Framework
- System Operability Framework
- Gas Markets Plan
- Gas Future Operability Planning

NETWORK INVESTMENT
- Network capability
- Network Options Assessment
- Centralised Strategic Network Plan
- Price controls
- Holistic Network Design
- National & local planning
- European electricity and gas operators also use FES data for their ten year development planning (Electricity, Gas)

SECURITY OF SUPPLY
- Ten year statements (Electricity, Gas)
- Electricity Capacity Market
- Winter & summer outlooks (Electricity, Gas)

KEY STAKEHOLDERS

PRIVATE SECTOR & ENERGY INDUSTRY
- Energy and low carbon industries
- Generators & flexibility providers
- Suppliers
- Independent thought leaders
- Shippers & producers
- Energy systems catapult

POLICY & REGULATION
- Department of Energy Security and Net Zero
- Local & central government
- Academia, research and innovators
- Ofgem
- Climate Change Committee
- Consumer Groups

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FES Users

NETWORK INVESTMENT

Network capability
Assessment of the capability of the gas network.

Network Options Assessment (NOA)
NOA uses the scenarios in its economic analysis of network reinforcements. It also uses them to calculate the optimum levels of interconnection between GB and European markets.

Price controls
Ofgem and RIIO2.

National & local planning
National Gas has a licence obligation to forecast gas demand for the National Transmission System (NTS) and the Local Distribution Zones (LDZ). FES data informs this process.

European electricity and gas operators also use FES data for their ten year development planning.
Electricity: ENTSOE
Gas: ENTSOG

Ten Year Statements
Electricity and Gas Ten Year Statements (ETYS and GTYS) are used for investment planning by System Operators (SOs) and Distribution Network Owners (DNOs).

Holistic Network Design
HND has a strong focus on improvements to how we connect offshore generation to the onshore network and the overall coordination of network reinforcement to facilitate 2030 government offshore wind targets.

Centralised Strategic Network Plan
CSNP is designed to facilitate the strategic development of an efficient, co-ordinated and economical system of electricity transmission and the development of whole energy system. The CSNP will be developed and implemented over the next few years.

SECURITY OF SUPPLY

Electricity Capacity Market (ECM)
The Electricity Capacity Report recommends to DESNZ the amount of capacity to secure through auction.

Winter & summer outlooks
The outlook reports look at the coming six months, assessing any potential issues or opportunities for both gas and electricity.

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FES Users

POLICY & REGULATION

Ofgem
The production of FES is a licence obligation of National Grid Electricity System Operator set by Ofgem, to help them understand how the energy industry might develop in Great Britain.

Local & central government
For example, Office for Low Emission Vehicles (OLEV), Department for Transport (DfT) and Department for Environment, Food and Rural Affairs (DEFRA).

Department of Energy Security and Net Zero
The Department of Energy Security and Net Zero refers to FES when considering new energy policy.

Climate Change Committee
CCC produce pathways for decarbonisation.

Academia & research
Universities are active contributors to the development of FES and our work also informs their research.

Consumer groups
Ranging from large industrial plants to residential houses, consumers are the direct users of energy.

PRIVATE SECTOR & ENERGY INDUSTRY

Shippers & producers
Gas shippers and producers look at FES to understand how their markets might evolve over time.

Suppliers
Energy suppliers look at FES to understand how their markets might evolve over time.

Generators & flexibility providers
FES is used to help assess how muchn investment to make in generation and flexibility facilities.

Energy Systems Catapult
Energy Systems Catapult works towards ways to decarbonise energy.

Independent thought leaders
Changes to energy supply and use is a topic of much debate by independent observers and think tanks.

Energy and low carbon industries
This includes a wide range of stakeholders and activities such as Research & Development (R&D) and innovation. Industries include major energy users (incl. power stations, steel etc), vehicle manufacturers, heat pumps, insulation thermal stores, house builders and investment banks.

OPERABILITY

Gas Future Operability Planning
Gas network operability planning by National Gas.

System Operability Framework (SOF)
SOF combines insights from FES with technical assessments to identify medium-term and long-term requirements for operability.

Gas Markets Plan (GMaP)
GMaP considers market change over a ten-year time frame.

Distribution System Operability Framework
Distribution Network Operators also produce SOFs.

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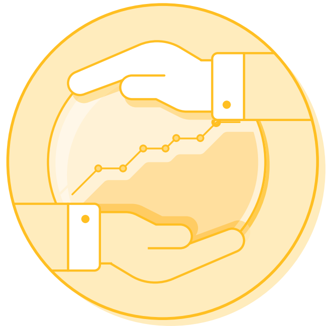
Regionalisation

Regionalisation allows us to understand what FES means for different areas and local communities. This improves the UK's potential to meet our net zero commitments through models that more accurately reflect local requirements and plans.

Regionalisation is about the whole energy system

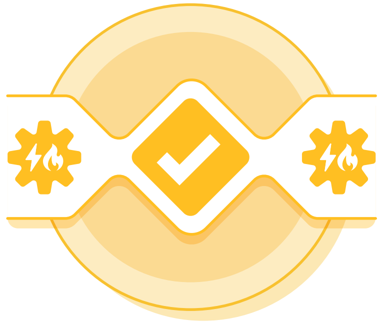


Regionalisation is collaborative

We are working closely with energy companies and other stakeholders, including local decision makers, to understand the challenges and opportunities in particular areas and where these may differ from the national picture. We have started to take a more "bottom-up" approach, where regional data is directly incorporated into our national models. In some cases, this has been vital, for example in predicting how hydrogen or district heat networks may be seeded and grow. We are also keen to continue our conversations with local stakeholders to provide better information for policy and investment decisions that align with our scenario projections and are both ambitious yet achievable.

Regionalisation of FES will simplify and optimise the interface between the scenarios, data, and assumptions developed by gas and electricity network companies, for example the Distributed Future Energy Scenarios (DFES). The FES does not replace regional scenario projections, but it is valuable as a common framework for scenario planning. We also need to compare our outputs and explain where and why we have differences between projections at a national and local network level. Our stakeholder engagement also highlighted the importance of us reflecting national best practice across regions and in championing the need for open data and methods.

Better insights for better decisions



More consistent and transparent outputs

Greater granularity for targeted solutions

We are often asked for increasingly granular datasets and projections so that geographical areas can better understand what net zero could mean for them. Improving our data and insights enables us to model spatial and temporal variations to a greater level of accuracy and comparability. As an example, this year we are providing a series of regional spotlights alongside our central FES narrative.

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Net Zero

ESO

Reaching net zero Greenhouse Gas (GHG) emissions by 2050 is critical to limiting the negative impacts of climate change. Climate scientists are emphasising the urgent need to reduce emissions for the future of society, with some of the impacts of climate change already being witnessed today.

The effects of climate change are already being seen, with parts of the UK hit with drought, 40°C heat waves and forest fires in summer 2022. These types of events have severe environmental, economic, and social consequences. It is critical to implement a net zero whole energy system to reduce GHG and minimise consequences of climate change.

In this chapter, we look at the potential emissions reductions across our Future Energy Scenarios (FES). Due to the significant challenge of decarbonisation in some sectors like aviation, shipping and agriculture, negative emissions are required in the energy sector to deliver a net zero economy. This year, we carried out additional sensitivity analysis to further examine the role of negative emissions technology in achieving a net zero whole energy system.

Changes to international emissions calculation methodology led to a reduction in forecast emissions compared to FES 2022. We look at these methodology changes and which areas they impact most in more detail later in this chapter.

FES 2023 / Net Zero 32

Introduction

In February 2023, a new government body, the Department of Energy Security and Net Zero (DESNZ), was created with the remit to deliver net zero while ensuring the UK's energy security and independence. The revised UK energy strategy 'Powering Up Britain' plan was announced in March 2023, with the explicit intention to enhance our country's energy security, seize the economic opportunities of the transition, and deliver on our net zero commitments.[1]

Environmental and net zero obligations remain high on the UK's agenda, but the war in Ukraine and resulting high cost of living has brought energy independence and cost of energy to consumers into sharp focus. Net zero policy announcements, which form part of Powering Up Britain, are shown in the graphic on the following page.

There was a high degree of debate at COP27 over the pace of transition towards low carbon fuels. Specifically, there was resistance towards a strengthening of proposals for phasing out unabated coal, as well as the inclusion of natural gas in 'low carbon' generation enhancement plans. This position is linked to the global post COVID-19 economic turmoil and energy supply uncertainty caused by the conflict in Ukraine. Globally, concerns over near-term affordability and energy security appear to be impacting actions to mitigate climate change.

The COP27 climate meeting in Sharm El-Sheikh, Egypt, ended with a pledge for financial support to be provided to climate vulnerable nations for any "loss and damage" caused by climate change. However, there was a lack of consensus on projects for developed countries to meet the required limits for climate change adaption, as well as indications of slowing progress needed to meet the 1.5°C temperature increase target. The Net Zero chapter examines Great Britain's contribution to the critical reduction of GHG emissions out to 2050.

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1 Department for Energy Security and Net Zero - GOV.UK (www.gov.uk)

Introduction

Selected announcements reaffirmed in Powering Up Britain

Powering Up Britain

Domestic Heat
Boiler Upgrade Scheme (BUS) extension to 2028

Hydrogen
Net Zero Hydrogen Fund (NZHF) announce 6 GW capacity by 2030

Carbon Capture, Usage and Storage (CCUS)
Progression of track 1 & 2 clusters

Transport
£350 million for Local Electric Vehicle Infrastructure Fund (LEVI)

Nuclear
Launch of Great British Nuclear (GBN)

Renewables
£160 million funding for pilots in floating offshore wind manufacturing

Green investment
Updated green finance strategy

NET ZERO

International collaboration
Published the international climate finance strategy for net zero

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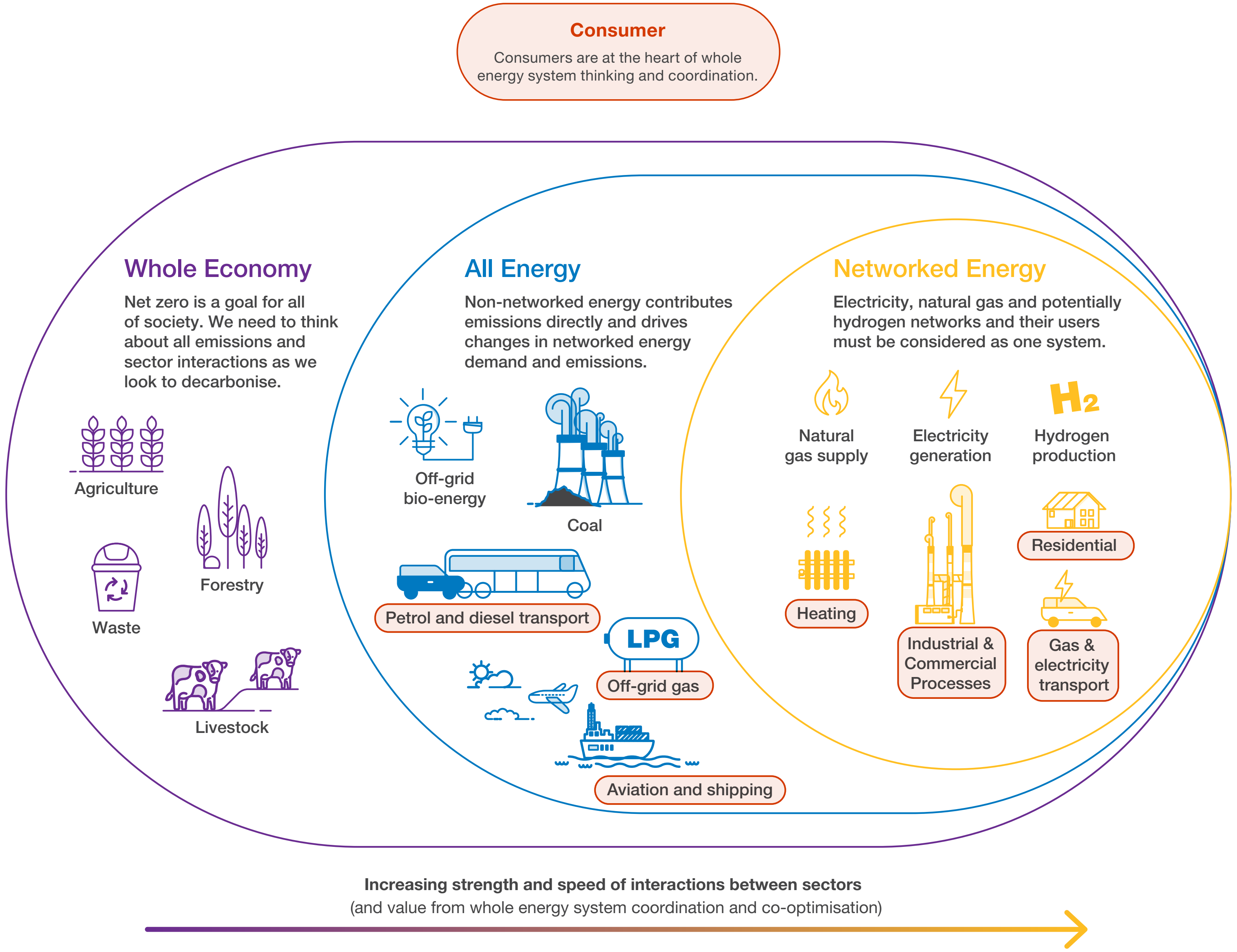
What we model

Our FES analysis directly models UK electricity, gas and hydrogen demand for energy and transport, but other sectors (for example aviation, maritime and agriculture) are accountable for significant GHG emissions. A whole economy view is needed when assessing the route to net zero and balancing the trilemma.

Net zero is achieved when the amount of greenhouse gases going into the environment are balanced by those being removed. To achieve a net zero economy, it is important to address each sector and develop solutions to reduce their associated GHG emissions. Considering the whole economy in net zero allows for greater cross-sector decarbonisation, such as the use of hydrogen produced at times of surplus renewable electricity generation being blended into the gas network or used for alternative fuels. Policy and government support should be holistic and cross-sector in design to achieve net zero. This is because some sectors will need to be net negative by 2050 to offset emissions from hard to abate sectors such as agriculture.

For these other sectors, we use the CCC (Climate Change Committee) pathways in their 6th carbon budget analysis as our basis. These sectors are typically those in the "Whole Economy" boundary of the adjacent graphic, but also include aviation and shipping which sit in the "All Energy" boundary.



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What we model

The key areas where we've used CCC data, alongside the assumptions we have made, are presented in Table 1 (overleaf). For System Transformation and Consumer Transformation, we have generally followed the CCC's Balanced Pathway and for Leading the Way, we have largely used Widespread Innovation. Where we have differed from these assumptions it is noted in Table 1.

Away from non-energy sectors, one other key assumption in FES relating to net zero relates to interconnectors. We model interconnectors directly in FES, and follow international carbon accounting rules, where emissions are assigned to the country that generates them. So, any electricity which is imported to the UK via interconnectors is assumed to be zero carbon from a UK perspective.

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What we model

Table 1: Assumptions taken from the CCC

	Aviation	Shipping	Agriculture	Land Use	Waste
System Transformation and Consumer Transformation (based on CCC Balanced Pathway)	• 42% emissions reduction (compared to 2018) due to slower demand growth (only 25% increase compared to forecast 65%), improvements in aircraft efficiency and a modest share of sustainable aviation fuels at 25%	• Emissions reduce to close to zero by 2050 using zero carbon fuels • 87% of the emissions savings come from using ammonia • Remaining reductions come from electrification	• 38% reduction in emissions from agriculture by 2050 (compared to 2018) • By 2050, reduction by a third for weekly meat consumption and 20% reduction for dairy	• 50,000 hectares of trees planted annually by 2035 • 79% of peatland restored • 700,000 of perennial energy crops by 2050	• All net zero scenarios follow the Widespread Innovation pathway • 51% fall in edible food waste by 2030 and 61% by 2050 (compared to 2007) • 50% fall in inedible food waste by 2050 and more widespread wastewater treatment improvement • Emissions fall just over 75% from today's levels by 2050
Leading the Way (based on CCC Widespread Innovation)	• 64% reduction in emissions despite 50% increase in demand (both compared to 2018) • Achieved through 25% carbon neutral synthetic jet fuel, 25% biofuels and efficiency improvements for planes	• Widespread adoption of low carbon fuels over the 2030s, so that by 2040 shipping is at practically zero emissions • System Transformation followed the Widespread Innovation pathway for shipping	• 57% reduction in emissions from agriculture by 2050 (compared to 2018) • By 2050, 50% less meat and dairy, with 30% of meat coming from lab-grown sources	• 70,000 hectares of trees planted annually by 2035 • All peatland restored by 2045 • 1.4m hectares of energy crops by 2050	

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What we model

Table 2 shows progress made to date on emissions reduction by sector. Total emissions have fallen by nearly 50% compared to their 1990 levels which demonstrates the overall progress made so far. Looking at each sector separately though, we see very different levels of decarbonisation. This highlights the varying level of challenges across the sectors and the focus to date.

The UK has the fastest decarbonising electricity grid in the world[3] achieving an almost 75% reduction in emissions. This has, in large part, been due to moving away from coal powered generation to gas power and renewables. We will need the electricity grid to continue to decarbonise, whilst also meeting an increasing electricity demand in our transition to net zero.

Road and rail emissions have only decreased by 10% since 1990 with most of these emissions coming from petrol and diesel cars.[4] This makes up the largest proportion of emissions in 2021. Decarbonising the top emitting sectors like transport will make the biggest contribution to net zero. Even though we have seen improvements in efficiencies for motor vehicles since 1990, this has largely been offset by increased car mileage and a growth in the average size and weight of vehicles. For road transport there are alternative low carbon options to ICE (Internal Combustion Engines) vehicles such as EVs (Electric Vehicles) which can help to decarbonise this sector. However, we need to make sure the electricity supplied to power these vehicles is coming from low carbon sources. This highlights the importance of whole energy system thinking on our transition to net zero with the need for policy design for each sector of the economy to complement each other.

Table 2: Emissions progress[2]

Sector Emissions ($MtCO_2e$)	1990	2021	Reduction
Industrial Process	42	11	74%
Electricity	204	55	73%
Industrial Heat	98	53	46%
Service Heat	28	19	32%
Residential Heat	80	68	15%
Fuel Supply	79	32	60%
Shipping	17	12	31%
Aviation	22	16	30%
F-gases	15	11	28%
Road Transport and Rail	113	102	10%
Waste	72	19	74%
LULUCF P	31	24	22%
LULUCF N	-20	-23	15%
Agriculture	54	48	12%
Total	**835**	**447**	**47%**

2 gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021
3 nationalgrideso.com/future-energy/our-progress-towards-net-zero
4 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1134664/greenhouse-gas-emissions-statistical-release-2021.pdf

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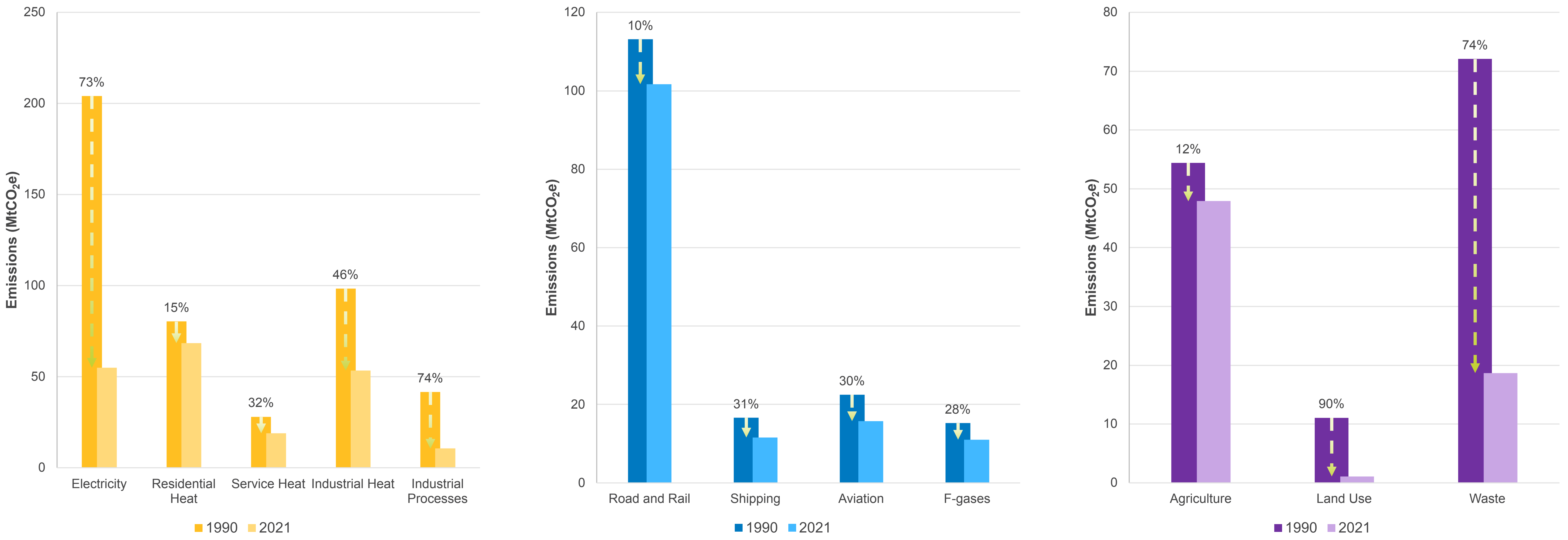
Figure NZ.01: Emissions reductions by sector between 1990 and 2021



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Key insights

With the right action, Great Britain will reach net zero by 2050.

The route to net zero:

- Leading the Way reaches net zero by 2046 and achieves annual net emissions of -34 $MtCO_2e$ in 2050, which amounts to removal of GHG emissions from the atmosphere.
- Consumer Transformation and System Transformation reach net zero in 2050.
- Falling Short does not get to net zero by 2050, resulting in 178 $MtCO_2e$ of residual emissions. In this scenario we still see a 79% reduction in emissions against 1990 levels.
- Moving away from the combustion of fossil fuels is a necessary step in the transition to a sustainable energy system. This involves energy consumers fuel switching to low carbon fuels.
- To meet carbon budgets and net zero we will need to see the large-scale deployment of Carbon Capture, Usage and Storage (CCUS) within the next ten years, which relies on delivering on transport and storage business models and industrial cluster ambitions.
- Some sectors, like power generation, have already made good progress in decarbonisation, and transport decarbonisation is accelerating, but without greater progress in heat it becomes harder to meet net zero.
- We expect the 4th and 5th carbon budgets to be met in our net zero scenarios, but this requires delivery of existing policy commitments.
- Each region faces unique challenges in supporting the transition to net zero and some may need to compensate for technical and geographical barriers of others. Regional targets must consider whole economy benefits to avoid conflict with UK wide targets.
- Consumers need to be engaged, supported, and enabled to adopt new, smarter technologies and change the way they use energy to reach net zero. Under some scenarios, a doubling or even trebling in uptake of some technologies is needed by 2035.

Emissions calculation methodology:

- Removal of climate feedback in emissions calculations, resulted in a reduction in forecast emissions across the sectors, with agriculture seeing the biggest fall.

Negative emissions:

- Negative Emissions Technologies (NETs) are required to enable a net zero whole energy system, but further action is needed to increase confidence in its contribution to decarbonisation.
- NETs do not materialise until 2030 due to a combination of delayed policy for Bioenergy with Carbon Capture and Storage (BECCS), outcomes of the recent Track 1 Cluster Sequencing Competition and low technology and commercial readiness of DACCS (Direct Air Carbon Capture and Storage).
- Acceleration of business models alongside robust emissions accounting standards are needed to ensure both investor and public confidence in a negative emissions market.
- Further demonstration of innovative emissions reduction technologies is required to reduce uncertainties over technology and commercial readiness.
- GHG removal and Negative Emissions Technologies are reliant on both delivery of, and proximity to, CO_2 transport and storage networks and/or large CO_2 users.

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The route to net zero

Figure NZ.02 shows the annual emissions projections of our four scenarios. Due to changes in the way that emissions are calculated, we see a drop in emissions from the sectors not directly modelled in FES such as agriculture and land use which means that there is further scope to meet net zero by 2050.

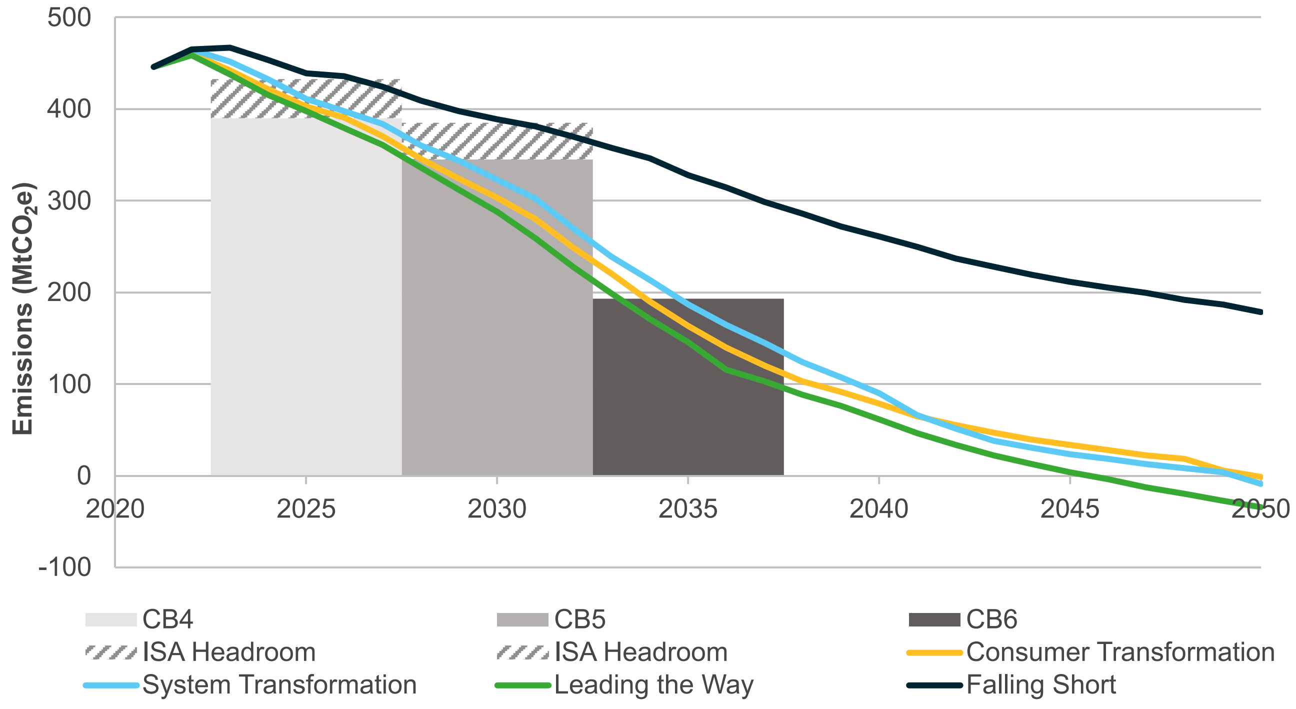
Leading the Way meets net zero by 2046, System Transformation and Consumer Transformation meet net zero by 2050. Leading the Way achieves annual net emissions of -34 $MtCO_2e$ by 2050, which equates to removal of GHG emissions from the atmosphere.

There is still significant risk and uncertainty around exactly when and how net zero will be delivered. While Leading the Way could deliver net zero before the 2050 target, bringing forward action in the areas of biggest impact, such as heat, and delivering low regret technologies, such as Vehicle-to-Grid (V2G), will mitigate the risks of non-delivery of net zero by 2050.

Falling Short does not get to net zero by 2050, resulting in 178 Mt of residual emissions.

Carbon budgets set by the CCC limit UK emissions over a five-year period. These legally binding limits can be used to track progress on emissions reduction efforts and aid the transition towards net zero. Budgets are set at least 12 years in advance to allow policy makers, businesses, and individuals the time to adapt.[5]

Figure NZ.02: Net greenhouse gas emissions and carbon budgets



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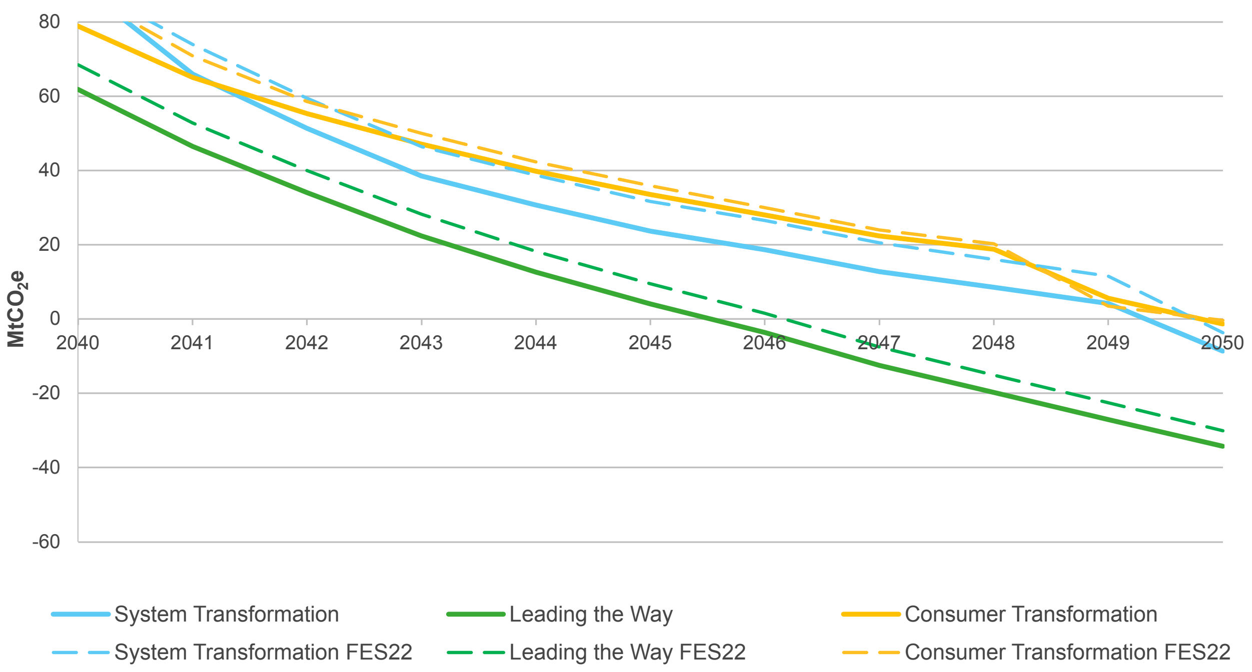
5 theccc.org.uk/what-is-climate-change/a-legal-duty-to-act

The next carbon budget will be CB7 covering the period 2038-2042. From figure NZ.02 we see there is a significant reduction in emissions allowances from CB5 (1,923 $MtCO_2e$) including International Aviation and Shipping (IAS) headroom to CB4 (965 $MtCO_2e$). For the UK to meet CB6 we will need to see significant changes across the economy, such as more low carbon electricity production, deployment of CCUS, and shifting away from petrol and diesel vehicles and gas boilers.

Figure NZ.03 shows a closer look at the ten years leading up to 2050.

Good progress is made regarding the emissions reduction going into 2040s. Leading the Way reaches 95% reduction against 1990 levels in 2042, followed by System Transformation and Consumer Transformation which reach 95% reduction in 2043 and 2044 respectively. A 98% reduction in emissions is achieved by Leading the Way, System Transformation and Consumer Transformation in 2044, 2046, 2048 respectively. By 2050 both Consumer Transformation and System Transformation reach net zero.

Figure NZ.03: Route to net zero 2040 to 2050



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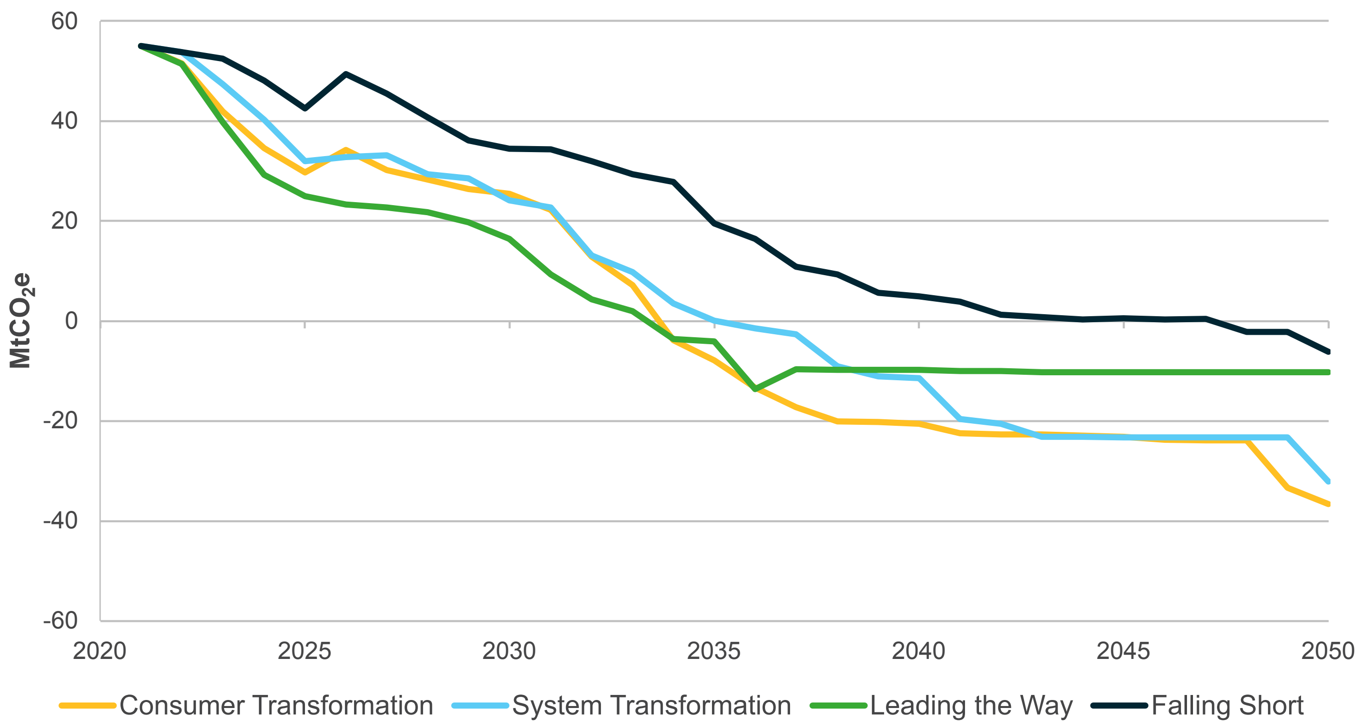
Net zero power sector emissions are reached in 2034 for Leading the Way and Consumer Transformation which is one year earlier than the 2035 target. System Transformation reaches net zero power sector emissions by 2035 and Falling Short in 2046. These are underpinned by the development of BECCS, from which the negative emissions offset residual power sector emissions from other sources.

We do not expect negative emissions to emerge before 2030 in any scenario. Acceleration of business models alongside robust emissions accounting standards are needed to ensure both investor and public confidence in the negative emissions market. Further demonstration of innovative emissions reduction technologies is required to reduce uncertainty over technology and commercial readiness.

Meeting net zero will require large scale deployment of CCUS which we first expect to see towards the end of this decade. It is estimated by the British Geological Survey (BGS) that the UK has potentially over 70 billion tonnes of CO_2 storage.[6] To put this into context, total whole economy emissions in 2021 were 446 $MtCO_2e$,[7] meaning there is currently enough storage to capture all the 2021 emissions for over 100 years. The scale-up of CCUS will be critical to meet both CB6 and net zero as we require this technology to help decarbonise industry and power (through BECCS and Gas CCUS), and low carbon hydrogen production through reformation of natural gas. Additionally, implementation of CO_2 transport and storage will help the scale-up of DACCS.

Figure NZ.04: Power generation emissions out to 2050



6 bgs.ac.uk/geology-projects/carbon-capture-and-storage/
7 gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021

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Regional spotlight - net zero targets

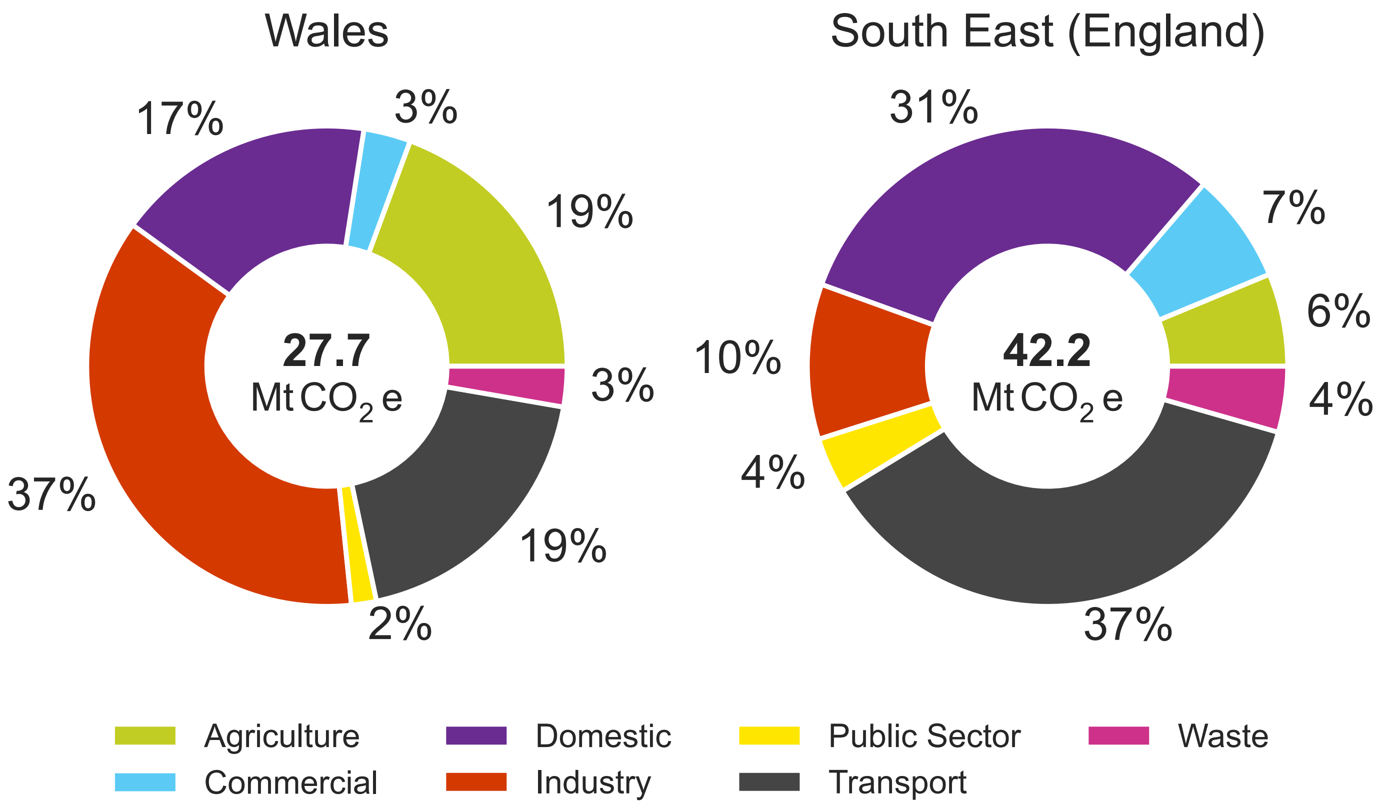
Regional emissions highlight a wide range of progress on meeting net zero targets. They are indicative of the local challenges faced by industry and by regional government in meeting their obligations.

We know that electricity generation capacity needs to increase significantly to meet the demands from electrification of heat and transport. This generation needs to come primarily from renewable sources which is reflected in targets proposed by the UK, Scottish and Welsh Governments. The local ambition for low carbon generation is clear, the challenge is how regions can effectively store or transfer this energy to where it is needed and how regions with high levels of renewable generation can meet demand when wind or solar resources are less available.

All regions across GB will need to cut their emissions from present levels. How this is achieved differs across the country as the sources of these emissions vary. Areas like London and the South-East of England with high domestic heating demands will benefit from the expected fall in power sector carbon intensity that will remove a significant percentage of emissions at a national level. Wales and the North-East of England have more challenging journeys to net zero with a significant number of emissions attributed to large industrial sites, for example steel and cement production.

How we coordinate these different targets and challenges will be an important part of the success of the overall strategy and ensuring that we have a pathway that works for all areas of the country. The government net zero review and recent Ofgem proposals both identified the lack of regional coordination across the whole energy system as impacting delivery of many local area ambitions.

Figure NZ.05: Emission contributions from different sectors excluding land use change for Wales and the South East of England, showing the significant increase in Welsh large industry contributions[8]



8 BEIS 2020 data

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Regional spotlight - negative emissions

Optimal locations for Negative Emissions Technologies (NETs) are a trade-off between competing factors, but delivery is linked to proximity of, and transport to, suitable carbon storage sites.

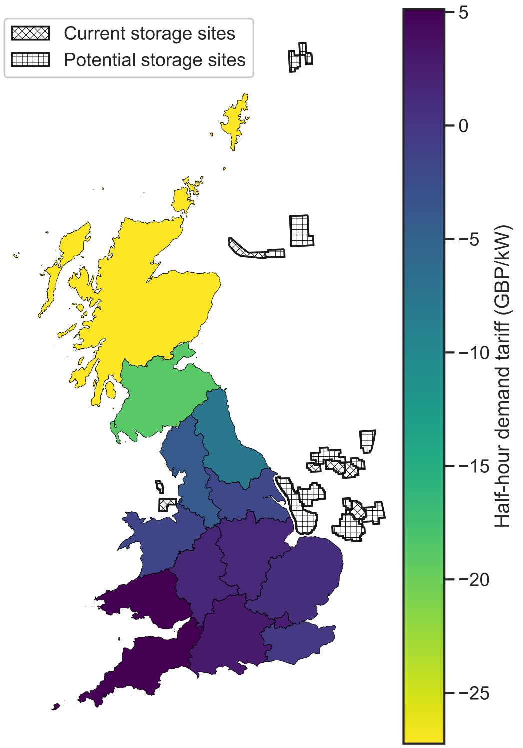
Negative Emissions Technologies remove carbon dioxide from the air directly through mechanical means or land use change. Crop growth for bioenergy may be coupled with capturing and using or storing the emitted carbon dioxide for overall net negative emissions. The delivery of these technologies is linked to proximity to suitable carbon storage.

Bioenergy Carbon Capture and Storage requires a mature and accessible supply of processed crops grown for bioenergy. BECCS plants generate electricity and so we expect them to be located close to regions of high demand but with access to carbon storage sites, for example on the East-Coast of England.

Current BECCS technology is dependent on international sources for bioenergy. The UK Government is funding a programme[9] which aims to promote a domestic supply chain for bioenergy that could reveal regional differences in crop yields.

Direct Air Carbon Capture and Storage takes carbon dioxide direct from the air and transfers it to local storage sites. It is energy intensive, and the key requirement is access to low cost energy, whilst leveraging waste heat from industrial processes. Further innovation could mean that DACCS may not need access to heat in the future. In addition, access to local storage sites is important. We expect DACCS sites to establish close to existing industrial and storage infrastructure in North Scotland or North-East England where lower electricity prices improve the economics as shown on Figure NZ.06.

Figure NZ.06: Locational elements of the half-hourly year-round demand charge for network regions combined with proposed carbon storage sites



Locational elements of the half-hourly year-round demand charge for network regions (ESO 2023 data) combined with proposed carbon storage sites identified by the North Sea Transition Authority (NSTA): Carbon Storage - NSTA Open Data - Data centre (nstauthority.co.uk). The NSTA are responsible for licensing offshore CO_2 storage. They work closely with other organisations such as The Crown Estate and the government to help deploy CCUS at the scale we need to meet net zero. Currently, as indicated in Figure NZ.06, there are 6 licenses which have been issued, the first of which was granted in 2018. In June 2022 the NSTA held their first licensing round for 20 licensed sites.[10]

9 gov.uk/government/publications/apply-for-the-biomass-feedstocks-innovation-programme
10 nstauthority.co.uk/the-move-to-net-zero/carbon-capture-and-storage

Changing emissions accounting methodology

Changes to the emissions calculation methodology have led to a reduction in forecast emissions for non-energy sectors compared to FES 2022. The biggest changes come from removing climate feedback to align with international standards and impacts the sectors not directly modelled in FES which have high emissions of methane.

Changes to emissions calculation methodology over the past year fit broadly into two categories:

- Revisions to historical data
- Alignment with international standards

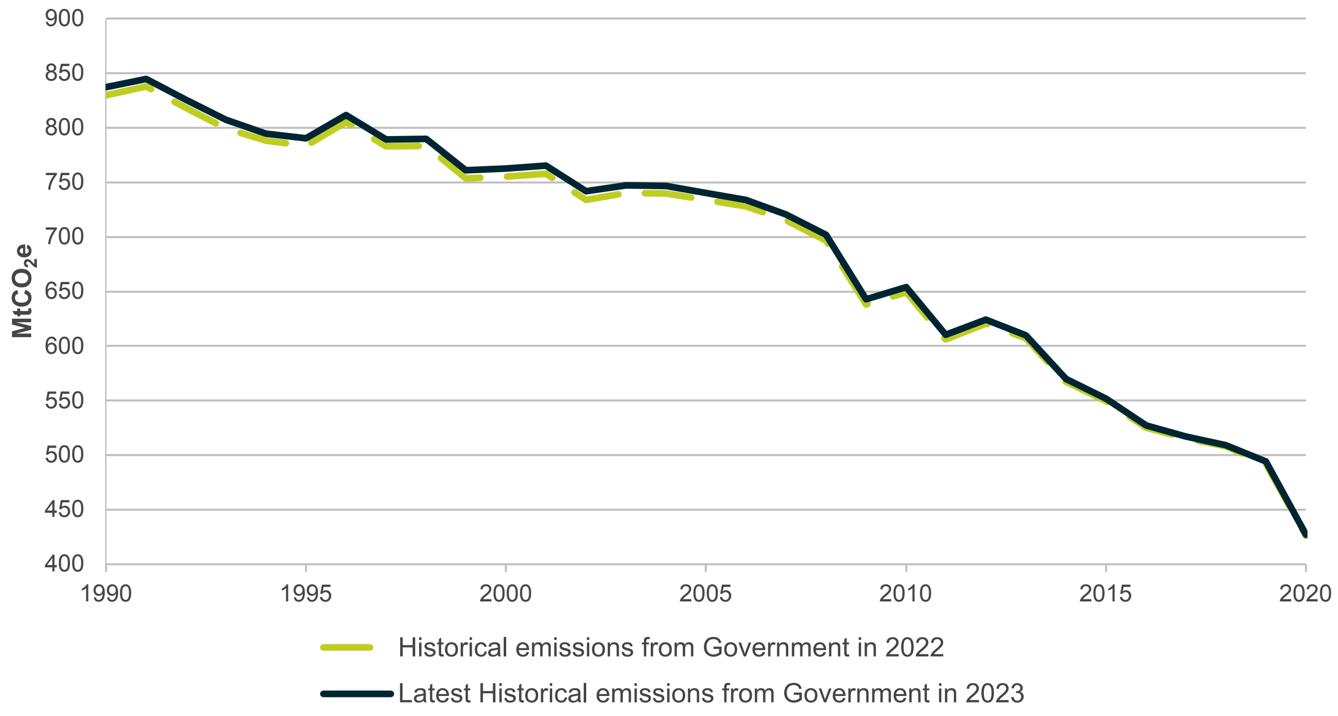
The UK Government publishes revisions to the historic estimates of UK GHG emissions annually to incorporate improvements in methodology, updated data, outcomes of new research and changes to international guidelines. These changes are minor and do not change the action required to meet net zero, demonstrating that historical emissions are not set in stone. The effect of these changes is shown in Figure NZ.07.

Emissions conversion factors, used to estimate the climate impact from non-CO_2 emissions such as methane and nitrous oxide, were updated in 2023. This conversion was required as total emissions or net emissions are measured in the units of CO_2 equivalent ($MtCO_2e$). Emissions conversion factors are now based on the IPCC's (Intergovernmental Panel on Climate Change) Fifth Assessment Report (AR5).[11] The AR5 includes new scientific data and updated models for estimating the Global Warming Potential (GWP) of various greenhouse gases.

The GWP is a measure of how much a given amount of a greenhouse gas is estimated to contribute to global warming over a specified period, which is variable and can be anywhere between 20 to 100 years, depending on the international standard used. The choice of 100 years is widely accepted for calculating GWP.

These changes mean that the historical net GHG emissions published in 2023 are slightly higher than those published in previous years as shown in Figure NZ.08. Further changes to the calculation methodology have caused a reduction in forecast emissions from the sectors not directly modelled within FES.

Figure NZ.07: Total net GHG emissions



11 gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021

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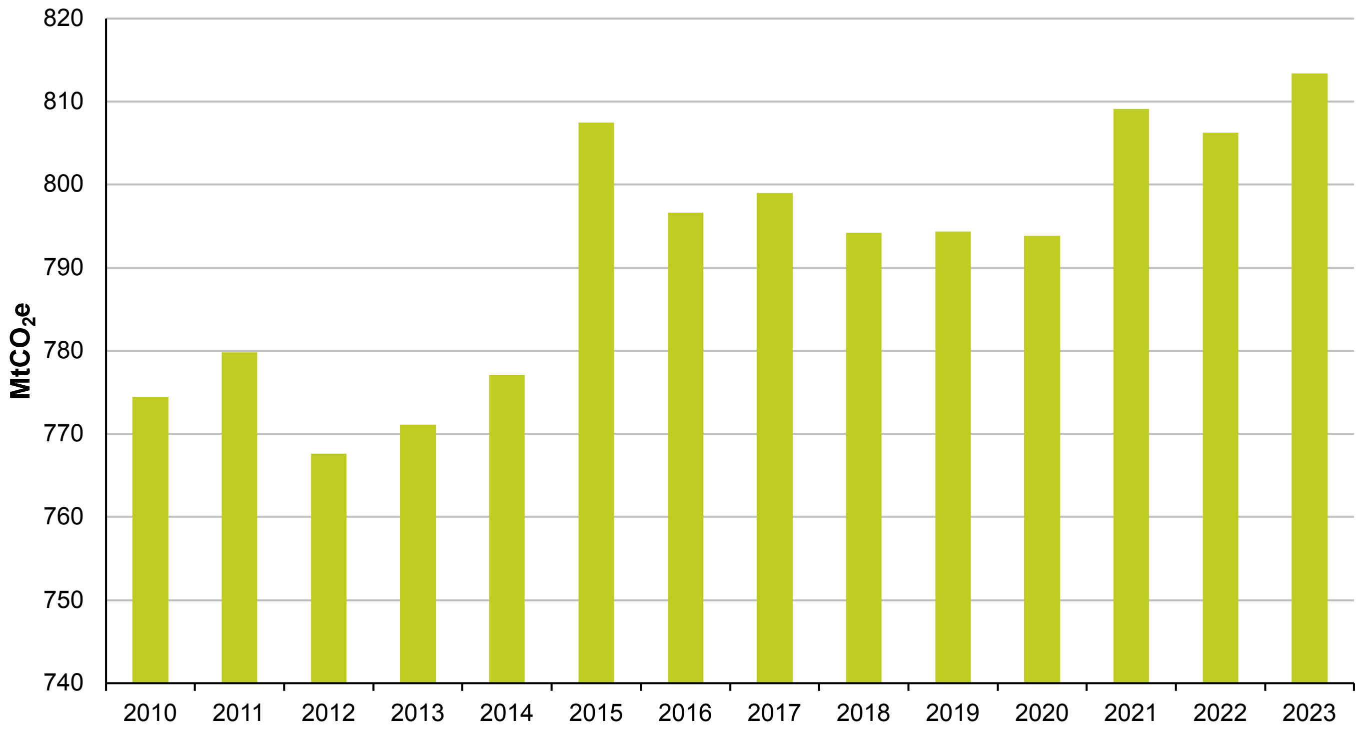
Changing emissions accounting methodology

Figure NZ.08: Changes to reported 1990 emissions by year



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Changing emissions accounting methodology

Climate feedback refers to the interactions between the earth's temperature and the amount of radiation. These interactions can amplify the initial warming caused by greenhouse gas emissions.

The Climate Change Committee has updated their methodology for calculating emissions by removing climate feedback, aligning themselves with international agreements on emissions reporting, and we have reflected this in our emissions modelling.

When climate feedback is removed from emissions calculations, it impacts various sectors differently depending on the type and amount of greenhouse gas emissions they produce. The biggest impact is in the agricultural sector. Agricultural activity produces a mix of methane, nitrous oxide, and carbon dioxide. Methane and nitrous oxide emissions are more strongly influenced by climate feedback mechanisms. Removal of climate feedback from the calculation leads to lower emissions than previously reported.

Changing the emissions calculation method also has implications for future emissions reductions. If the new method results in higher emissions than previously estimated, it may indicate a need for more urgent mitigation to achieve the same emissions reduction targets. Conversely, if the new method yields lower emissions, it may provide some breathing space for the mitigation effort but also pose a risk of complacency and underestimation of the true emissions trajectory. Therefore, it is important to be transparent about emission accounting methods, and communicate the results effectively to stakeholders, and the public.

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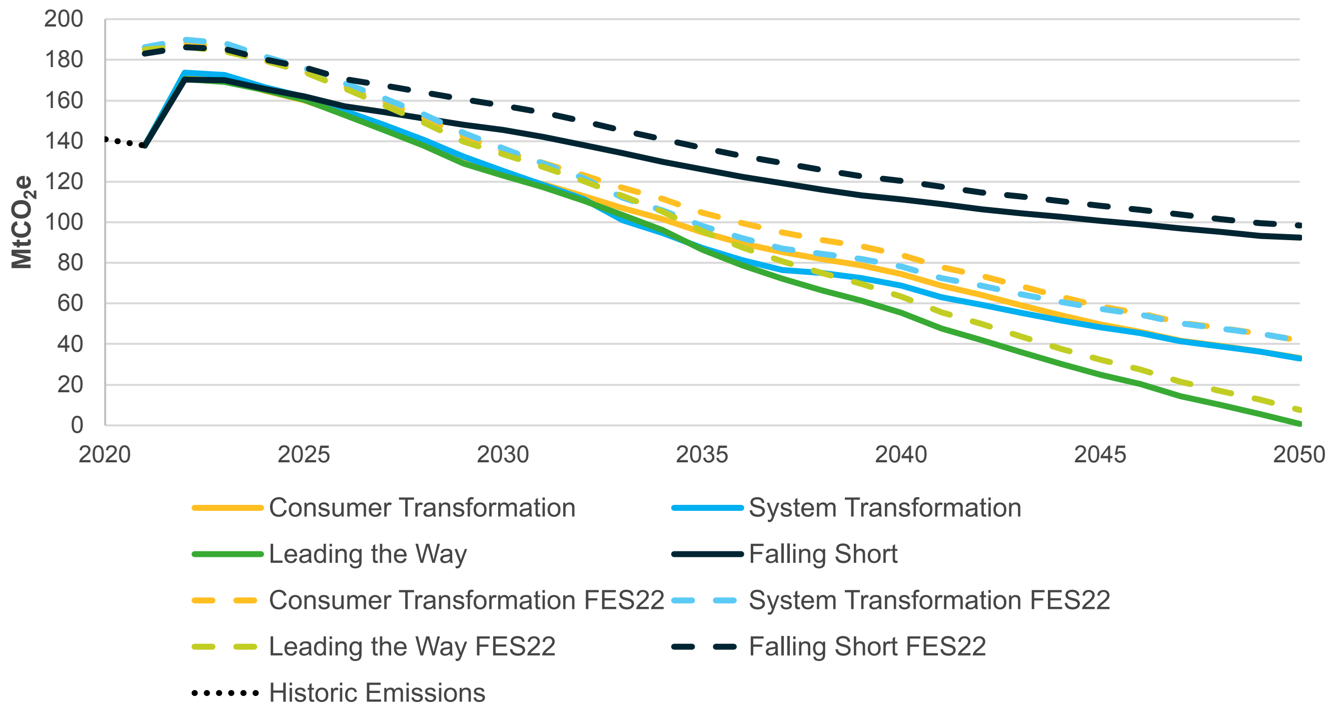
Changing emissions accounting methodology

Emissions are a complex and dynamic system, and it is essential to look at the full range of emissions and their drivers, including sectoral analysis, and modelling assumptions. It's also important to recognise that scientific understanding of climate change is constantly evolving, and updates to methodology can help ensure that reports accurately reflect the latest research and knowledge. The changes to the emissions calculation methodology reflects the ongoing efforts to improve the accuracy and relevance of reporting emissions.

To align our forecast with the latest actuals, we removed climate feedback from our emissions analysis. This change resulted in lower scenario emissions compared with FES 2022. The increase in non-FES sector emissions between 2021 and 2022 is due to the partial recovery in air travel following the removal of COVID-19 restrictions. These changes are shown in Figure NZ.09.

Figure NZ.09: Non-FES sectors emissions



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Negative emissions

Negative Emission Technologies should not be seen as a "magic bullet" to achieving our net zero targets, however they can play a role in this transition. The UK should aim to decarbonise as many sectors as possible through efficiency improvements, reduction in demand and fuel switching to mitigate the risk of non-delivery of NETs.

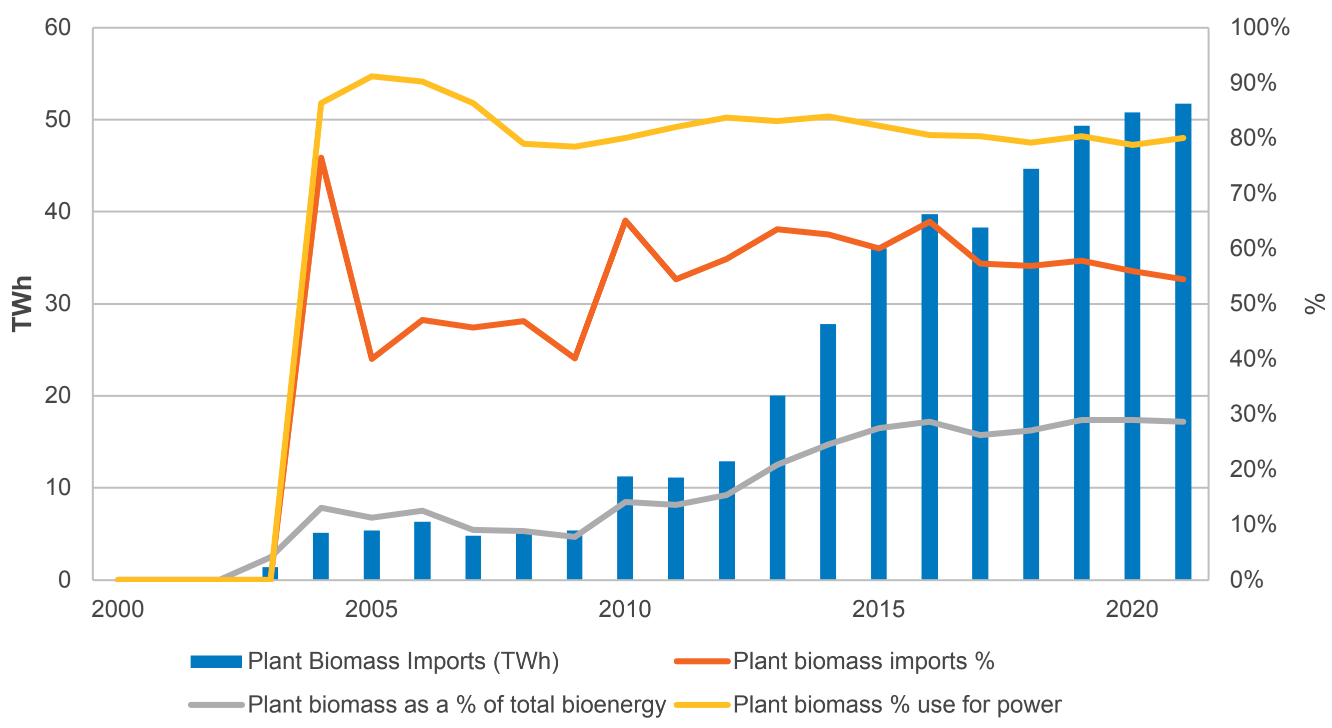
As the UK aims to achieve net zero emissions by 2050, Negative Emissions Technologies are becoming increasingly important. NETs can broadly be broken down into two main categories:

- **nature based** such as afforestation
- **engineered** such as Bioenergy with Carbon Capture and Storage

BECCS involves capturing CO_2 emissions from bioenergy plants and storing the carbon underground, effectively removing carbon from the atmosphere. While BECCS is considered by many as a key tool in achieving net zero emissions, it continues to divide opinion.

BECCS currently relies on imported biomass as a feedstock. As global demand for biomass increases, consideration must be given to the levels of biomass supply to meet demand. Figure NZ.10[12] shows there has been a large increase in imported plant biomass since the beginning of the century, with imports making up roughly 50% of total plant biomass supply (orange line). Most of the biomass is used in the power sector (yellow line). We use biomass supply ranges from the CCC to limit the amount of biomass used in our modelling across each sector.

Figure NZ.10: Plant Biomass



12 gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

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Negative emissions

Biomass growth competes with land for food supply, which comes into sharper focus as the world's population grows.

For BECCS to be widely accepted as a solution for net zero, carbon accounting in BECCS supply chains must be transparent. To address concerns over Negative Emissions Technologies leading to a continued reliance on fossil fuels, clear and strict criteria for qualifying as an emissions removal project must be implemented based on transparency of supply chain emissions.

Several Negative Emissions Technologies are available, including afforestation and reforestation, Direct Air Capture with Carbon Storage and Bioenergy with Carbon Capture and Storage.

Figures NZ.11 to NZ.14 show the breakdown of Negative Emissions Technology for each scenario. Consumer Transformation is dominated by BECCS for power. System Transformation sees a contribution from hydrogen production through the process of biomass gasification where biomass is used as the feedstock of the process, and with emissions being captured. While Leading the Way includes a growing contribution from DACCS beyond 2040, Falling Short only includes negative emissions from BECCS for power generation.

Overall, while Negative Emissions Technologies such as BECCS have the potential to play a significant role in achieving net zero emissions, there are several challenges associated with their implementation. It is important to carefully consider the environmental, social, and economic implications of these technologies.

Different sectors are facing various challenges of reaching full decarbonisation by 2050, and some sectors and regions face greater challenges than others.

Despite these challenges, NET will need to play a crucial role in mitigating the effects of climate change. Achieving a net zero economy will stop the accumulation of more greenhouse gases in the atmosphere but it will not remove the excess that has built up historically and so will not return global temperatures back to pre-industrial levels.

Additionally, the potential whole energy system benefits of emissions reductions technologies should be considered, as DACCS could play a key role in the management of network constraints and reducing balancing costs if it is in the right location. We will consider this as we develop our strategic network investment process.

Following the announcement of successful projects within the first industrial clusters, large scale BECCS will not be delivered before 2030. We have updated our scenarios to reflect this.

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Negative emissions

Figure NZ.11: Negative emissions by technology in Consumer Transformation

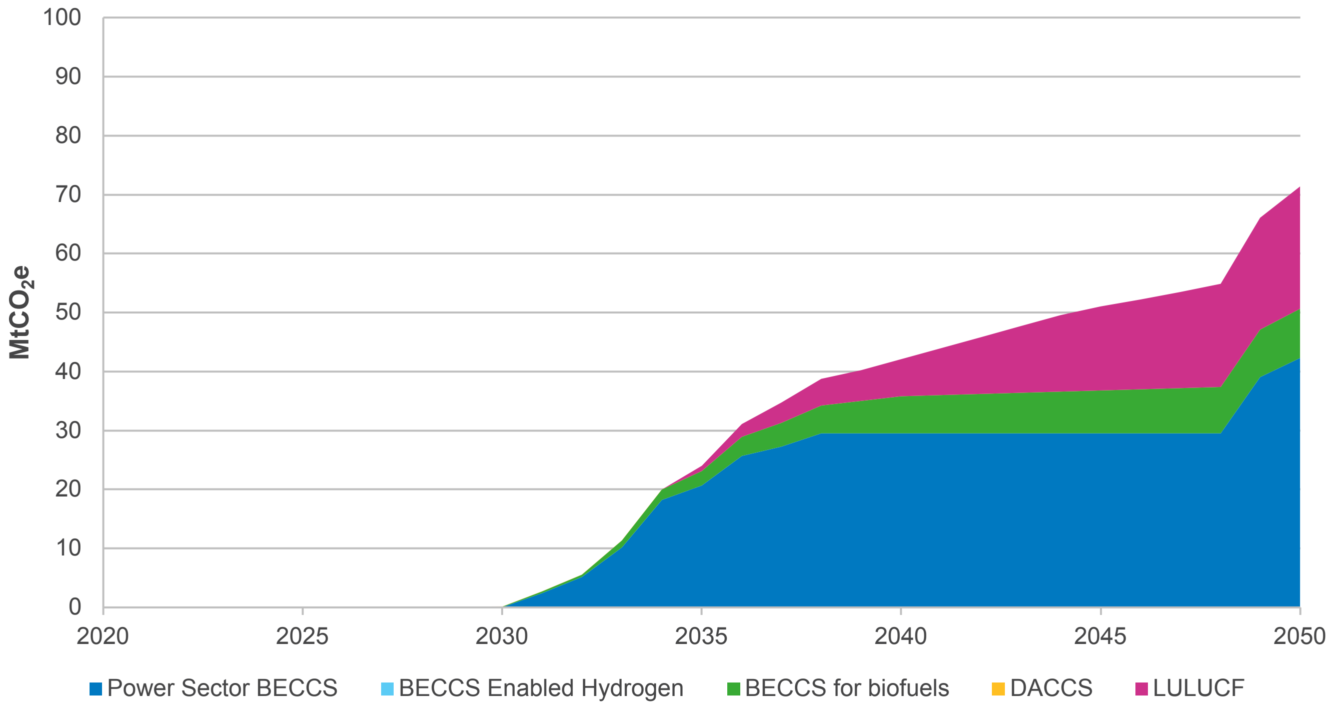
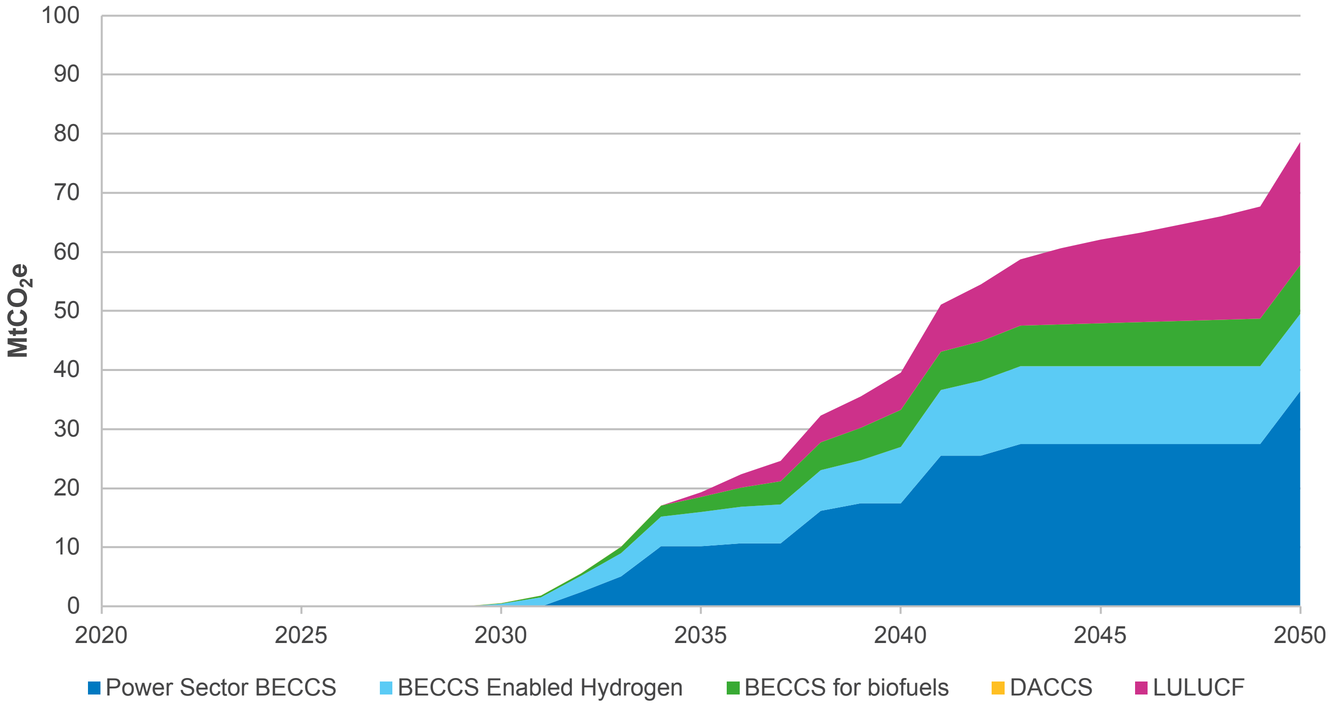


Figure NZ.12: Negative emissions by technology in System Transformation



Negative emissions

Figure NZ.13: Negative emissions by technology in Leading the Way

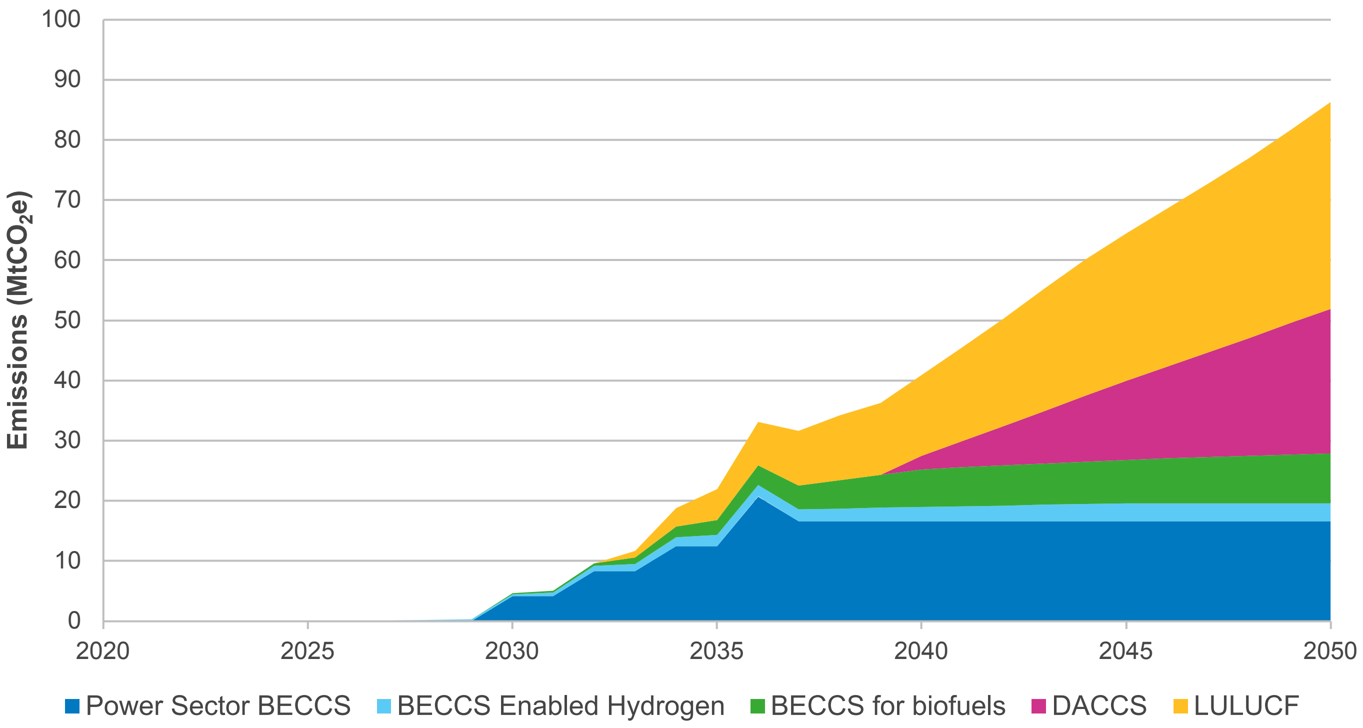
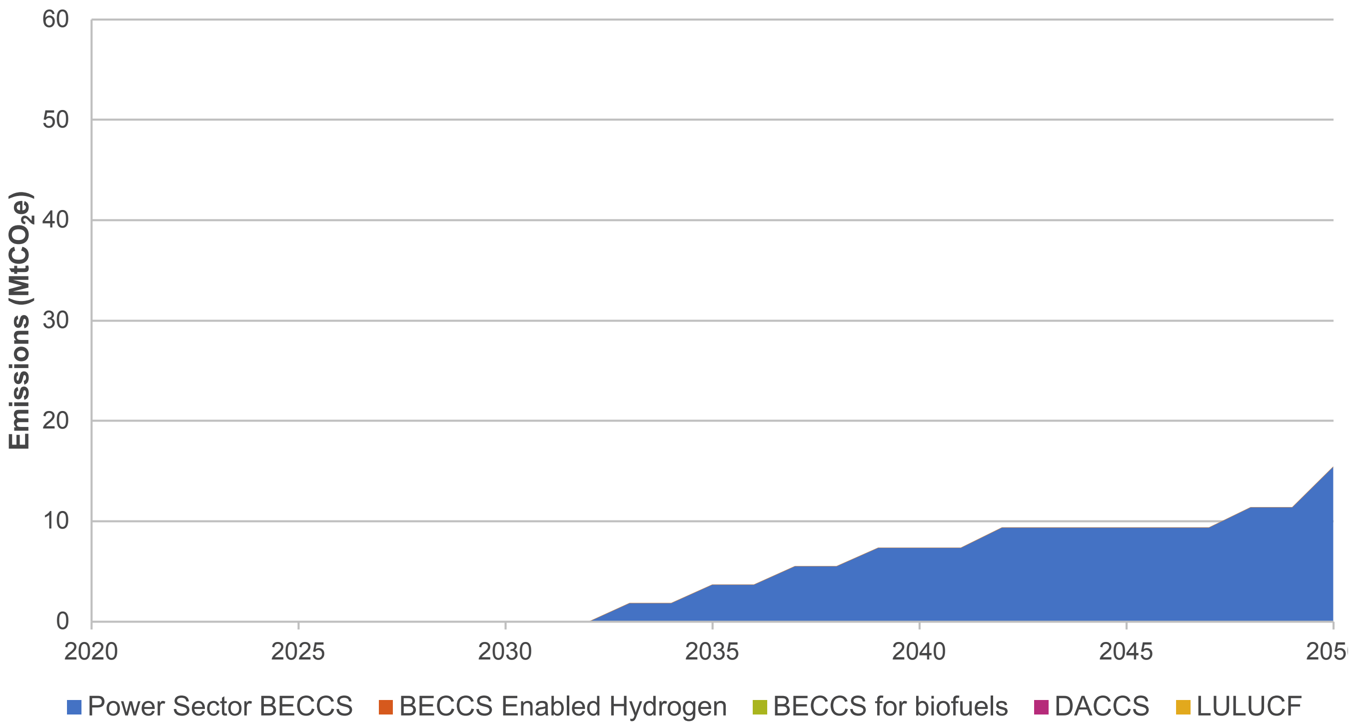


Figure NZ.14: Negative emissions by technology in Falling Short



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Negative emissions

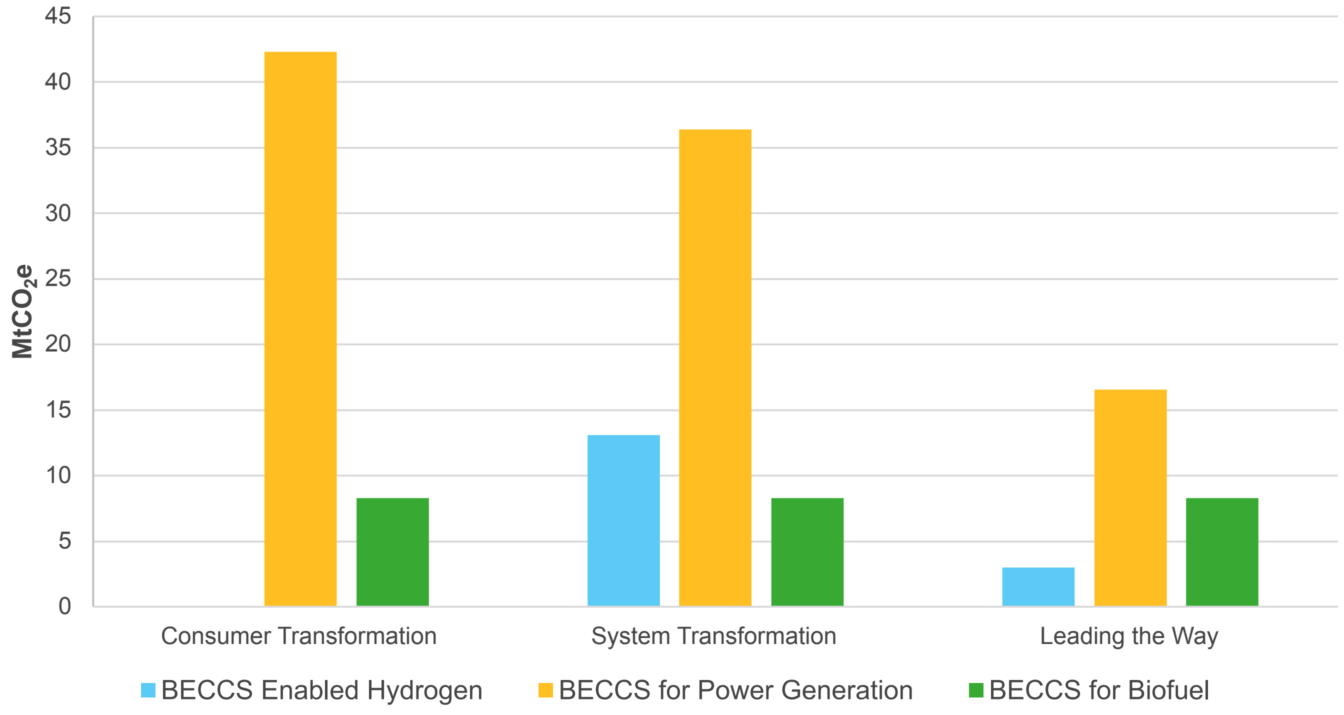
Figure NZ.15 shows the contribution of BECCS towards negative emissions across our net zero scenarios in 2050, split across BECCS for hydrogen production, power generation and biofuel.

The total contributions of BECCS in 2050 are -51 $MtCO_2e$ for Consumer Transformation, -58 $MtCO_2e$ for System Transformation and -28 $MtCO_2e$ for Leading the Way. The greater contribution in System Transformation is due to higher levels of BECCS for the production of low carbon hydrogen from the reformation of biomass.

Sensitivity analysis to understand the impact of removing BECCS from the scenarios shows that net zero is not achieved by 2050 in either Consumer Transformation or System Transformation, with residual annual emissions sitting at 49 $MtCO_2e$ in both scenarios. It is still possible for Leading the Way to achieve negative annual emissions of -6 $MtCO_2e$ by 2050 but this relies on the development of DACCS and further progress in other sectors. Leading the Way relies on deeper decarbonisation of agriculture, bringing emissions down from 48 $MtCO_2e$ in 2021 to 21 $MtCO_2e$ in 2050, and Land Use, Land Use-Change and Forestry (LULUCF) bringing 1 $MtCO_2e$ in 2021 to -34 $MtCO_2e$ through afforestation etc. NZ.16 shows the net annual emissions without DACCS.

If both BECCS and DACCS were removed it would mean that none of our scenarios meet net zero by 2050. Residual emissions in Leading the Way in 2050 without BECCS or DACCS remain at 18 $MtCO_2e$ as shown in Figure NZ.17.

Figure NZ.15: Negative emissions from BECCS by 2050



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Negative emissions

Figure NZ.16: Net annual emissions sensitivity analysis (BECCS only)

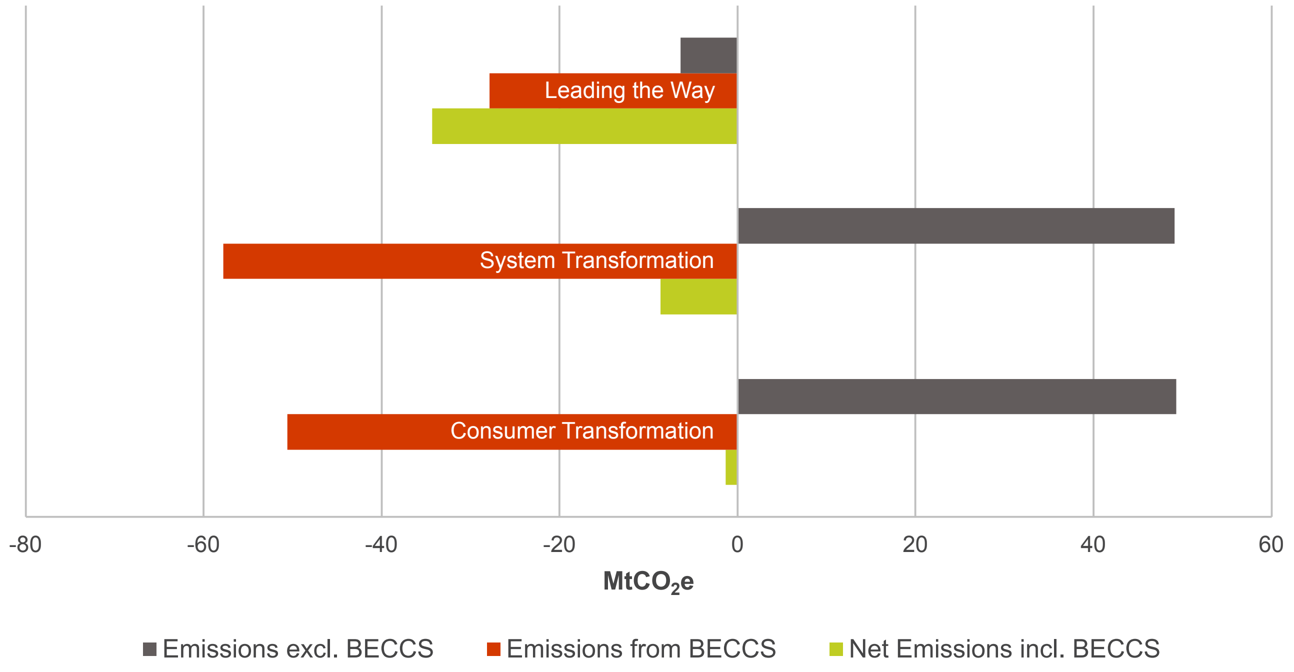
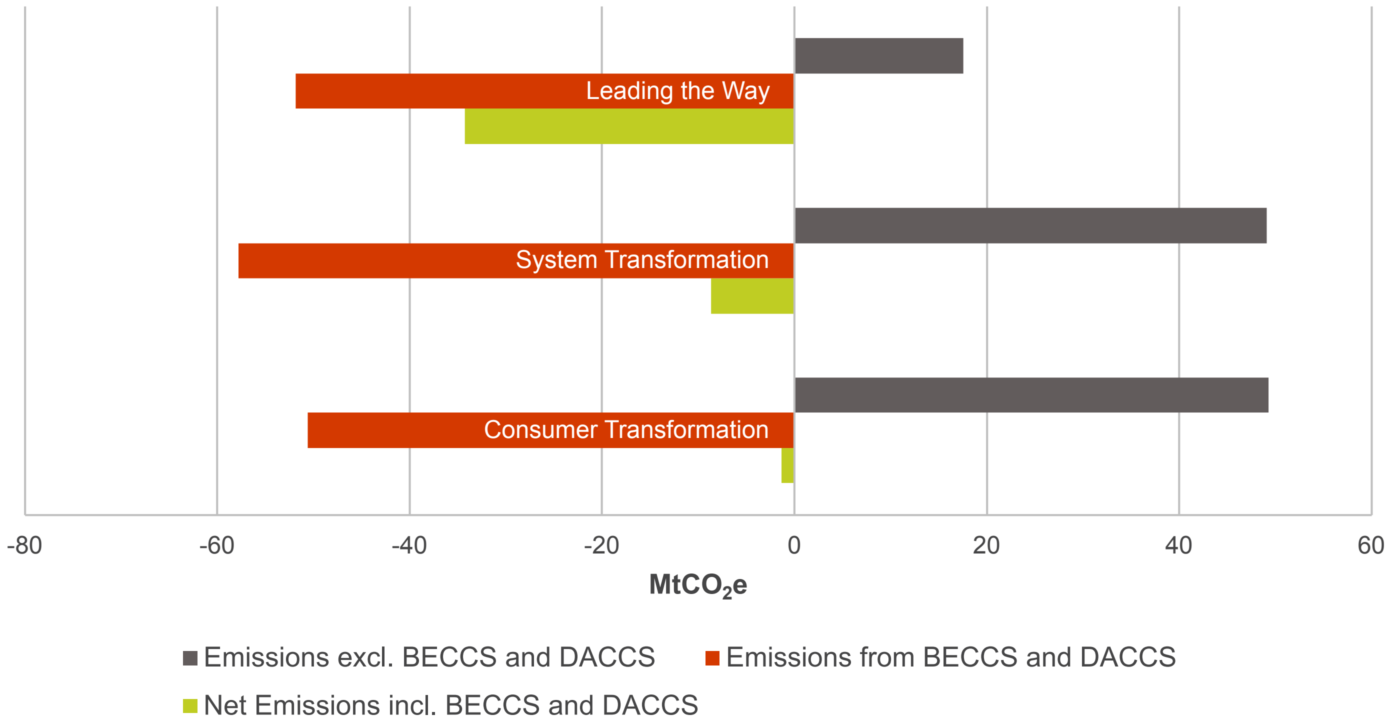


Figure NZ.17: Net annual emissions sensitivity analysis (BECCS and DACS)



Negative emissions

Acceleration of business models to support the development of a market, alongside robust emissions accounting standards, is required to ensure both investor and public confidence in a negative emissions market.

One of the biggest barriers to further development of Negative Emissions Technologies is the absence of predictable and long-term revenue streams for investors. While the Government has proposed contract-based models via consultations on power BECCS and GGR, significant uncertainty remains over the monetary value of negative emissions in the market. It is essential to develop business models that are both financially viable and sustainable in the long-term. This means further identifying and developing technologies that can deliver negative emissions at scale, while also generating revenue streams that can support ongoing investment and innovation.

It is equally important to establish a regulatory framework that incentivises the adoption of these technologies, while also ensuring that negative emissions projects are held to rigorous environmental and social standards. Any business model implemented must be supported with a clear standard for the monitoring, reporting and verification of negative emissions.

It is essential to implement emissions accounting standards that accurately capture the carbon impact of NET. This requires the development of standardised methodologies for measuring and verifying emissions reductions, as well as clear guidelines for reporting and disclosure. By doing so, negative emissions projects will be held to a high level of transparency and accountability, critical to building investor and public trust in the market.

A further challenge facing the deployment of innovative emissions reduction technologies such as DACCS, is uncertainty over their readiness for commercial use. While many of these technologies have been tested in laboratories or in small-scale pilot projects, there are often questions about their ability to operate at scale and at a cost that is competitive with more established technologies. This uncertainty can make it difficult for investors and policymakers to make informed decisions about which technologies to support and deploy.

To address this challenge, further demonstration of innovative emissions reduction technologies is needed. This can take a variety of forms, including large-scale pilot projects, demonstrations at industrial sites, or the deployment of technologies in real-world settings. By demonstrating the commercial viability of these technologies, we can reduce uncertainty and build confidence in their ability to deliver emissions reductions at scale.

Demonstration of innovative emissions reduction technologies can also help to identify and address any potential technical or operational issues. This can help to streamline the deployment process and ensure that these technologies are adopted as quickly and efficiently as possible.

DACCS is still in the early stages, with the current largest plant able to remove around 3600 tonnes a year.[13] The government are currently running a “Direct Air Capture and other Greenhouse Gas Removal technologies competition” which funds the development of GHG removal technologies.[14]

13 climeworks.com/roadmap/orca
14 gov.uk/government/publications/direct-air-capture-and-other-greenhouse-gas-removal-technologies-competition

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Fuel switching

Moving away from the combustion of fossil fuels is a necessary step in the transition to a sustainable energy system. This involves energy consumers fuel switching to low carbon fuels.

The combustion of fossil fuels is responsible for almost three quarters of global GHG emissions, as estimated by the International Energy Agency.[15] Replacing these fuels with cleaner alternatives, such as renewable electricity, low carbon hydrogen and biofuels, is necessary to reduce carbon emissions and meet climate targets.

After reducing demand through behavioural change and efficiency improvements, fuel switching is the key route to decarbonisation for many sectors, including transport and heat, where Carbon Capture and Storage at the point of use is not possible.

Fuel switching in vehicles

Figures NZ.18 to NZ.21 show the estimated number of vehicles in the UK and associated emissions across the scenarios and the fuel switching that is assumed for the decarbonisation of transport. The dashed line represents the forecast reduction in emissions out to 2050 under this scenario and the shaded area shows the fuel switch away from petrol and diesel and the proportion of emissions reduction attributed to the replacement fuels. The number of vehicles drops off in 2040 in most scenarios, most starkly in Leading the Way, due to the growth of Autonomous Vehicles (AVs). As this technology becomes more developed, it encourages greater sharing of resources or 'carpooling', meaning less of a need for individual private ownership.

The largest proportion of emissions is associated with cars, which supports the previous focus on supporting the transition to EVs and the ban on the sale of petrol and diesel cars after 2030. The largest proportion of emissions reduction comes from electrification, which accounts for a reduction of 50 $MtCO_2e$ in Leading the Way, by the late 2030s, against the counterfactual emissions (i.e. if all vehicles were fuelled by petrol and diesel).

15 iea.blob.core.windows.net/assets/3c8fa115-35c4-4474-b237-1b00424c8844/CO2Emissionsin2022.pdf

Fuel switching

Figure NZ.18: Estimated number of vehicles in the UK and associated emissions in Consumer Transformation

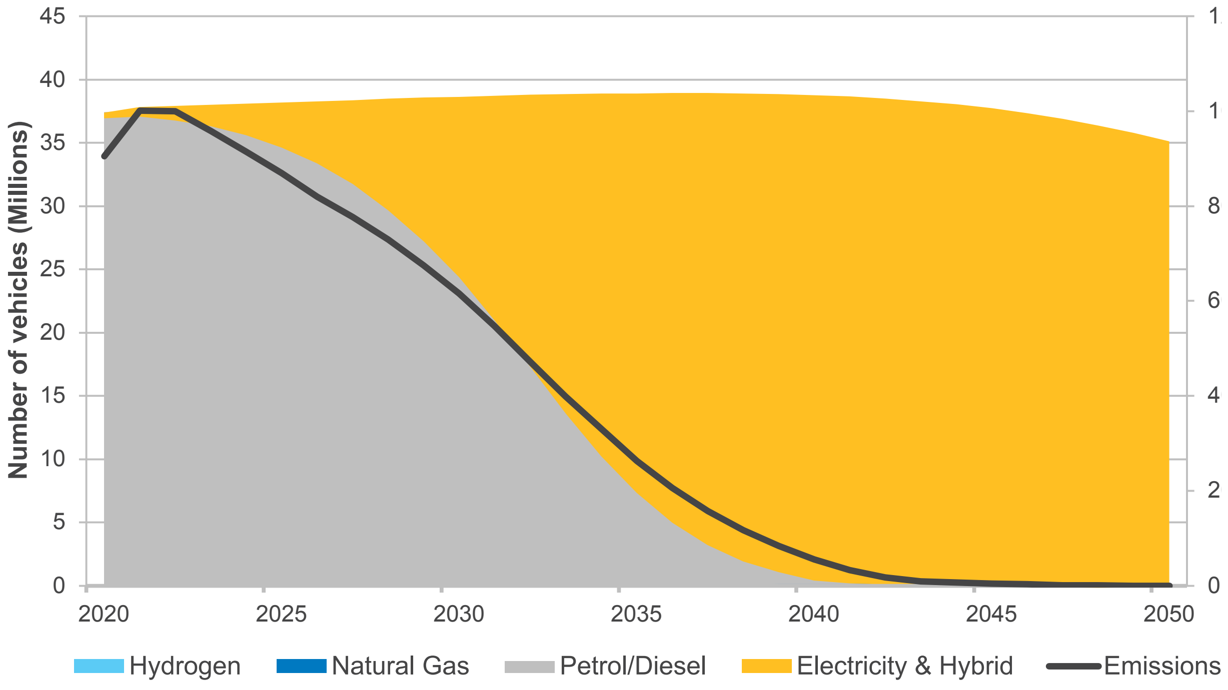
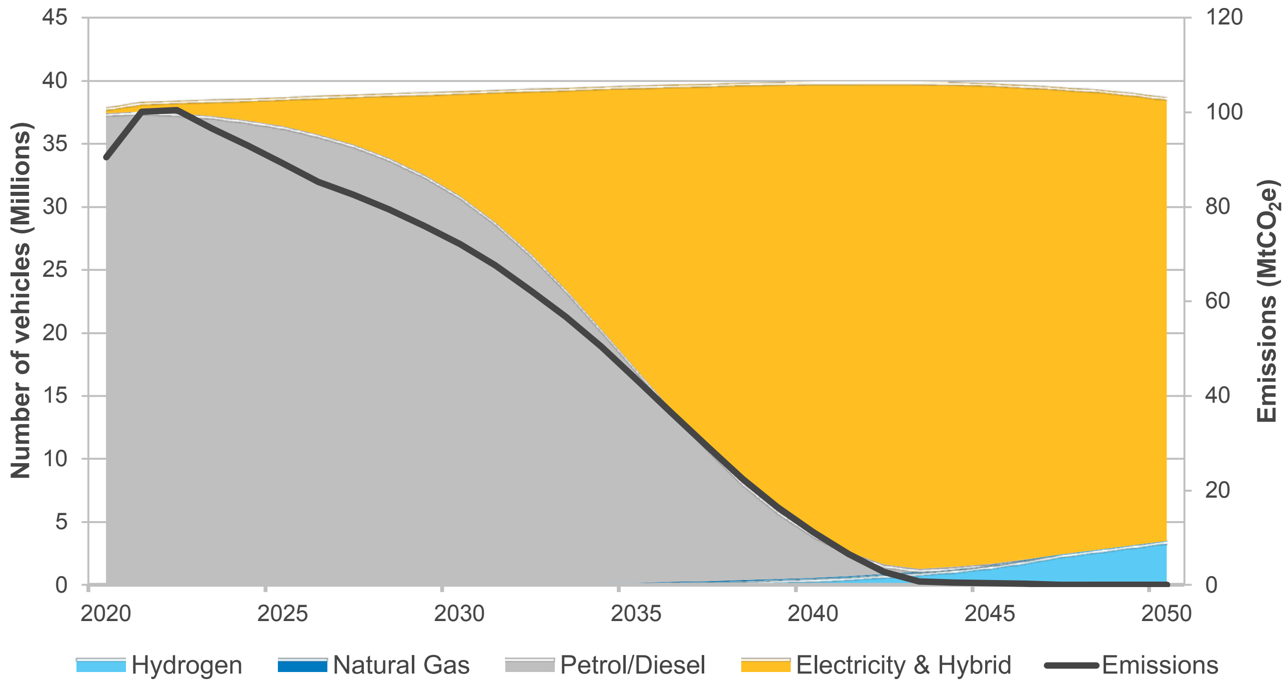


Figure NZ.19: Estimated number of vehicles in the UK and associated emissions in System Transformation



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Fuel switching

Figure NZ.20: Estimated number of vehicles in the UK and associated emissions in Leading the Way

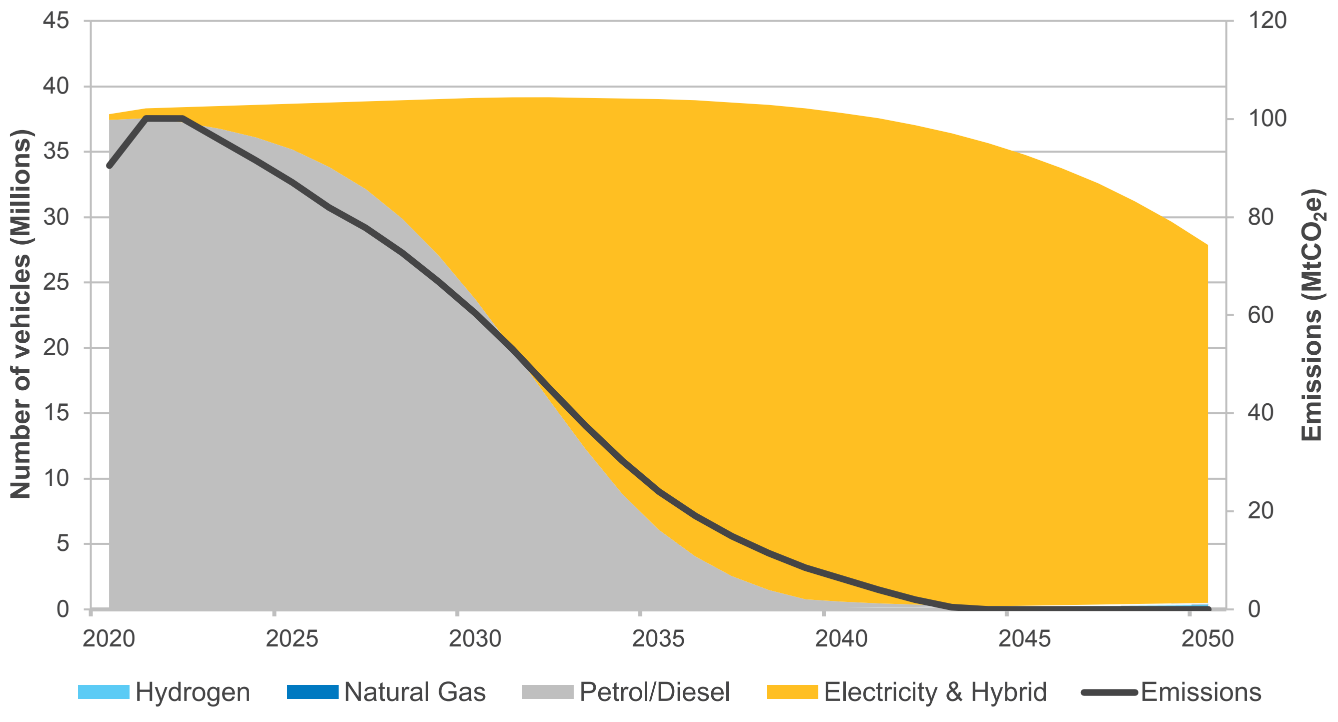
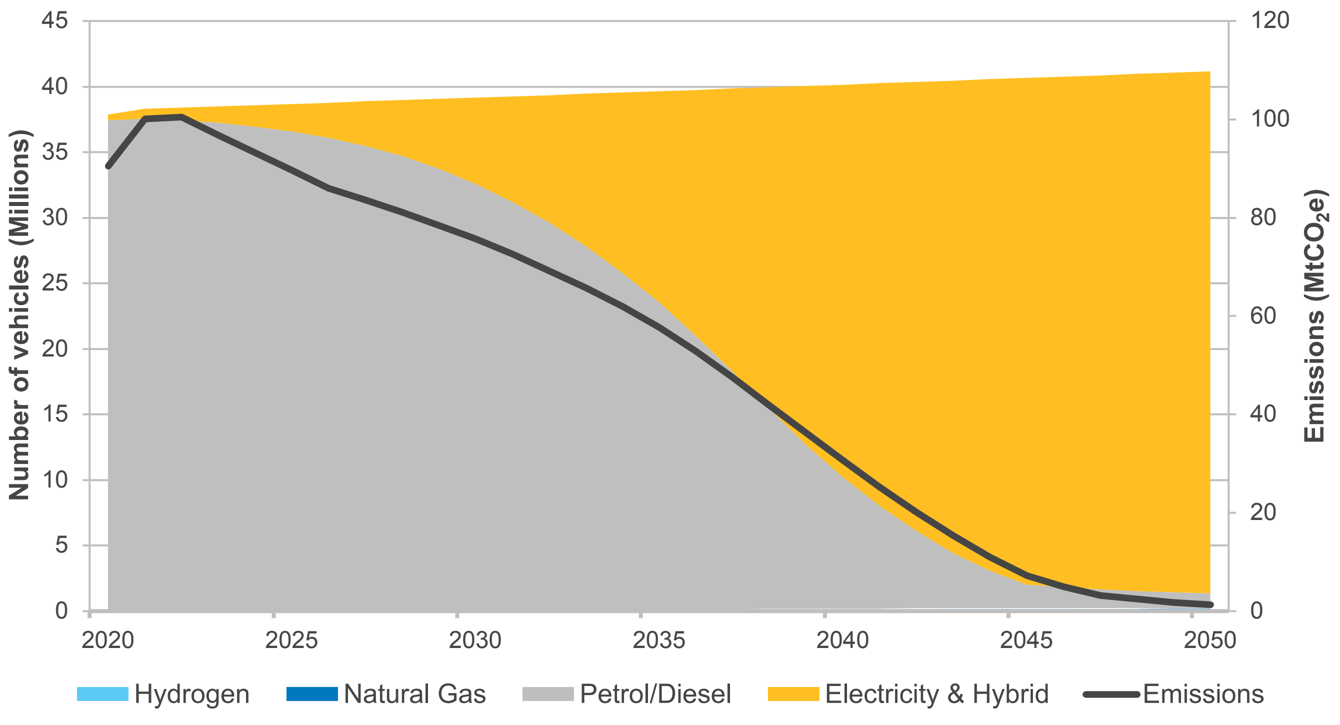


Figure NZ.21: Estimated number of vehicles in the UK and associated emissions in Falling Short



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Fuel switching

Fuel switching for heating

Figures NZ.22 to NZ.25 show the estimated number of heating technologies across the four scenarios and the associated emissions reduction to 2050.

The bulk of emissions in this sector currently come from heating via gas boilers. As gas boilers are phased out and other technologies such as heat pumps are installed, the level of emissions from heating reduces. It is important that the electricity used to replace gas boilers comes from renewable sources such as wind. This highlights the importance of whole energy system thinking when it comes to meeting net zero. System Transformation is the only scenario which uses high levels of hydrogen for home heating, the government will decide in 2025 if hydrogen should be used for home heating.

Transport and heating make up nearly 40% of total emissions in 2021, meaning if we are to meet our net zero ambition by 2050 we will need to see mass adoption of these technologies in the coming years. To aid consumers switching to these technologies, we must make sure our transition to net zero is fair, meaning people are able to adopt these new technologies in an affordable manner, while the system adapts to ensure the transition to these new technologies is as seamless as possible.

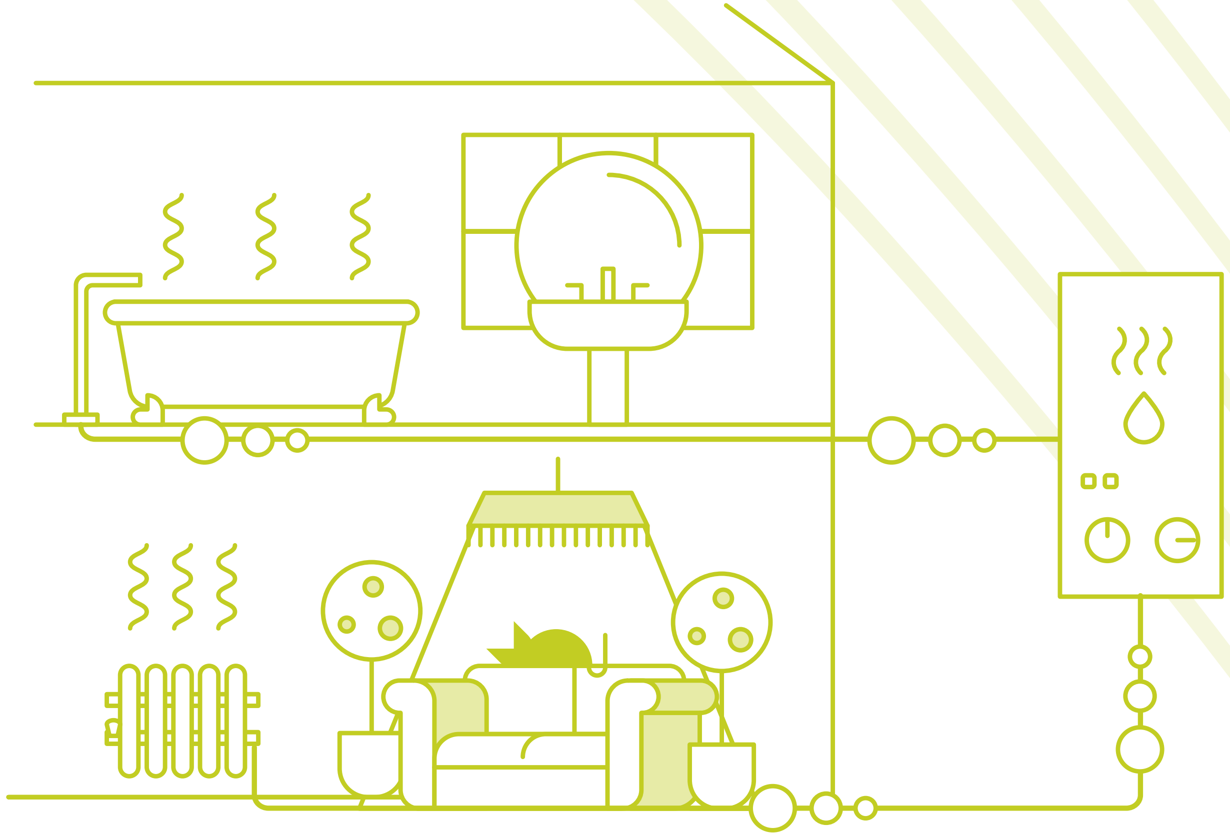


Figure NZ.22: Estimated number of heating technologies and the associated emissions reduction to 2050 in Consumer Transformation

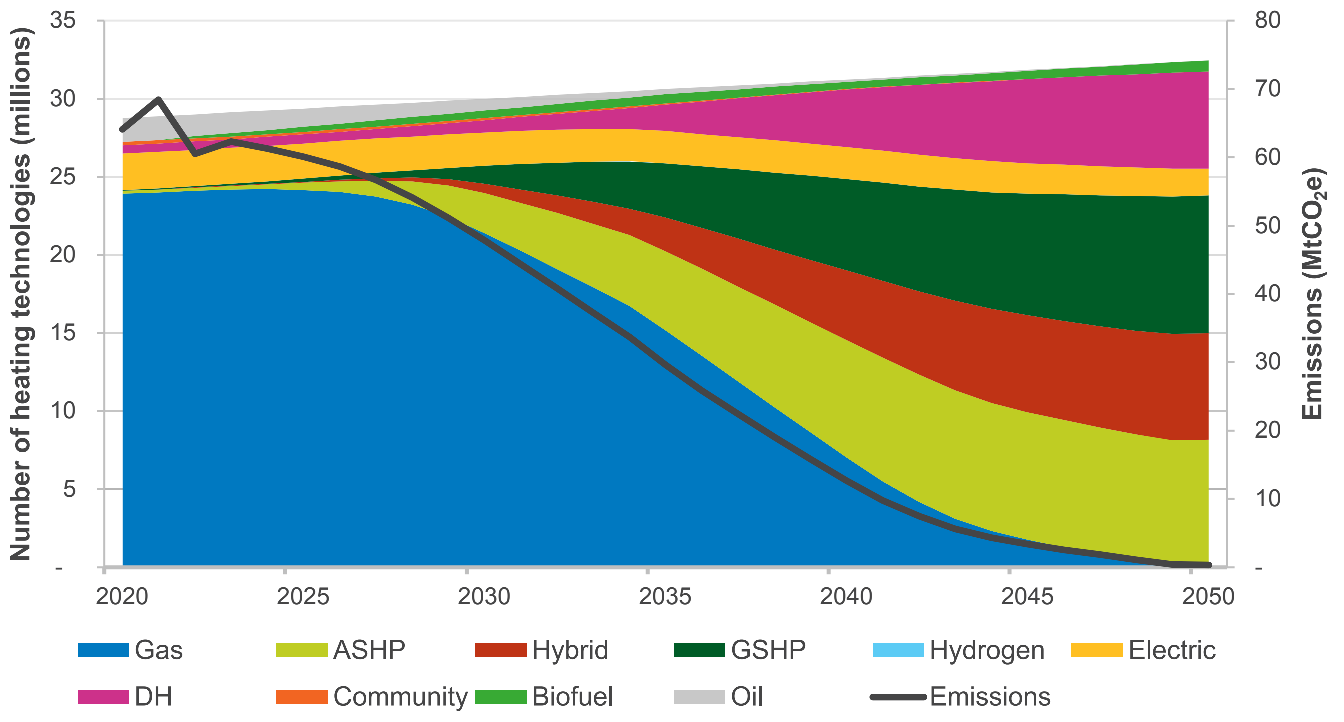
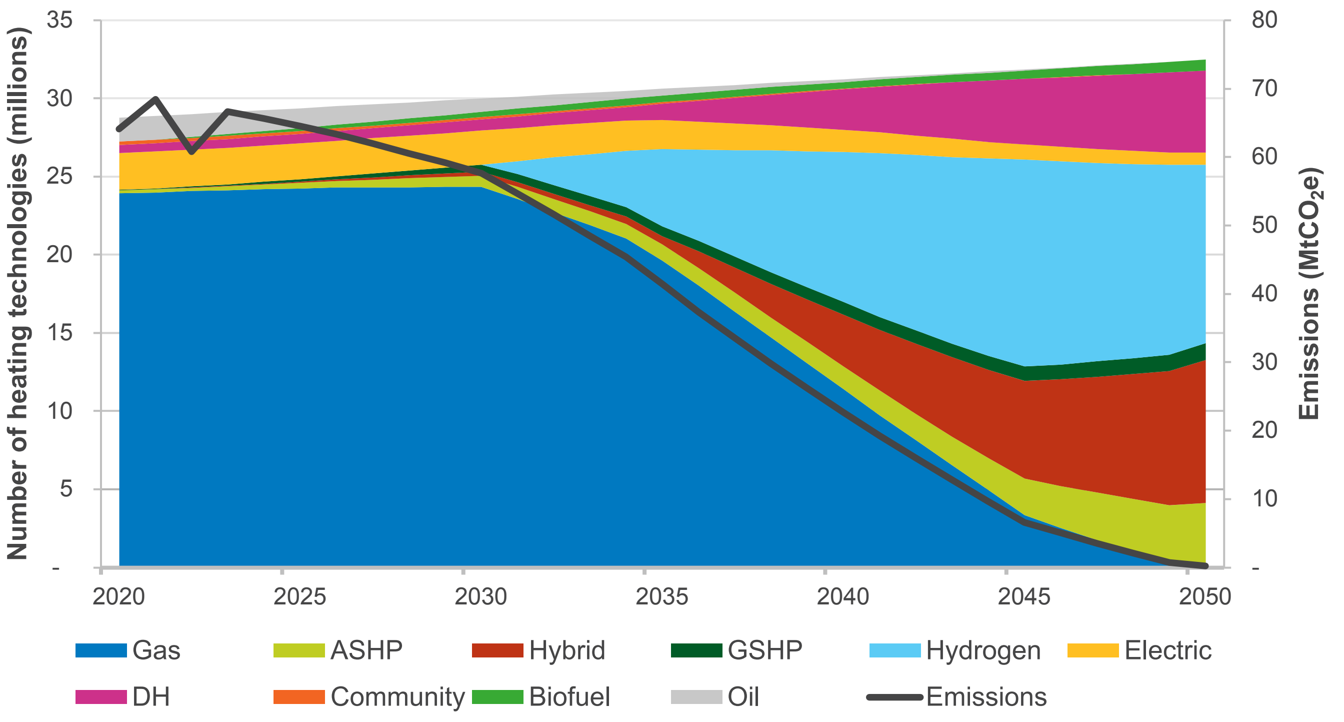


Figure NZ.23: Estimated number of heating technologies and the associated emissions reduction to 2050 in System Transformation



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Fuel switching

Figure NZ.24: Estimated number of heating technologies and the associated emissions reduction to 2050 in Leading the Way

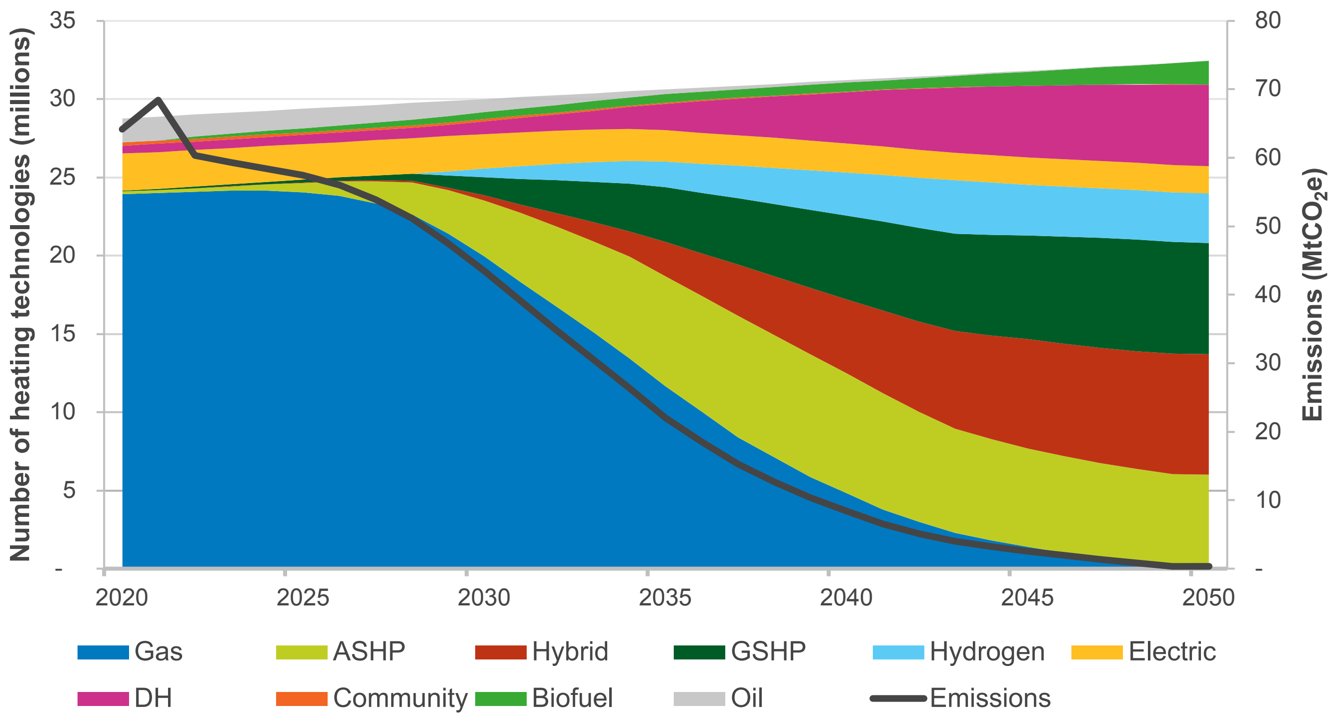
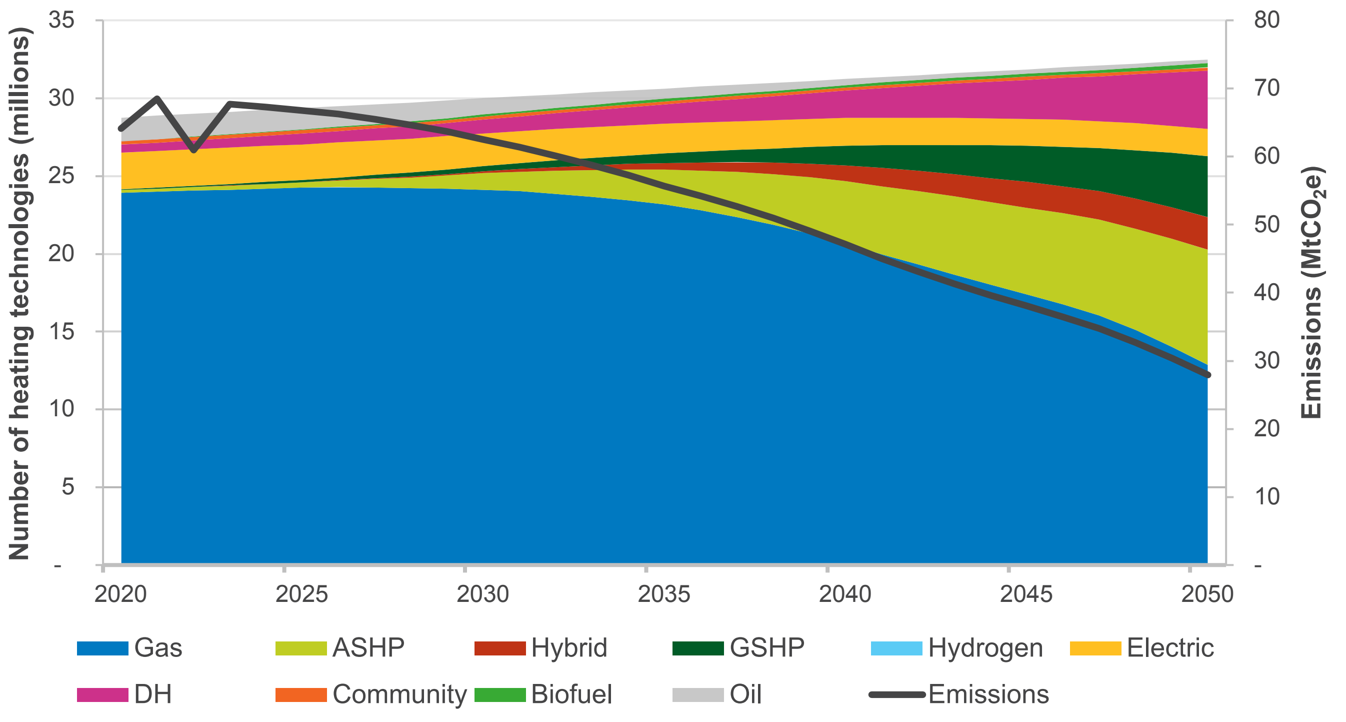


Figure NZ.25: Estimated number of heating technologies and the associated emissions reduction to 2050 in Falling Short



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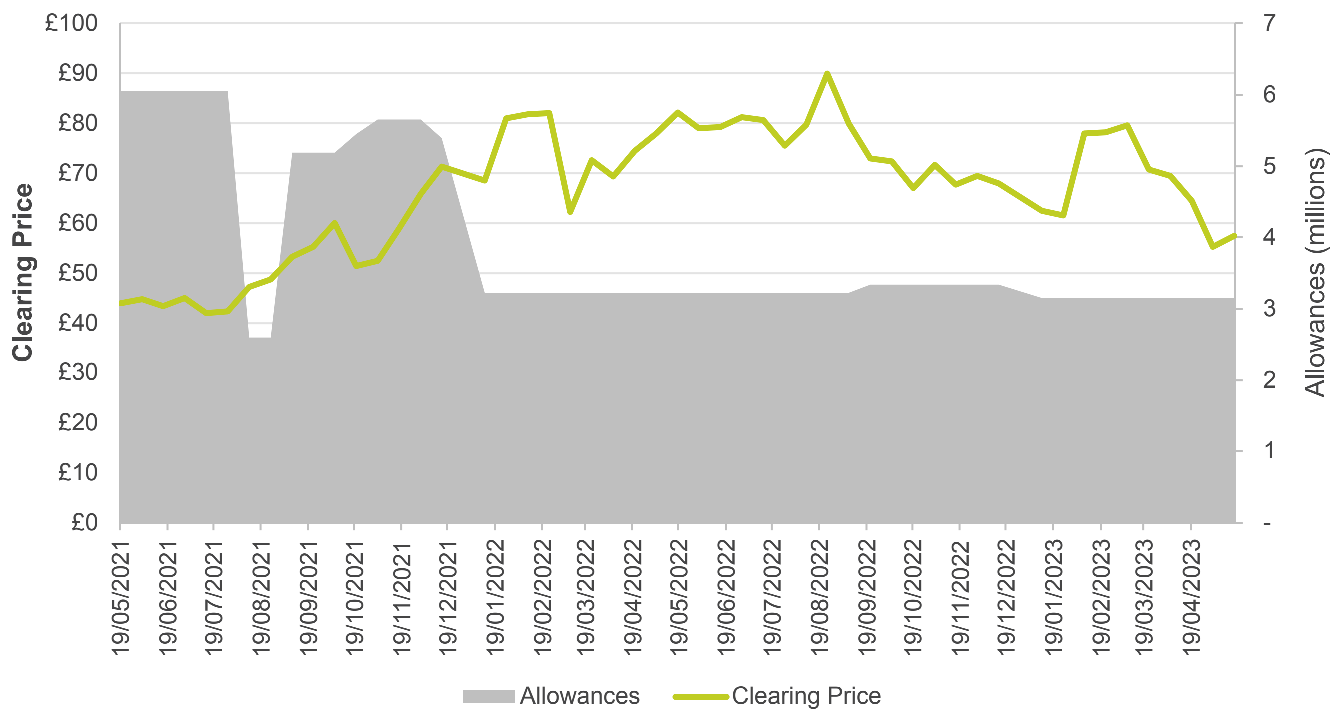
Carbon trading

In 2021 the UK ceased participation in the EU Emissions Trading Scheme (EU ETS) and now operates the UK ETS. The process works on a "cap and trade" system where the total number of greenhouse gas emissions for participating sectors can be limited, these limits will be decreased over time to help meet our net zero target and carbon budgets. Emissions can be traded on the secondary market if required and some sectors are given free allocations to avoid carbon leakage.[16]

Figure NZ.26 shows the clearing price and total allowances of the UK ETS since the first auction back in May 2021.[17] Since inception only one auction did not completely sell out (6th October 2021) and the unsold 1 million allowances were rolled over into the next four auctions.

We would expect, as the total number of allowances and exemptions decreases over time, the clearing price of CO_2 to increase, which in turn could incentivise competing industries to find alternative fuel sources. It is vital that the transition to fuel switching is fair, enabling and incentivising those who can decarbonise earlier without penalising those who can't.

Figure NZ.26: Clearing price and total allowances of the UK ETS since the first auction back in May 2021



16 gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets
17 ICE Report Center - Data (theice.com)

The Energy Consumer

Introduction

Consumers will play a bigger role in the energy system in future, but care must be taken to ensure fairness so changes to markets and policy have an equitable outcome for all consumers.

The energy price spikes seen over the past year have driven additional uncertainty in the short-term. The effects of COVID-19, followed by the energy crisis, has had unprecedented impact on consumers. This has driven challenging economic conditions as well as unprecedented energy costs with over 5 million households spending over 10% of disposable income on energy costs in 2023.[1] We have also seen changes to both how and when consumers use energy, for example with increased levels of home working. We expect prices to fall gradually over the next 18 months and to continue to see some level of price-related demand suppression until the end of 2024.

These recent developments placed added focus on consumer bills, while recent developments such as the ESO's Demand Flexibility Service (DFS)[2] that operated over winter 2022/23 highlighted the opportunities for consumers to be incentivised to actively engage with the energy system. Consumer engagement with the energy system through smart home devices enabling automation and shifting of energy demand offers an opportunity to meet net zero in the most cost effective way. Widespread uptake of demand side flexibility that maximises the use of variable renewable energy resources will result in a more cost effective energy system than building supply and transmission infrastructure to meet unconstrained electricity demand.

The extent to which consumers are willing and able to change their behaviour and lifestyle to enable the net zero transition has a high level of uncertainty. We explore this using our 'level of societal change' axis on our scenario framework. Societal change ranges from Falling Short where consumers are relatively unwilling to adjust their behaviour, through to Leading the Way where consumers actively engage with the energy system and provide high levels of demand side flexibility.

Rising inflation has put additional pressure on manufacturers of technologies such as Electric Vehicles (EVs), heat pumps and solar panels, offsetting some of the capital cost reductions that have been seen in recent years. The cost of living crisis and the spike in energy bills seen in 2022 also put added pressure on consumer budgets and has therefore increased awareness of energy costs and the impact on these of the net zero transition.

Energy costs can be reduced substantially by adoption of low carbon technologies and energy saving approaches that will play an important part in meeting net zero. For example, insulation of homes or energy efficiency improvements for appliances and businesses can help reduce energy costs substantially, while heat pumps are three times as efficient as gas boilers, and EVs are much more efficient than petrol or diesel vehicles. However, while many decarbonisation measures can be cost effective and save consumers money, there can be high up-front costs for new low carbon technologies. Appropriate incentives and support schemes need to be put in place to ensure that low carbon technologies are accessible to the whole population.

Further actions are needed from many parties across the energy sector to enable consumers to participate in the energy transition. This includes policy support from government, reform of energy markets and changes in tariff, technology and incentive offers to consumers, as well as consumer awareness and education initiatives.

1 policy.friendsoftheearth.uk/insight/whos-impacted-fuel-poverty-2023
2 nationalgrideso.com/news/demand-flexibility-service-delivers-electricity-power-10-million-households

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Total consumer energy demand

We expect total consumer energy demand to reduce in all scenarios in the medium and long-term, driven by savings from energy efficiency measures and electrification.

We see total energy demand fall in all scenarios, with consumer energy demand for residential, transport and Industrial & Commercial (I&C) demand falling significantly. We use the term consumer demand to represent the fuel used directly by these energy consumers. It does not cover additional demand for upstream primary energy sources or the conversion losses associated with production of some of these fuels, such as hydrogen. Residential demands exclude energy for Electric Vehicle charging as this is covered under transport demand. Aviation and shipping demand are also excluded but are explored in greater detail in the Net Zero chapter.

Figures EC.01 and EC.02 show falls in total consumer energy use across all sectors but most pronounced for transport and heat, which see the highest levels of electrification. EVs and heat pumps have much higher efficiencies than their fossil fuel counterparts, helping to significantly reduce energy demands, and therefore also to reduce the level of primary energy input needed to supply them. Energy efficiency improvements also play a key role in reducing demand, particularly in Consumer Transformation and Leading the Way.

This reduction in consumer demand has a range of impacts, most significantly on natural gas demand; all of our net zero scenarios reach close to zero (unabated) natural gas use by 2050. To decarbonise consumer energy demand either the fuel they use must be decarbonised or they need to shift to a zero carbon fuel. This can be through the shift to zero carbon electricity sources, low carbon fuels such as hydrogen or the use of Carbon Capture Usage and Storage (CCUS) alongside fossil fuel use.

There is a significant variation in the role of hydrogen in the scenarios, with Consumer Transformation seeing only limited adoption of this within industry, aviation and shipping, through to System Transformation which sees the development of a national hydrogen network and widespread hydrogen use across all sectors from residential heat to industry to Heavy Goods Vehicles (HGVs). Leading the Way has a more mixed picture. Hydrogen is used in limited quantities in certain areas for residential heat, generally in areas around industrial clusters with a local distribution network converted to deliver hydrogen but is more widespread in the I&C sectors.

The greater the level of electrification within a scenario, the lower the overall consumer energy demand. This is primarily due to the increased efficiency of electrified options compared to alternatives. For example, heat pumps have a much higher efficiency than gas boilers, and EVs a much higher efficiency than combustion engine or hydrogen fuel cell vehicles.

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Total consumer energy demand

Figure EC.01: Annual consumer demand in Consumer Transformation by fuel and sector

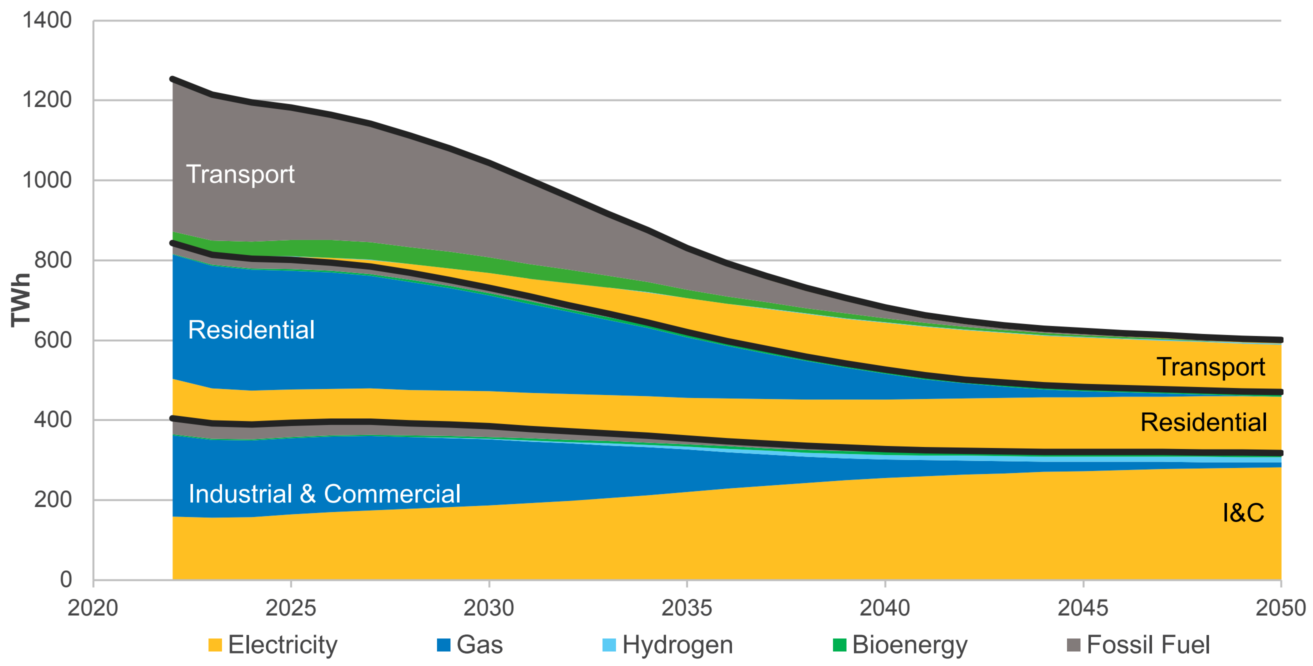
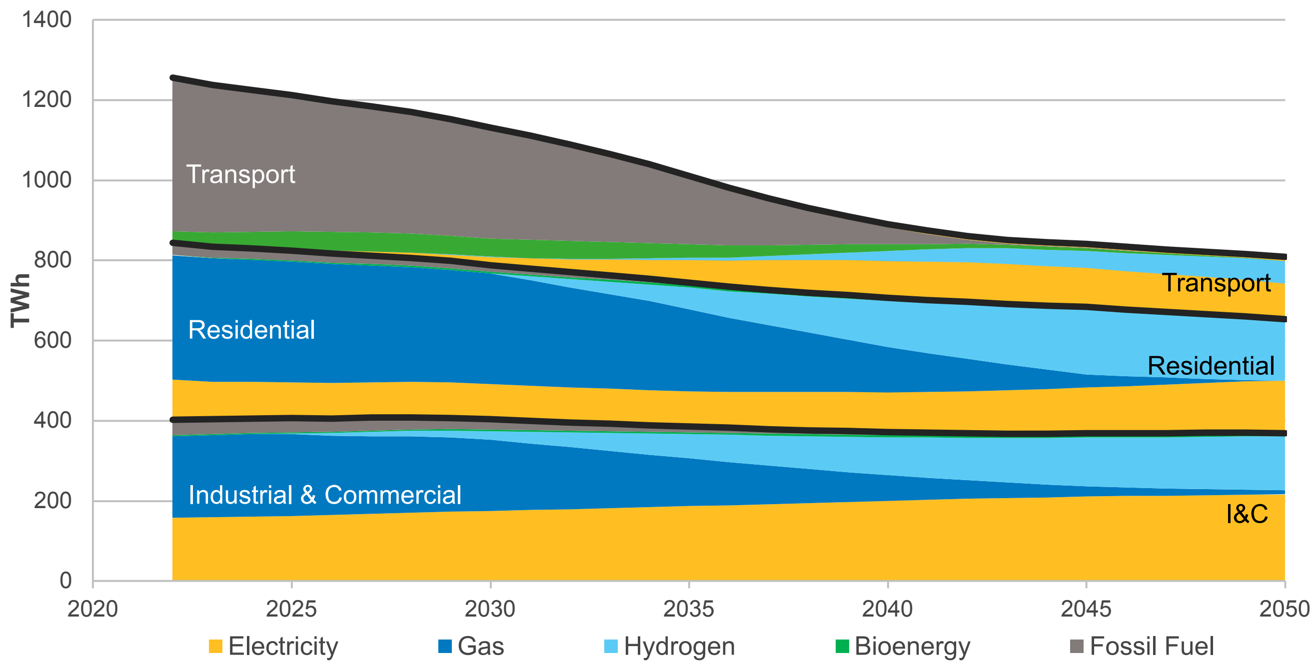


Figure EC.02: Annual consumer demand in System Transformation by fuel and sector



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Policy timeline / key comparison chart

CT Consumer Transformation
LW Leading the Way
ST System Transformation
FS Falling Short
Policy

This chart contains a selection of recent policy ambitions in relation to net zero and energy security and highlights how they compare to the different scenarios. Analysis for FES 2023 commenced before the publication of several key policy documents and does not signify that any individual targets cannot be met across the range of scenarios.

		2022	By 2025	By 2030	By 2035	By 2040	By 2045	By 2050	Maximum potential by 2050
Transport	Sales of petrol and diesel cars and vans banned	1.6m petrol and diesel cars and vans sold		CT LW (policy)	ST	FS			37m battery electric cars and vans FS
	Zero tailpipe emissions for all new cars	7% of cars sold			CT LW ST (policy)	FS			Zero ICE cars still on the road CT ST LW
	Zero tailpipe emissions for all new HGVs	<1% of HGVs sold				CT LW ST (policy)	FS		Zero ICE HGVs still on the road CT ST LW
Heating	600,000 heat pumps installed per year	Approximately 60,000		CT LW (policy)	ST	FS			1.6m per year CT
	4 in 5 homes not using natural gas boiler as primary heat source	1 in 5				LW	CT ST		100% CT ST LW
Natural Gas	Gas grid connection for new homes ends	>60%	CT LW (policy)		ST				0% LW
Industry	Annual industrial hydrogen demand over 10 TWh	<0.5 TWh		ST (policy)	LW		CT		88 TWh ST

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Key insights

Residential

- Further policy support and incentives are needed to increase uptake rates of heat pumps, in addition to the progress being made through the Boiler Upgrade Scheme (BUS). Based on the current environment and outlook, heat pump annual installation rates do not meet the Government's 600,000 per year target by 2028.
- Alongside this, a clear decision on the role of hydrogen in heating should be accelerated and heat pump targets and incentives reviewed accordingly. If heat pump take-up remains off-track in 2026 and hydrogen for heat is not supported, then the task of increasing heat pump uptake will be more difficult and expensive.
- Current and expected funding for home insulation is insufficient to deliver the levels of energy efficiency improvement in our net zero scenarios.
- Designating zones for specific heating systems provides a more cost-optimal system than full consumer choice, particularly when considering growth of technologies with greater local infrastructure requirements such as district heating or hydrogen for heat.
- Demand from electrical appliances is expected to continue to reduce in our net zero scenarios due to increasing energy efficiency.
- The Demand Flexibility Service has demonstrated the potential benefits to consumers and the energy system from mass participation in consumer flexibility.

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Key insights

Road transport

- Sales of electric cars are still accelerating, but further action is needed to meet the Government's target for no new sales of petrol and diesel cars by 2030. Electric Vehicle uptake rates remained strong in 2022 but face some challenging headwinds in the coming years that could jeopardise the 2030 ban date on new sales of petrol/diesel cars and vans.
- Careful consideration is needed to ensure there is fair transition and affordable, equitable access to charging infrastructure in the shift to EVs. There is the potential for different consumer segments to face different costs, due to use of different types of chargers, their accessibility and location.
- Optimal whole energy system outcomes that shift EV charging away from evening peak require appropriate technology development, incentives, tariffs and level of automation to be in place.
- Hydrogen is expected to start to play a role in road transport demand, particularly for larger vehicles such as HGVs and buses, but overall volumes will remain low other than in System Transformation, as electrification dominates among low carbon transport options.

Industrial & Commercial

- High energy prices, inflation and low economic growth are likely to help suppress energy demand in the industrial and commercial sectors in the short-term.
- Developments in the industrial sector suggest that fuel switching to hydrogen may take place further and faster than previously thought, with take-up expected to accelerate from the late 2020s onwards as subsidised hydrogen supply projects are brought forward. In the commercial sector, electrification of heat is frequently more cost-effective than use of hydrogen.
- Energy efficiency improvements are important to help offset increasing electricity demand from electrification in the industrial and commercial sectors.
- Industrial cluster locations for Carbon Capture Usage and Storage and hydrogen need to be carefully considered to maximise use of existing network infrastructure and avoid exacerbating system constraints.
- We expect high growth in energy demand in some sectors such as commercial data centres. This could represent up to 6% of GB electricity demand by 2030 from around 1% today, however there remains considerable uncertainty still in the range of the final energy demands for this sub-sector.

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Consumer energy demand

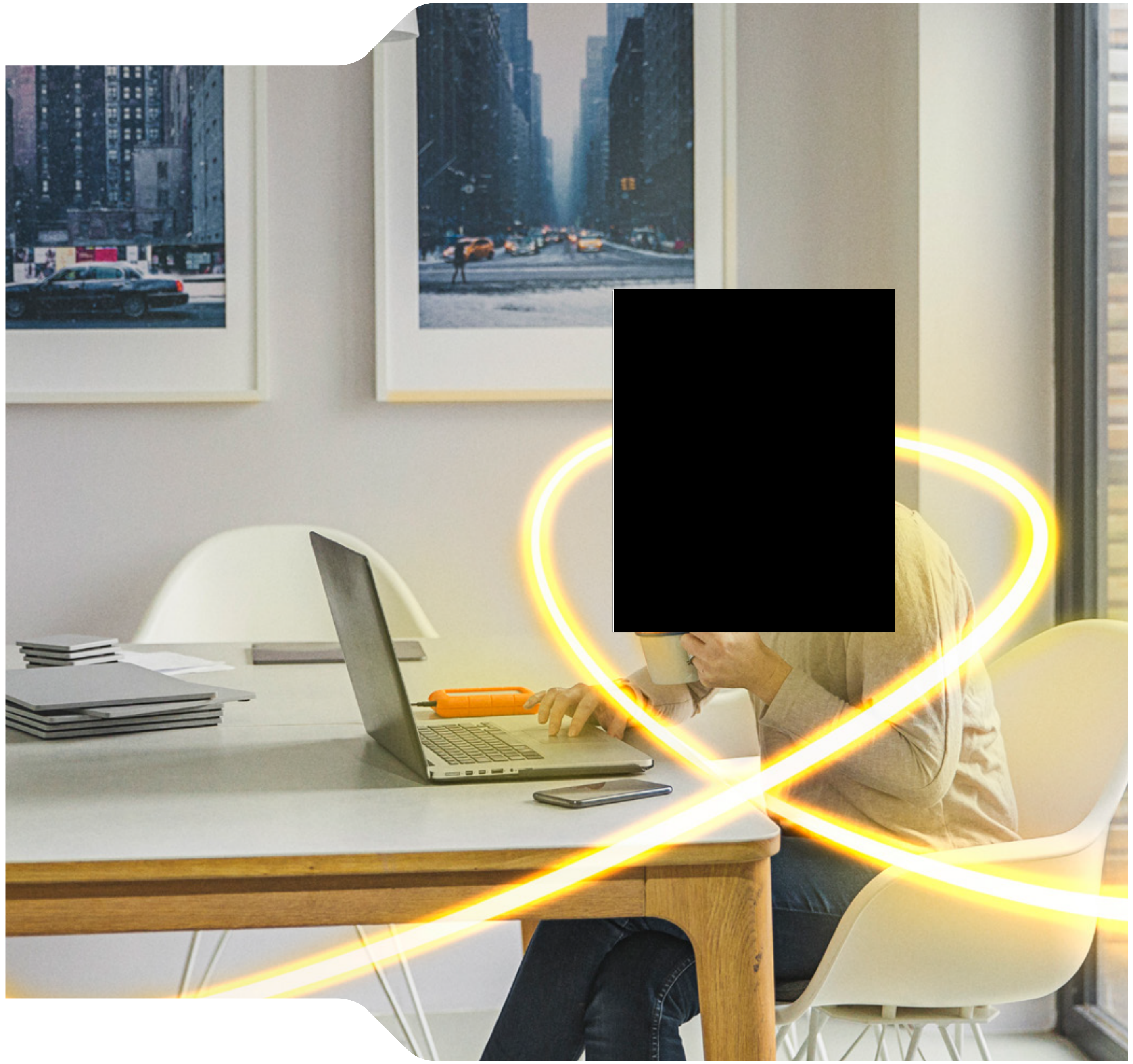
Total consumer energy demand[3] is expected to fall in the short-term, driven by the pressure of high energy prices, with gas demand seeing the biggest fall.

Between 2021 and 2022 there was a 9.5 TWh drop in weather corrected electricity demand, partly in response to the spike in electricity prices. This added to pre-existing trends of decreasing annual electricity demand, driven by increasing efficiency of lighting and appliances.

Electricity prices are expected to fall slightly over 2023, but the impact on consumers and the wider economy is expected to continue into 2024. After this we expect energy demands to be more driven by levels of economic growth, growing sources of electricity demand such as data centres and the electrification of heat and transport. Individual sector developments are explored in more detail in the rest of the chapter.

Gas demand is closely linked to energy demand for heating. In the short-term we saw this suppressed by higher prices, and in our scenarios this translates to up to a 1 degree fall in average indoor temperatures out to 2024 in Consumer Transformation and Leading the Way. Subsequent to this we also start to see greater deployment of insulation impact gas demands.

Consumer Transformation and Leading the Way see larger falls in electricity demand in the short-term, driven by accelerated residential appliance and lighting efficiency improvements. Furthermore, modelled reductions in indoor temperatures are reducing demand for heating compared to Falling Short and System Transformation. Beyond this, greater levels of electrification lead to accelerating electricity demand in the late 2020s into the 2030s.



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3 This section covers annual energy demands, peak demands are discussed in the Energy System chapter

Consumer energy demand

System Transformation sees some electrification of demand but also some gas demand being replaced by CCUS enabled hydrogen, keeping growth slower relative to Consumer Transformation and Leading the Way.

Higher electricity demand in Falling Short is primarily driven by assumptions of the lowest credible deployment of energy efficiency improvements, combined with a modest uptake of EVs and other electrified demand.

Fuel switching and adoption of alternate heating technologies across all sectors increasingly affects gas demand in the late 2020s across the net zero scenarios.

Figure EC.03: Total annual consumer electricity demand

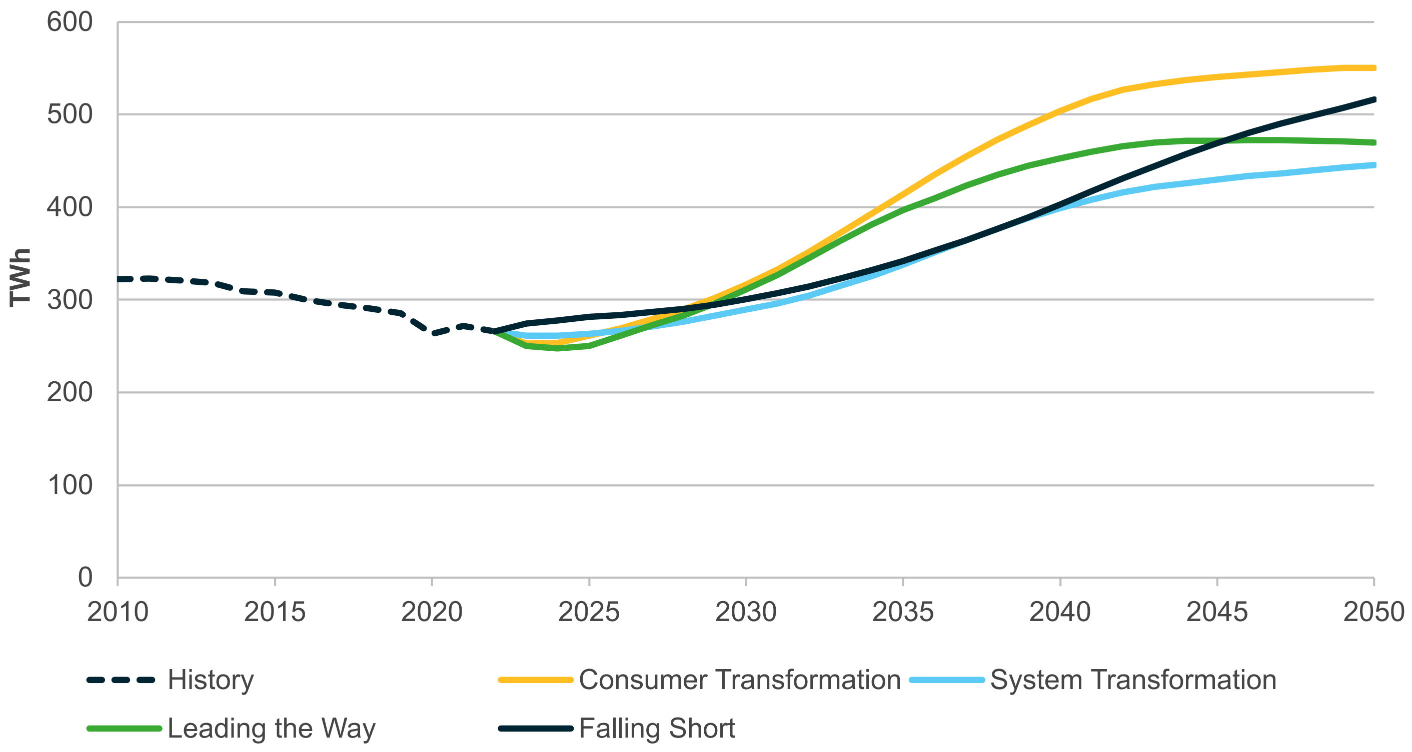
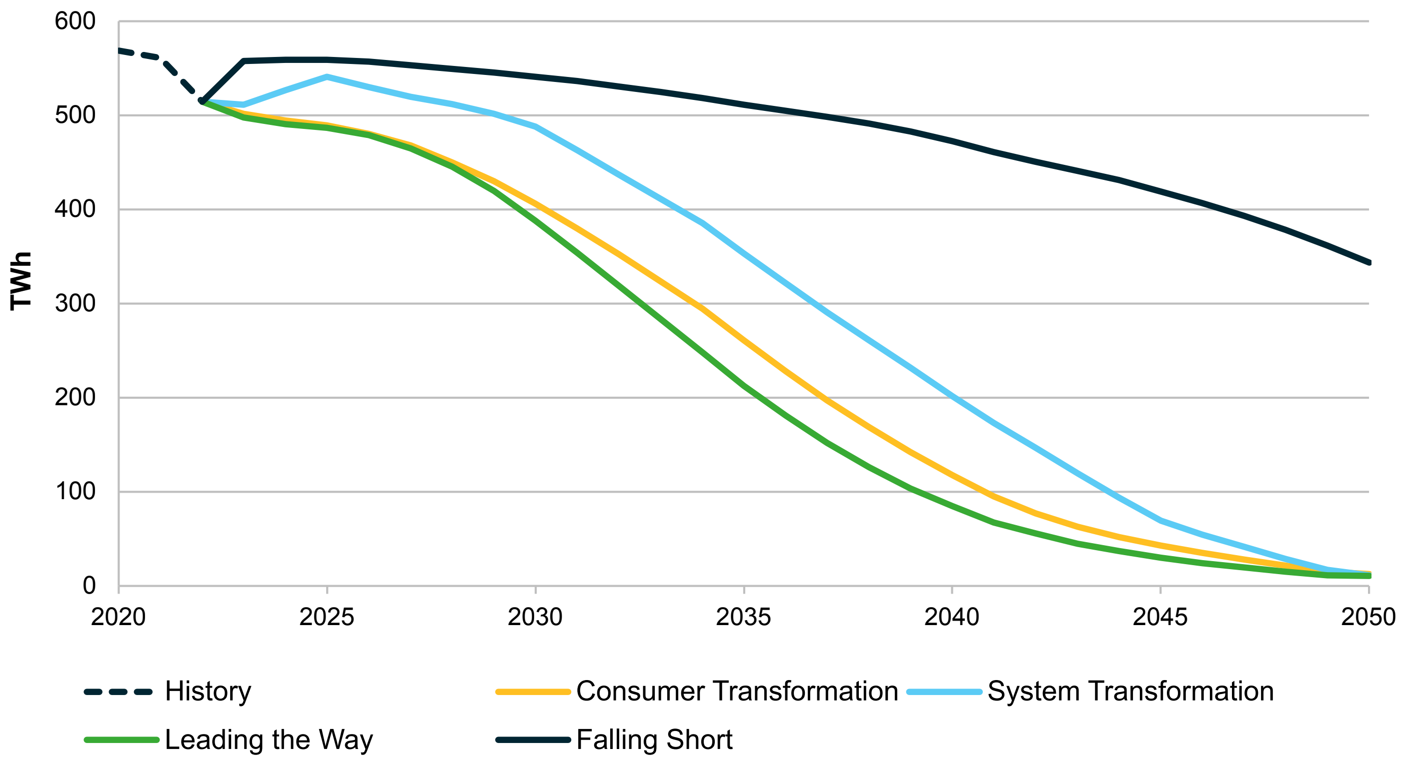


Figure EC.04: Total annual consumer gas demand



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Consumer Transformation

The route to 2050

- Heating and hot water demand is primarily electrified across all sectors. Residential heat pump installations exceed 600,000 by 2028, in line with the Government target. Industrial & Commercial electrification accelerates through the 2030s as strong carbon pricing encourages I&C consumers to switch away from unabated fossil fuels.
- Hydrogen production develops within industrial clusters and limited numbers of industrial consumers switch to use it in the 2030s. Some industrial consumers located outside of clusters who cannot electrify their demand begin to move to clusters from the 2030s.
- Energy efficiency plays a key role. From the early 2020s to 2035 homes are retrofitted with measures including insulation, triple glazing, and low carbon heating under government initiatives. Consumers also turn their thermostats down by 0.5°C on average to reduce heating demand. Uptake of energy efficiency measures in the I&C sectors increases through the 2020s, helping to suppress energy demand for heating and lighting.
- The 2030 petrol and diesel ban for cars and vans is met, followed by Plug-In Hybrid Vehicles (PHEV) from 2035. In the 2030s, uptake of battery electric lorries begins to increase and the 2040 target for all new HGVs to be zero emission is met.
- Smart charging of Battery Electric Vehicles (BEVs) is widespread and plays an increasingly important role as road transport is electrified.

What does 2050 look like?

- Total consumer energy demand is 601 TWh, 52% lower than today. Electricity meets 92% of consumer demand, while hydrogen meets only 3%.
- As this is our scenario with the highest levels of electrification, the use of Air Source and Ground Source Heat Pumps (ASHP and GSHP) is widespread. This scenario has the highest number of heat pumps – including hybrids - reaching over 23 million installations in homes by 2050. District heat networks are used in some areas, supplying 6 million homes, with hot water from large-scale heat pumps piped to homes.
- Hydrogen use in this scenario is limited, as there is no hydrogen used for residential or commercial heating. Hydrogen meets 7% of industrial demand, with some use in industrial clusters, and there is limited use for HGVs which rely on regional refuelling infrastructure, since there is no national hydrogen network in this scenario.
- Demand side flexibility is high, consumers respond to Time of Use Tariffs (ToUT) to change their demand at times of peak supply or demand on the local and national electricity networks. Smart appliances turn on, off, up or down throughout the day in response to changing supply and demand. Up to 45% of EV charging demand is shifted away from peak and highly engaged industrial and commercial users engage in Demand Side Response (DSR), shifting over 21% of peak I&C electricity demand to other time periods.
- Natural gas use is lowest in this scenario. It is used in limited amounts with CCUS in industrial clusters for very hard to decarbonise processes.

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System Transformation

The route to 2050

- This scenario sees the fastest growth in hydrogen demand. Hydrogen use grows in industrial clusters initially from the mid-2020s, with growth driven by carbon pricing, before spreading out from these locations in the 2030s for some residential and commercial customers. The gas network is entirely repurposed to deliver hydrogen in the 2040s allowing widespread uptake of hydrogen nationwide.
- Hydrogen-ready boilers and appliances such as hobs and kettles are installed from 2025 in readiness for switching the natural gas network to hydrogen from 2030. New build homes include hydrogen-ready boilers and appliances from 2025.
- Electrification plays a role in some areas, with growth in use of heat pumps for some residential and commercial consumers and widespread uptake of EVs. The ban on new petrol and diesel car sales is delayed until 2032. Sales of PHEVs are banned in 2035, along with new Internal Combustion Engine (ICE) van sales.
- From the mid-2030s, consumer uptake of Hydrogen Fuel Cell Vehicles (HFCVs) increases in line with the development of local and national hydrogen infrastructure. HGVs begin to decarbonise from the 2030s with the majority switching to hydrogen as a national refuelling network develops. The 2040 zero emission HGV target is met.

What does 2050 look like?

- Total consumer energy demand is 810 TWh, 36% lower than today. Electricity meets 55% of consumer demand, while hydrogen meets 42%.
- A national hydrogen network connects businesses and households across the country. Hydrogen plays a major role for heat with 57% of homes using hydrogen boilers for heating.
- Electrification still plays a significant role, with up to 14 million residential consumers using electric or hybrid heat pumps. Electricity meets 59% of I&C demand, up from 39% today.
- This scenario has our highest energy demand for road transport, primarily due to the higher uptake of hydrogen vehicles – over 3 million in total - and the subsequent lower efficiencies associated with using hydrogen compared to electricity.
- Lower consumer participation in DSR and less electrification – reducing the need for flexibility – means flexibility is lower than in our other net zero scenarios. However, there is some engagement with smart technology, appliances and tariffs. Over 50% of households use smart EV chargers at home or the office and up to one million private EVs engage with Vehicle-to-Grid (V2G) services. I&C customers shift up to 10% of their peak electricity demand.
- Natural gas is used in limited amounts with CCUS in industrial clusters for very hard to decarbonise processes.

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Leading the Way

The route to 2050

- Leading the Way has the fastest rate of decarbonisation across all sectors. In the residential sector annual heat pump installations reach 600,000 by 2026, ahead of the Government target. High energy prices incentivise uptake of energy efficiency measures across all sectors. The sale of natural gas boilers is banned by 2035.
- Retrofitting residential thermal efficiency improvements takes place from the mid-2020s, helping to offset increases in electricity demand from earlier heat pump installations. Consumers also turn their thermostats down by 1°C on average to reduce heating demand.
- High gas prices and strong carbon pricing encourages industrial consumers to switch away from unabated fossil fuels towards electricity and hydrogen from the mid-2020s. Hydrogen production in industrial clusters ramps up rapidly in the 2020s, ensuring that the industrial users aren't constrained by fuel availability.
- The development of local hydrogen networks starting from industrial clusters leads to an increase in hydrogen boiler and hybrid heat pump installations for residential and commercial customers in these areas from 2028. Availability of hydrogen remains limited by location, and so electrification is still the most common route for decarbonisation.
- The petrol and diesel ban is effective for cars and vans in 2030. PHEV sales are banned from 2032. Cars and vans are mainly electric, supported by the widespread national rollout of charging infrastructure, as well as smart charging devices at home. All HGVs are zero emission by 2040, in line with the zero emission HGV target and are primarily electrified.

What does 2050 look like?

- Total consumer energy demand is 630 TWh, 50% lower than today. Electricity meets 75% of consumer demand, while hydrogen meets 20%.
- Electrification is the dominant solution for heat, 64% of households have heat pumps (including hybrids), while 10% of homes have only hydrogen boilers. Over 1.8 million homes previously off the gas grid now use biofuel boilers or hybrid systems with a heat pump and a biofuel boiler.
- Hydrogen use is widespread but limited by locational availability. It meets 23% of I&C demand and 25% of residential demand.
- There are the fewest number of cars on the road in this scenario, at around 25 million, as availability of shared-use Autonomous Vehicles (AVs) starts to displace some car ownership. Many consumers also choose public transport, or use ride hailing apps for longer journeys.
- Leading the Way has the highest level of flexibility. In homes, thermal storage is used at times of peak demand to avoid high energy prices. Highly engaged I&C consumers engage in Demand Side Response, shifting up to 14% of their peak electricity demand to other time periods. BEV cars smart charge at home or at the office, frequently paired with on-site solar Photovoltaic (PV) and batteries to encourage self-consumption.
- There is some limited use of natural gas with CCUS in industrial clusters for very hard to decarbonise processes.

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Falling Short

The route to 2050

- Total demand falls gradually through the 2020s, driven primarily by electrification of passenger vehicles. Despite this the Government's target is missed, and the petrol and diesel new car sales ban comes into place from 2035, with PHEVs and vans sales banned from 2040.
- Limited progress is made in decarbonising heat. Some uptake of residential and commercial heat pumps is seen in the 2030s, but natural gas remains the dominant heating fuel until the 2040s. The 2025 Future Homes Standard is not met, but some new builds have heat pumps installed where it is seen to be cost effective.
- Energy efficiency improvements are limited. There is limited government policy to encourage consumer investment in thermal efficiency measures such as insulation or triple glazing and little to no additional policies exist to encourage widespread purchasing of highly efficient appliances like washing machines and computers.
- In the transport sector, all HGVs lighter than 26 tonnes are zero emission by 2040, primarily through electrification. There is also some growth in natural gas fuelled passenger vehicles.
- Industrial cluster development is slow, with limited levels of hydrogen production, and low levels of direct demand for hydrogen from industry.

What does 2050 look like?

- Total consumer energy demand is 907 TWh, 28% lower than today. Electricity meets 57% of consumer demand, while natural gas meets 37%.
- Nearly 40% of homes still use gas boilers for heating. Some consumers install heat pumps, particularly post-2035, but take-up of insulation or thermal storage measures alongside this is limited.
- There is no hydrogen network and very limited use of hydrogen in industrial clusters only. There is no direct use of hydrogen for heat.
- There are around 38 million BEV and PHEV cars and vans on the road – the highest out of all scenarios.
- Demand side flexibility is low. In residential properties, while some appliances are highly efficient, most are not smart and cannot provide flexibility at times of peak supply or demand. EV smart charging provides the highest level of flexibility with over 50% using smart chargers at home or at the office. However, only 5% of households take part in V2G services, and relatively few I&C consumers engage in Demand Side Response, shifting only 6% of peak electricity demand to other time periods.
- Natural gas continues to play a major role, meeting 42% of I&C and 46% of residential energy demand.

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Heat

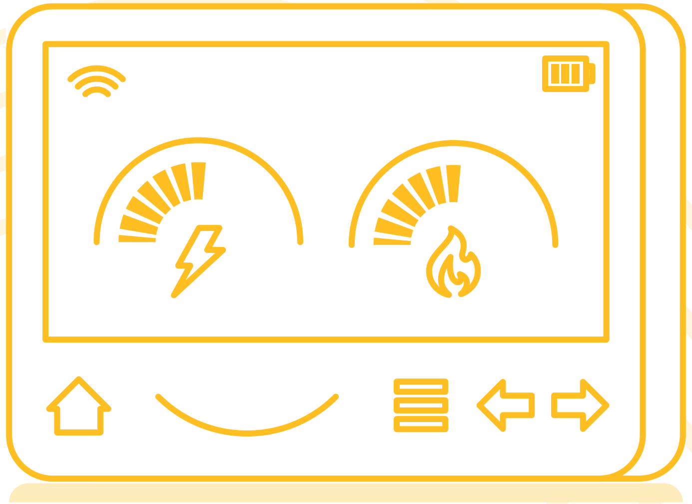
Energy demand for residential heat has fallen due to price-based demand suppression. Longer-term it will be significantly affected by choices on future heating technologies.

Energy demand for heat is driven by how much we consume, which is affected by comfort levels, energy efficiency measures and energy prices. In FES we assume average weather conditions, so while real consumption is affected by weather year-to-year, our scenarios remain comparable year-to-year by removing this effect. Longer-term, energy demand is also affected by changes in heating technologies used. This will be driven by government policy, proximity to hydrogen networks, and technology developments.

We have seen reductions in consumer gas and electricity demand for heat driven by high energy prices impacting consumer behaviour. In Leading the Way and Consumer Transformation we assume high levels of consumer engagement lead to climate-conscious consumers being willing to make changes to help reduce energy demand. We model reductions in average home temperatures of 1 degree and half a degree respectively which can suppress heat demand by up to 13% and 7%. These scenarios also assume higher levels of energy efficiency and so these measures are less likely to affect internal comfort. Recent price-related demand suppression has pushed demands closer to these scenario assumptions, but for different reasons.

In the late 2020s, we see a rapid acceleration of electricity demand for heating in the more electrified scenarios of Consumer Transformation and Leading the Way as heat pump take-up accelerates, with a corresponding reduction in gas demand. In System Transformation the planned transition to hydrogen boilers depresses electrification and heat pump uptake rates.

The longer-term outlook for gas and electricity demand for heat sees a rapid acceleration of electricity demand for heating in the late 2020s and 2030s in the more electrified scenarios as heat pump take-up accelerates, with a corresponding reduction in gas demand. In System Transformation the planned transition to hydrogen boilers depresses electrification and heat pump uptake rates.



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Residential

Figure EC.05: Domestic annual gas demand for heat

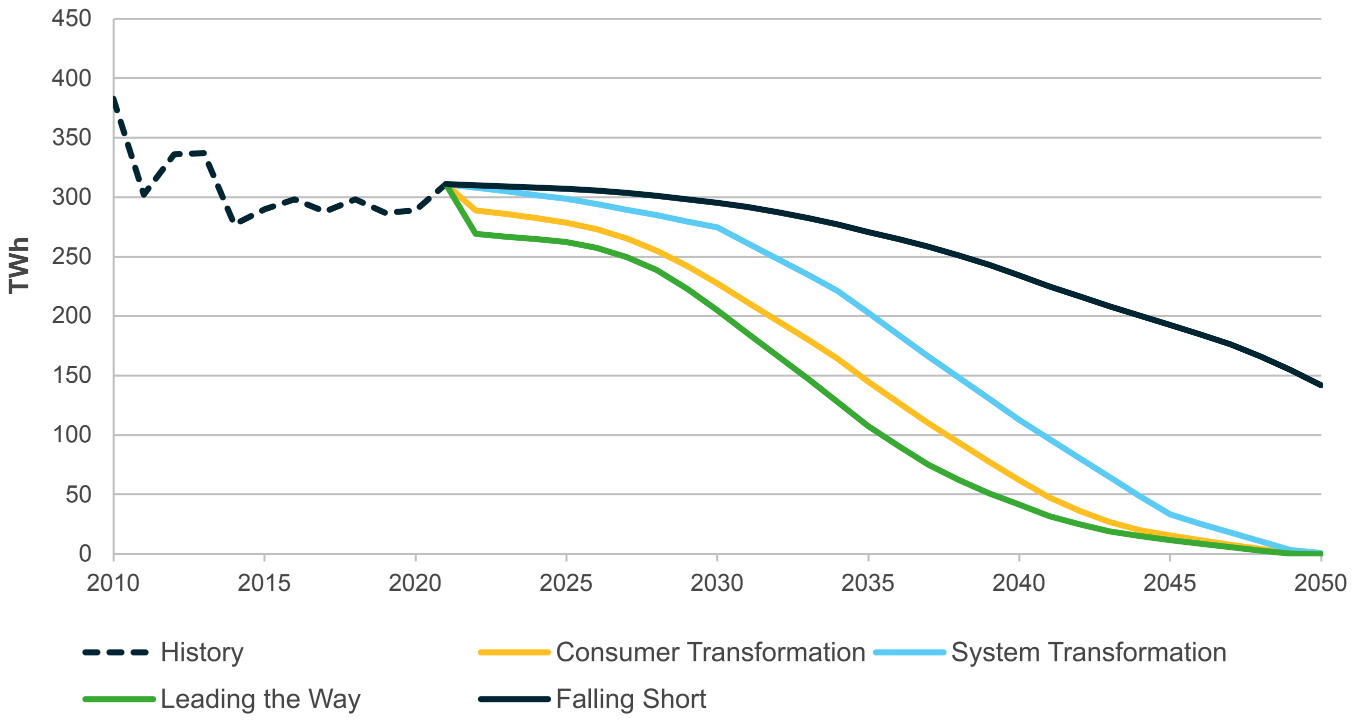
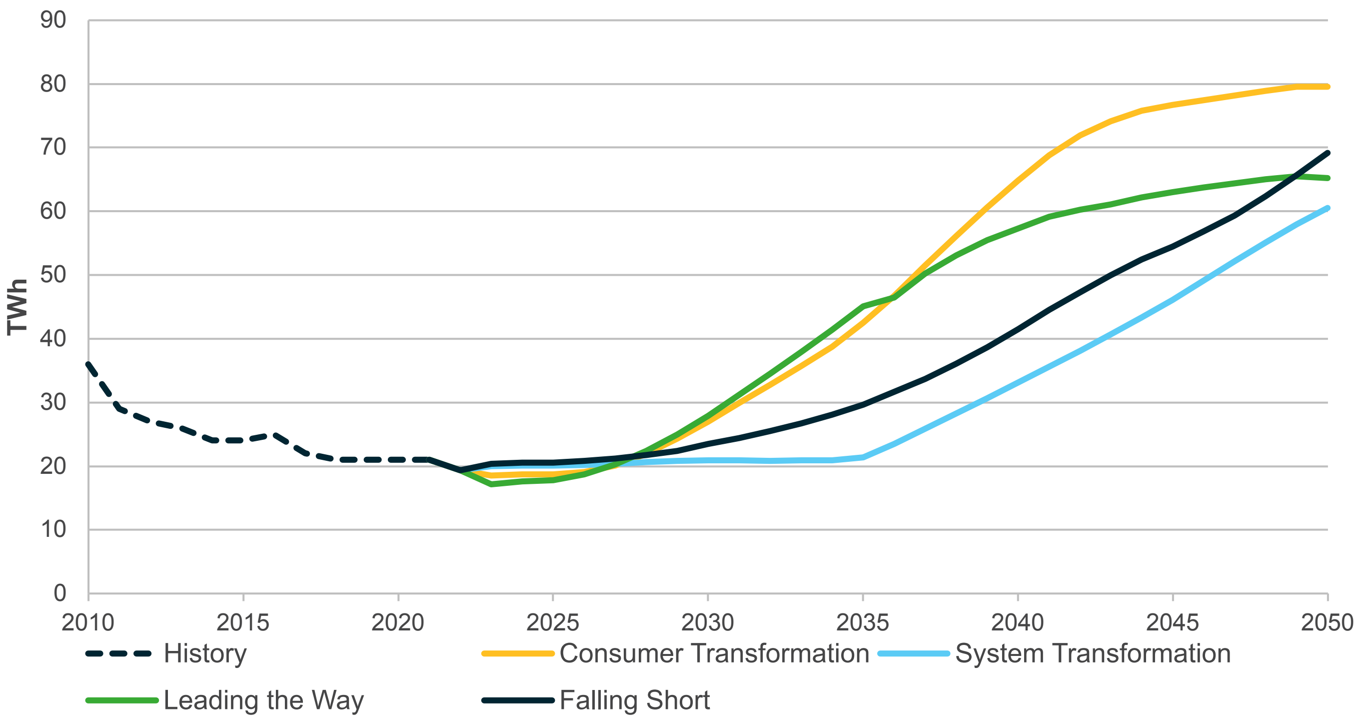


Figure EC.06: Domestic annual electricity demand for heat



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Energy efficiency

Current and expected funding for home insulation is insufficient to deliver the levels of energy efficiency improvement in our net zero scenarios.

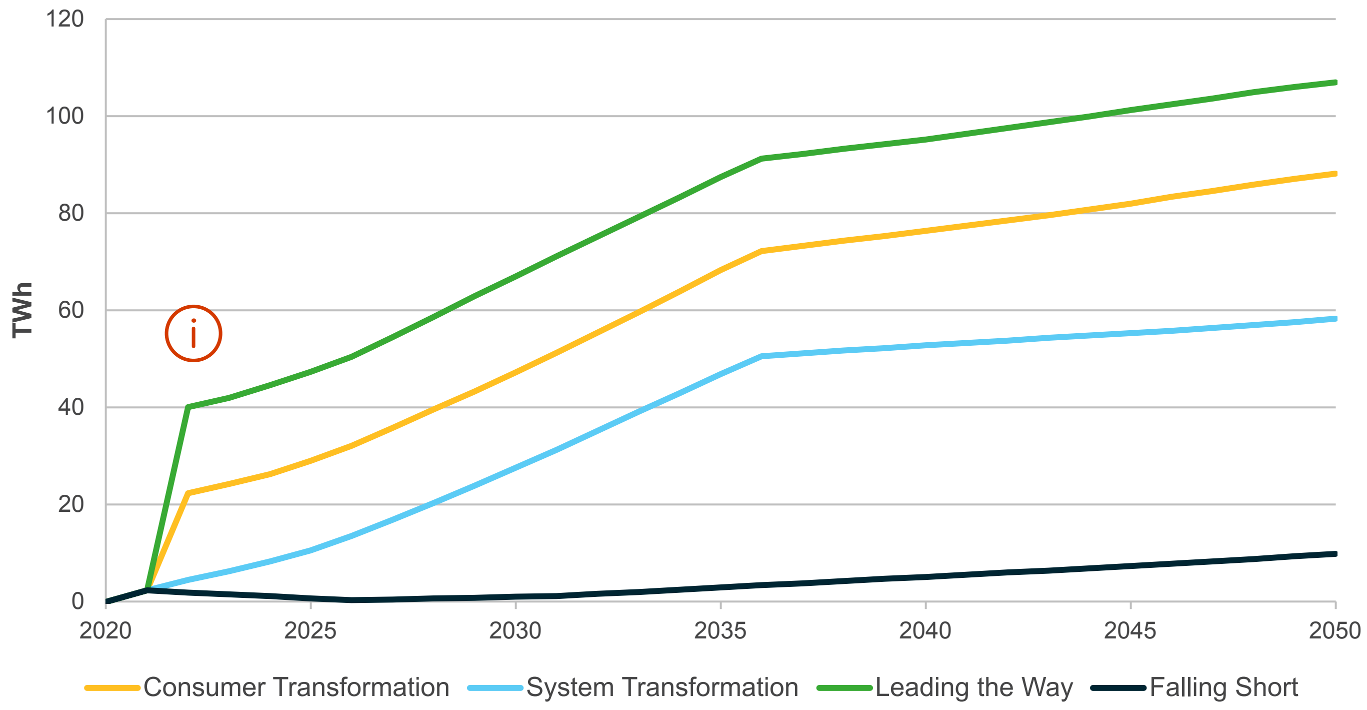
Adoption of thermal efficiency measures in homes – particularly from the early 2020s to mid-2030s – is key to achieving net zero emissions by 2050 in the residential sector. It needs to be supported by a nationwide government policy to encourage extensive retrofitting, alongside the increase in energy efficiency standards expected in new build properties driven by the Future Home Standard from 2025.

Improving home insulation upfront is needed to create a cost optimal heating system. Insulation gives high value return when considered in the context of total heating system cost, particularly for heat pumps. Insulating homes reduces costs due to efficiency improvements for the heat pump being able to run at lower temperatures, and the subsequent need for a smaller heating system which reduces capital cost as well as reducing peak and annual electricity demand.

Current funding for home insulation is below the level assumed in our net zero scenarios, which puts us at risk of a future energy system that has higher overall costs for residential heat. This can be seen in Figure EC.07 showing the underlying savings from fabric insulation measures.

Addressing this and increasing energy efficiency improvements must be a priority for government to enable a decarbonised heat sector.

Figure EC.07: Cumulative savings in underlying heat demand from applying fabric insulation measures to existing homes, higher standards in new builds and consumer behavioural change



Demand reduction jumps immediately in Consumer Transformation and Leading the Way due to their assumed 0.5 and 1 degree internal temperature reductions respectively.

Heat pump uptake

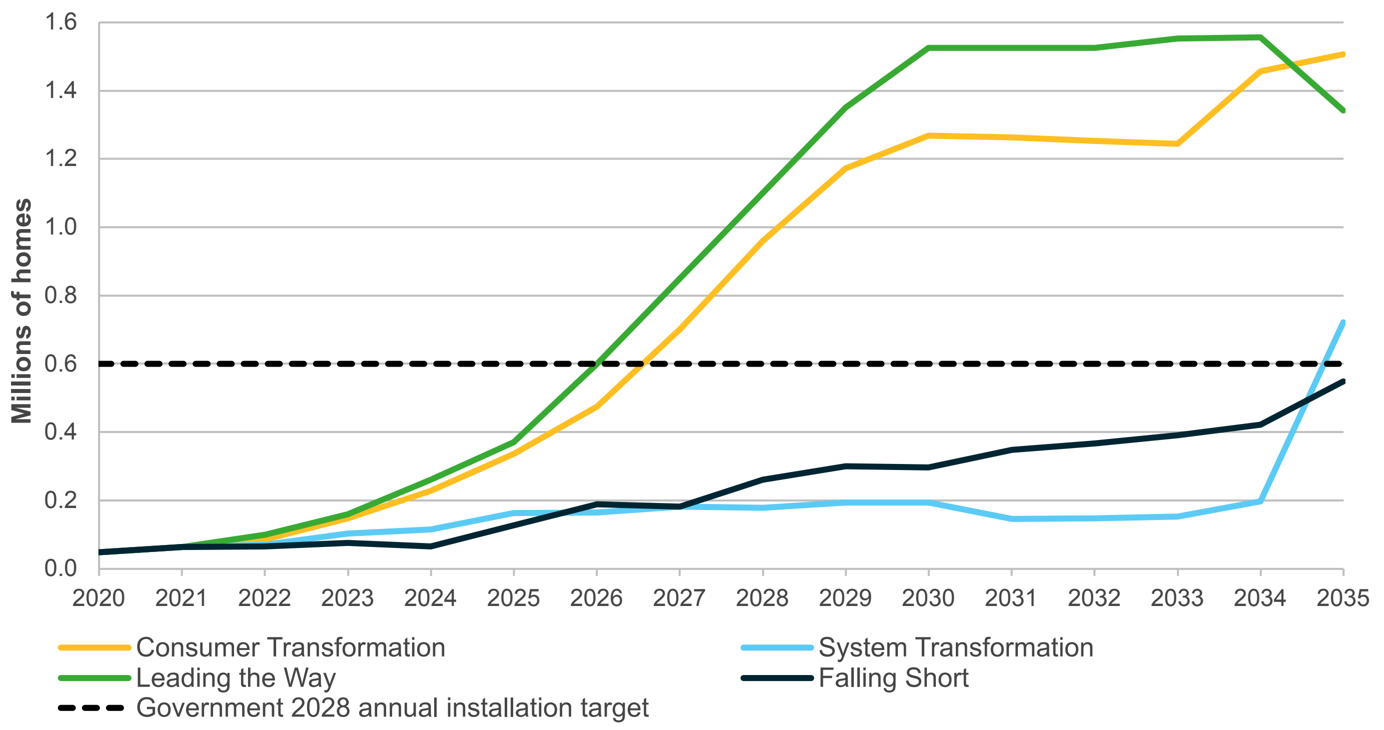
Current incentives are insufficient to drive uptake of low carbon heating technologies to stay on track with scenarios which meet the 2028 heat pump installation target.

Electrification of heat remains a major component of residential decarbonisation. The Government target is for 600,000 annual heat pump installations by 2028, up from around 60-80,000 today. Current incentives are insufficient to drive uptake of low carbon heating technologies to stay on track for this target and so it is only met in the Leading the Way and Consumer Transformation scenarios.

The Boiler Upgrade Scheme is the current policy incentive for residential heat pump installation, offering up to £5,000 off the up-front capital cost of installation of an Air Source Heat Pump. The scheme is budgeted to support the installation of up to 90,000 heat pumps per year until 2026, however as yet, demand has remained low, with only 32% of available first year funding claimed within the initial 12 months. This indicates that the scheme alone is unlikely to be sufficient to drive heat pump installations close to the target by 2028, and we believe it is credible that this target is missed as shown in our Falling Short and System Transformation scenarios.

The Future Homes Standard, which is due to come into force in 2025, is likely to drive additional uptake of heat pumps in new build properties. This drives installations in new builds alone to 90,000 per year from 2025, representing 75% of all new build properties, with no new homes connected to the gas network after 2025.

Figure EC.08: Annual heat pump installations[4]



4 Includes Ground Source Heat Pumps, standalone Air Source Heat Pumps (ASHP) and hybrid ASHP installations

Residential

System Transformation does not meet the 2028 installation target, however, this scenario still has a credible pathway to meeting net zero on this trajectory due to its later adoption of hydrogen boilers. Heat pump uptake is currently tracking System Transformation, and if the UK matches the heat pump uptake levels seen in this scenario through the 2020s, but hydrogen for residential heat is not seen as a viable solution when the decision is made in 2026, then the UK will be well off track for the uptake of heat pumps needed to decarbonise residential heat. The task of bringing heat pump uptake up sharply from this point will also then be more difficult and expensive.

The highly electrified Consumer Transformation scenario reaches at least 900,000 heat pump installations per year by 2028. This assumes additional levels of support to reach this and an assumption that hydrogen is not used for residential heat.

There are two main drivers that could increase heat pump uptake from its current low level. The first is a reduction in up-front capital costs from the manufacturer, technology development and innovation, or an expanded government support scheme to support greater volumes of heat pump installations.

The second is a reduction in ongoing running costs. This could be from reductions in electricity prices through the rebalancing of policy levies between electricity and gas, through improvements in heat pump efficiencies, or from direct subsides. A 10% increase of heat pump Coefficient of Performance (CoP) would be expected to increase heat pump uptake by up to 15% by 2028. More drastic measures, similar to the German Government ban on new gas and oil heating systems in homes from 2024 onwards, could also have a significant effect.

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Hydrogen boiler uptake

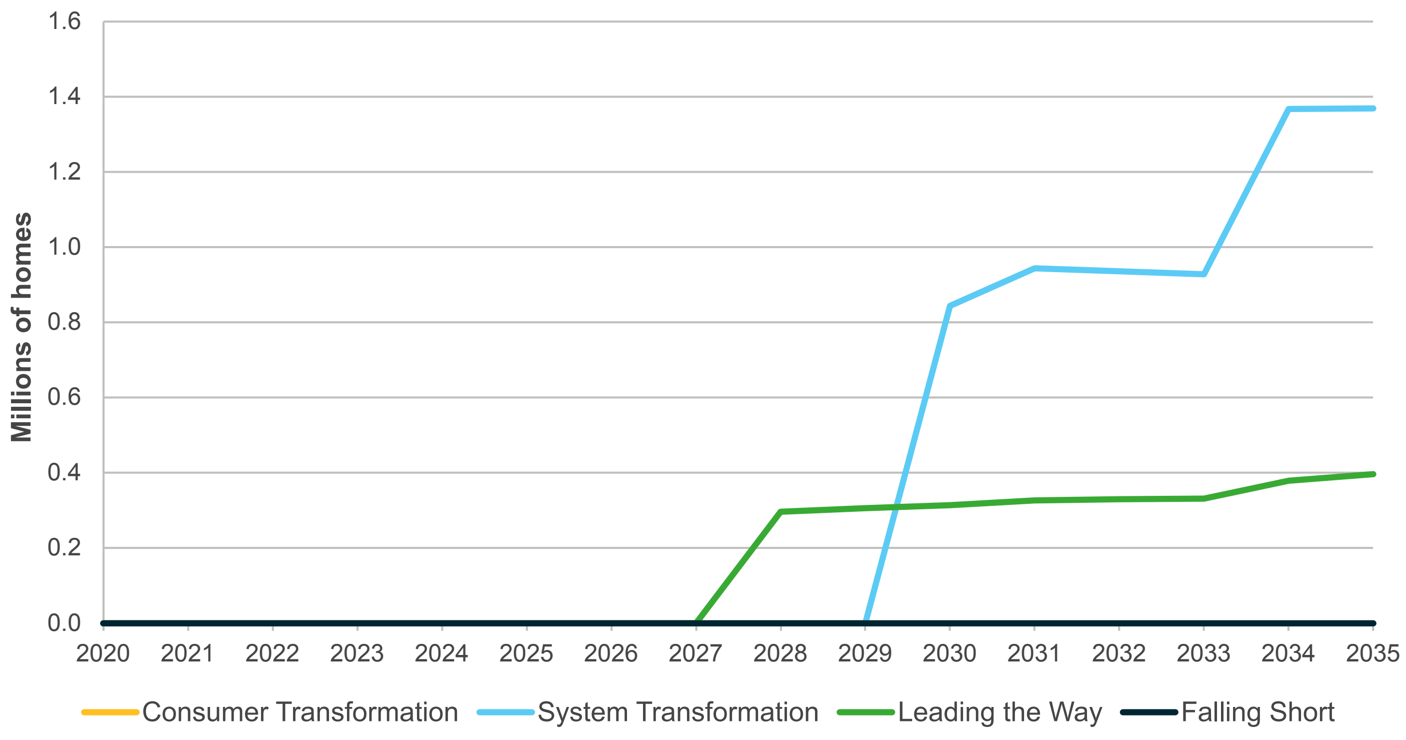
A decision on the use of hydrogen for residential heat is needed as soon as possible to help bring clarity.

There is significant uncertainty regarding the use of hydrogen for residential heat. It is not expected to play a role until 2028 at the earliest. There may be small localised trials, but it is unclear what scale these could be delivered at, so we don't expect to see any significant use of hydrogen for residential heat in the short-term.

There are major challenges to be addressed before hydrogen could play a significant role. Firstly, there is the lack of hydrogen supply, and the likelihood that as hydrogen ramps up it will initially see production and demand co-located on industrial sites. Secondly, short-term deployment is affected by the challenges of the transition from hydrogen to gas: in order for one household to transition to using hydrogen, either a new network of pipes would need to be installed or existing gas network infrastructure converted to deliver hydrogen. This would require all the other houses in the street or the local area to switch over at the same time, all requiring hydrogen-ready boilers (or an alternative solution) to be in place.

Without assurances on future hydrogen demand, new sources of hydrogen supply won't come online, and without certainty on future supply, businesses and households may not make investments to enable the adoption of hydrogen boilers. The planned government decision on the use of hydrogen for heat by 2026 is needed urgently to give clarity to on the future role of hydrogen. Three years until this date may not seem much, but hydrogen projects can be well in to development and construction in that time, and as long as uncertainty remains on the decision for hydrogen for heat, developers will find it difficult to commit to financial investment.

Figure EC.09: Annual hydrogen boiler installations



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Hydrogen boiler uptake happens earliest in Leading the Way, by 2028, in areas around industrial clusters where hydrogen supply is likely to be available, with System Transformation seeing the first hydrogen boilers in 2030. Leading the Way has regional hubs where smaller hydrogen networks develop, but outside these, hydrogen is not available. The cost of production of hydrogen from electrolysis and from methane reformation will affect the viability of hydrogen boilers.

System Transformation has widespread availability of hydrogen and a national hydrogen network from repurposing of the gas grid. Hydrogen-ready boilers installed post-2025 can be converted to run on hydrogen where the local network switches from gas to hydrogen. This scenario requires a very high number of annual hydrogen boiler installations as parts of the gas network are switched over to deliver hydrogen. More detail on the locational aspects of hydrogen are discussed in the hydrogen section.

There are no hydrogen boilers in Consumer Transformation due to the lack of a widespread infrastructure for delivering hydrogen to homes. Hydrogen is prioritised for industrial clusters and other specific uses including shipping, aviation and electricity peaking power plants. In Falling Short, hydrogen use is minimal and limited to industry and transport rather than residential.

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Residential

Appliances

Demand for electricity from residential lighting and electrical appliances[5] is expected to continue to reduce in our net zero scenarios.

Demand from electrical appliances is likely to continue on its recent downward trajectory in the short and medium-term.

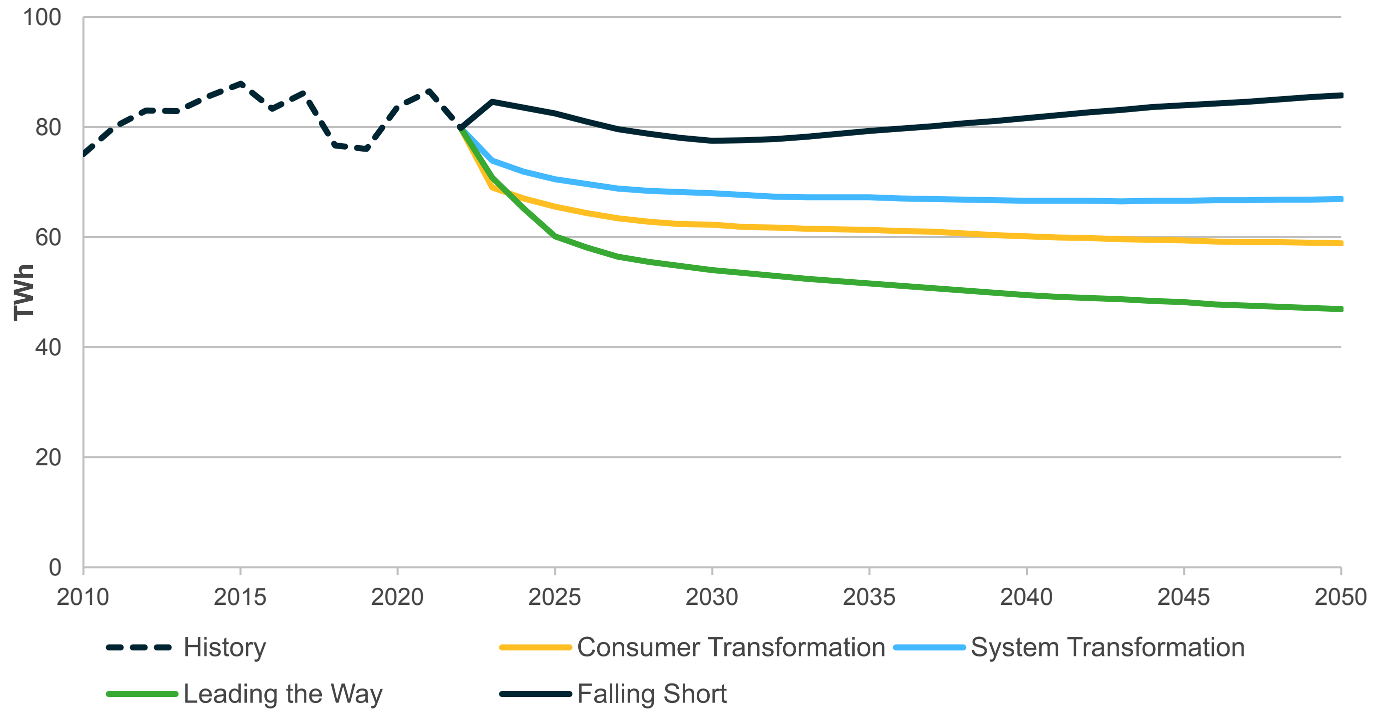
This demand reduction is primarily driven by increased energy efficiency, and the ongoing switch from filament bulbs and halogens to LEDs as lighting is replaced. We also expect rising energy prices to play a role, as consumers become more conscious of potential cost savings in areas such as standby electricity loads, and the smart meter rollout allows people to monitor consumption more closely during the cost of living crisis.

Falling Short has relatively higher electricity demand as consumers are less willing or able to purchase more energy efficient or smart appliances or engage with smart tariffs.

Consumer flexibility has become more high profile over the recent winter. In the past it has been a niche phenomenon where a relatively small number of highly engaged owners of EVs, heat pumps or battery storage, used Time Of Use Tariffs to reduce the cost of their energy. During the most recent winter over a million consumers signed up to participate in the ESO's Demand Flexibility Service: a new service where consumers were rewarded for reducing demand over evening peak period to help address the challenges of winter 22/23.

The response we had to this service helped the ESO manage some periods of peak demand cost effectively and at a lower carbon intensity. As a solution devised under exceptional circumstances, we can't compare the design of it with our FES flexibility modelling directly.

Figure EC.10: Residential electricity demand for appliances



However, it provides an important platform for a future means of managing consumer demand and supply, which we know will be necessary for efficient, low carbon system operation.

You can read more about consumer flexibility in our thought piece here and the delivery of the Demand Flexibility Service here. The response to this service and its implications is also explored in more detail in the Flexibility chapter.

5 Appliances that are contributors to residential electricity demand include white goods such as fridges, freezers, washing machines and dishwashers, lighting and computers and electronic equipment

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Battery Electric Vehicles

Growth in BEV sales remains strong, but there are challenging headwinds before we reach mass market adoption.

Recent BEV sales have been strong, with 2022 sales towards the top of our FES 2022 scenario range. 2022 saw a range of new models of electric cars and vans on the market which helped drive further uptake, while we also saw strong Plug-in Hybrid EV sales.

Growth rates of BEVs are expected to remain strong in the short-term, which would put them on track to meet the Government's proposed zero emission vehicle mandate in 2030, however EV take-up could start to face increasing challenges. While battery prices have been dropping year-on-year for some time, recent inflationary pressures on raw materials have halted or even reversed some of these reductions.

Linked to this is the reduction in consumer spending power caused by the cost of living crisis and high levels of inflation, which contributed to overall new car sales still being 30% below their pre-pandemic levels. BEVs continue to make up an increasing share of total vehicle sales each year, but battery price presents an additional barrier to mass market adoption.

Significant rises in electricity prices meant that while home charging of EVs is still cheaper per mile than refuelling petrol or diesel vehicles, recharging EVs at public chargers is now typically more expensive. This makes EVs less appealing for those who are unable to install a home charger and need to rely on public chargepoints.

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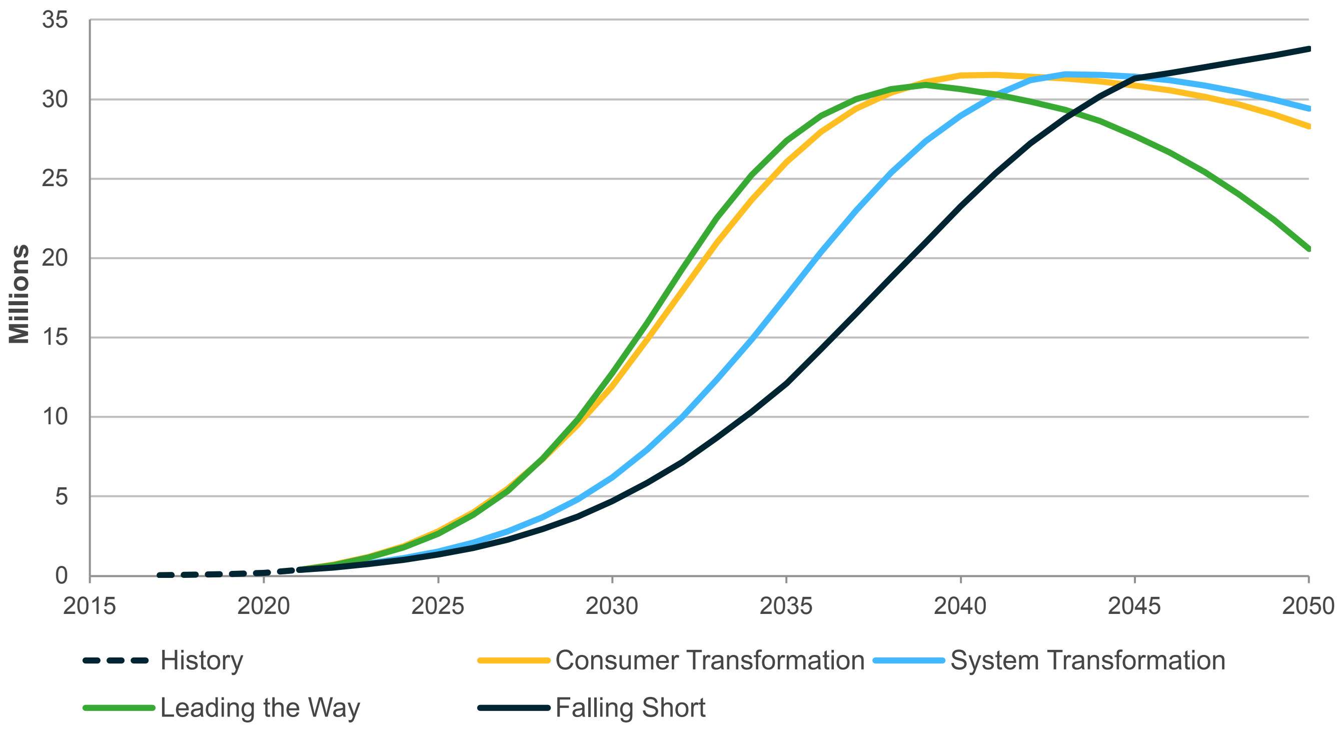
Figure EC.11: Battery electric cars on the road



Careful consideration is needed to ensure there is a fair transition, and affordable, equitable access to charging infrastructure in the shift to EVs. There is the potential for charging costs to be inequitable should different consumer segments face different costs due to use of different types of chargers, their accessibility and location. Consumers who can afford their own solar panels, batteries and off-street parking, will be able to charge cheaply at home, while those without could face higher costs charging away from home. This highlights the potential role for policy and regulatory protection to support consumer fairness. Nevertheless some progress is being made in tackling some existing barriers, with over £450m of funding awarded to support local authorities roll out charging infrastructure in 2022.

The wider FES scenario ranges are aligned with long-term policy. The range of headwinds and tailwinds outlined here contribute to the high levels of uncertainty around the outlook for Electric Vehicle growth. There are now over 1 million EVs on the roads and their purchase made up nearly 23% of cars sold in the UK in 2022, demonstrating the progress made to date. However, in our lower EV growth scenarios the 2030 target is missed, an outcome which remains credible.

In the net zero scenarios we start to see the impact of Autonomous Vehicles (AVs) post 2035, reducing total numbers of cars on the road as some consumers switch to mobility as a service solution and/or reduce the number of cars in their household. Fewer AVs do greater annual mileage in this market.

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Smart charging

There is a wide range of uncertainty around consumer engagement with smart charging, both today and in the future.

We look at the amount of charging which could happen at system peak, we call this the unmanaged peak demand. We then consider how much this could reduce due to smart charging. The reduction in peak demand we see from smart EV charging remains uncertain. In our net zero scenarios we expect this figure to increase as penetration of smart meters and awareness of and access to Time of Use Tariffs increases. In each scenario, peak demand reduction plateaus at a different level as the engagement rates and penetration of smart technology reach their maximum level, corresponding to the scenario's level of societal change.

Even in the near-term, there is a high level of uncertainty in charging behaviour. While we expect the majority of those who can charge at home to do, their charging behaviour will depend on the technology, incentives and level of automation that is in place. Nevertheless, we have seen early adopters of smart charging respond to new services such as the ESO's Demand Flexibility Service over winter 22/23.

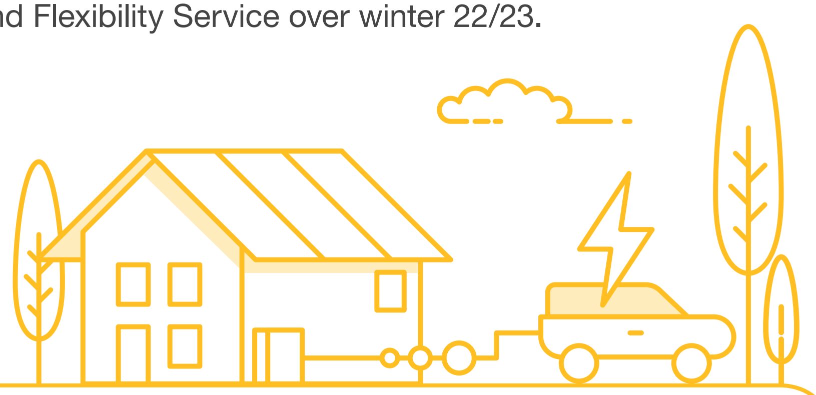

Figure EC.12: Reduction in unmanaged peak demand for EV charging due to smart charging

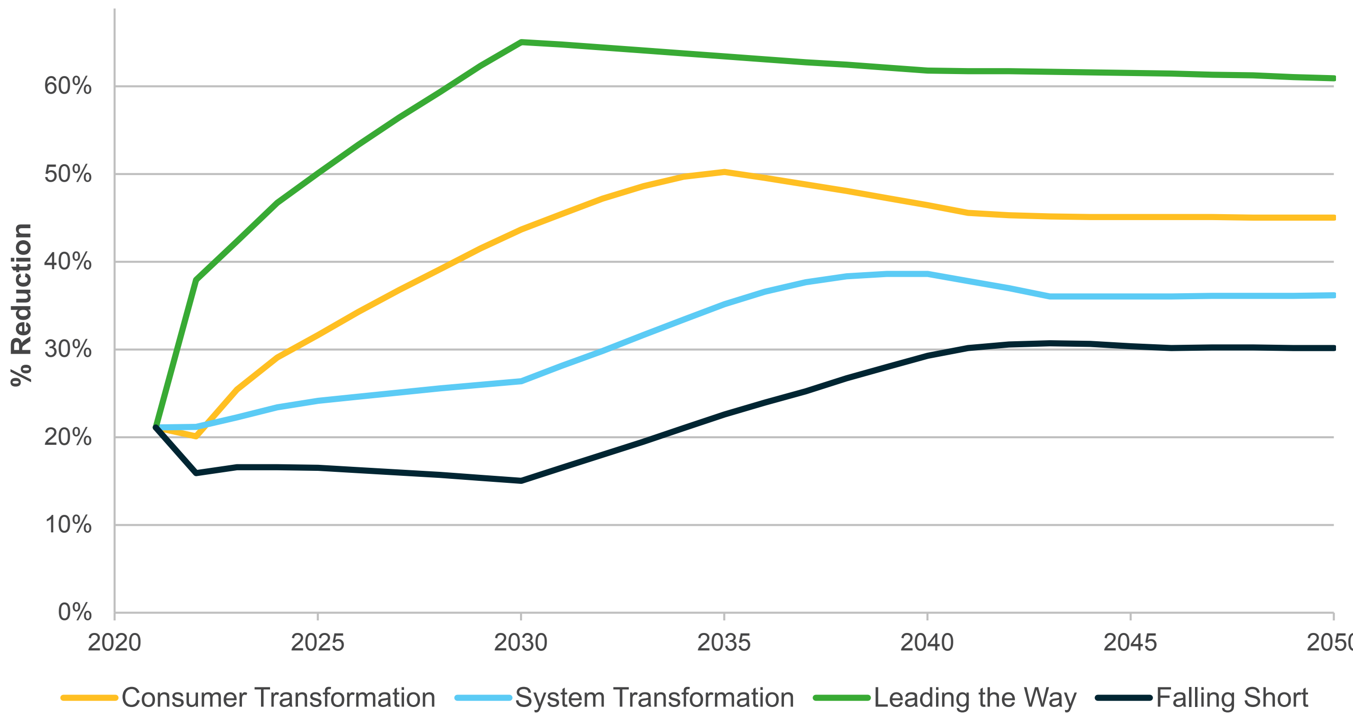

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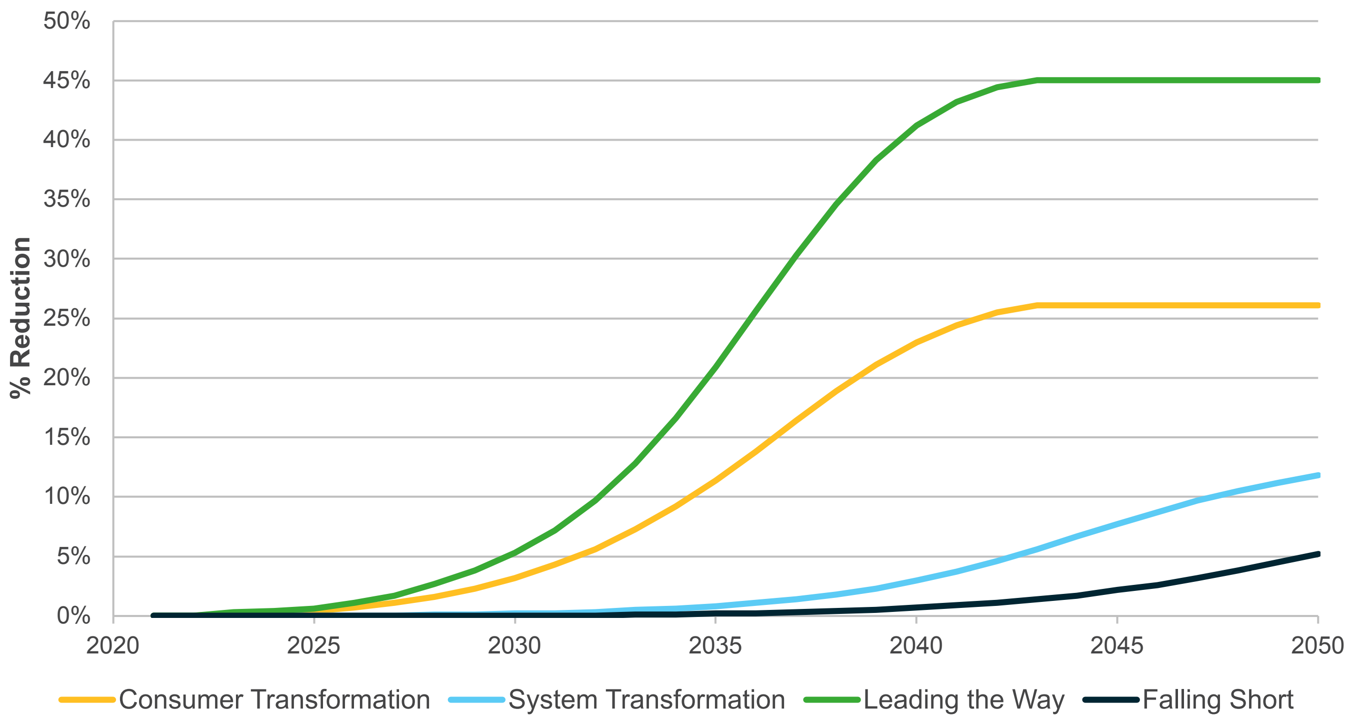
Figure EC.13: Proportion of privately owned EVs with access to off-street parking that participate in V2G



Vehicle-to-Grid engagement is expected to remain very low in the short-term. Increased take-up will require technology deployment of e.g. bi-directional charging, but also electricity market change so consumers are rewarded for participating in the energy system to optimise system costs for everyone.

Beyond this, however, there is the potential for consumer engagement to increase rapidly from the 2030s as seen in Leading the Way.

Access to V2G is likely to remain limited to households with home chargepoints and off-street parking, which represents an additional barrier to access, but among this group we expect V2G participation to reach a maximum of 45% even in our highly engaged scenarios. More detail on load shifting and response is in the Flexibility chapter.

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Hydrogen in road transport

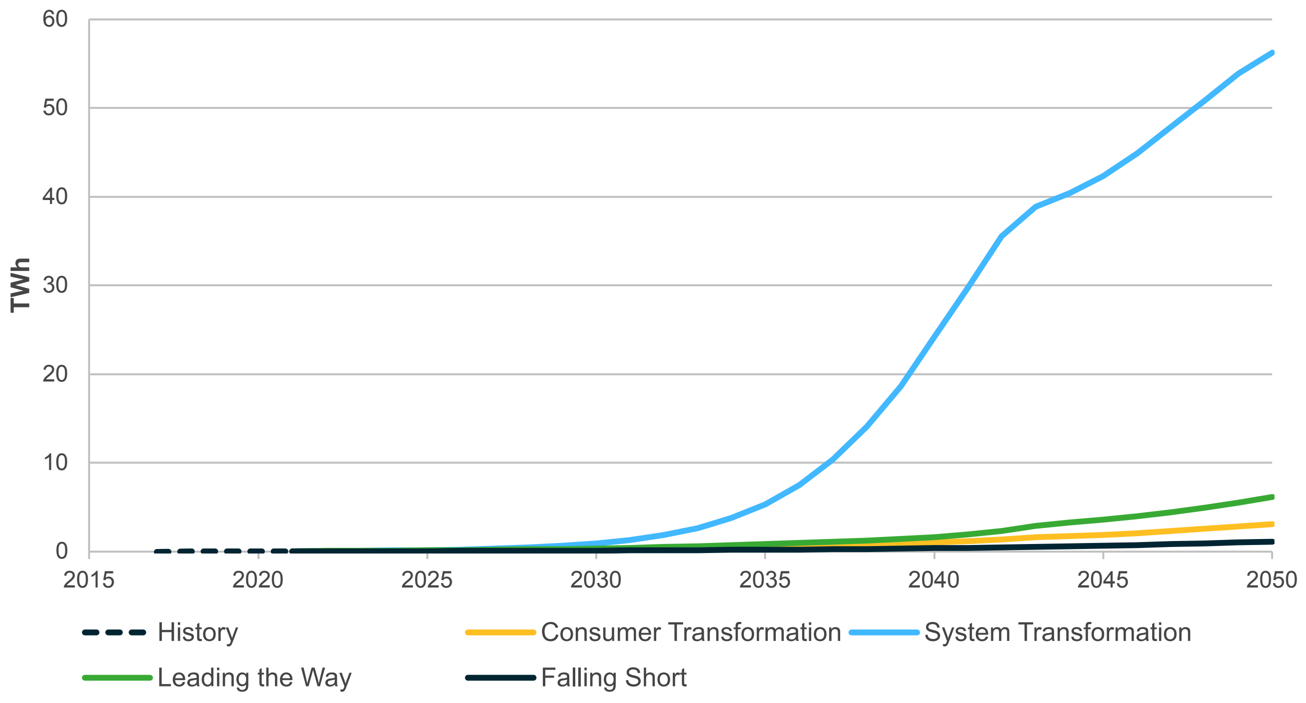
Hydrogen is expected to start to play a role in road transport demand for larger vehicles, but overall volumes will remain low as electrification dominates among low carbon transport options.

Road transport is the only area where we see consumer demand for hydrogen before 2024, but total volumes remain low. Early growth in hydrogen demand is driven primarily by growth in hydrogen fuelled buses and Heavy Goods Vehicles. We have seen local authority commitments for hydrogen buses, but we have not yet seen hydrogen HGV deployment make any meaningful headway, although this could start to change in the coming years as competitive Fuel Cell Electric Vehicle (FCEV) HGVs are brought to market after funded demonstrator trials. This level of growth also relies on supplies of transport-grade hydrogen growing in line with demand.

Hydrogen demand in areas other than road transport picks up later in the 2020s and rapidly begins to outweigh transport demand. By 2029 road transport represents only 3% of consumer hydrogen use (excluding hydrogen blended into the gas network).

The risks to growth in this sector other than hydrogen supply availability are primarily economic: that there are no viable HGVs available or insufficient appetite for bus operators to adopt hydrogen buses should electric buses prove more cost-effective.

Figure EC.14: Hydrogen demand for road transport



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Electricity and natural gas demand

Industrial electricity and gas demand is expected to fall in the short-term due to the impact of high energy prices.

The impact of the recent extremely high electricity prices on the industrial sector has been to suppress energy demand. Electricity demand continues to be linked to price assumptions. In Leading the Way and Consumer Transformation we expect industrial electricity demand to continue to fall in 2023 and remain low in 2024, driven by these high energy prices. From 2025 we see a return to electricity demand growth in the industrial sector across the scenarios, because of the return to economic growth and more typical electricity prices. Prices paid by industrial customers change more gradually than wholesale prices due to these large consumers purchasing electricity in advance on longer-term contracts. Industrial energy efficiency improvements offset some demand growth in the 2020s. In the net zero scenarios electricity demand is lower in 2028 than it was in 2019.

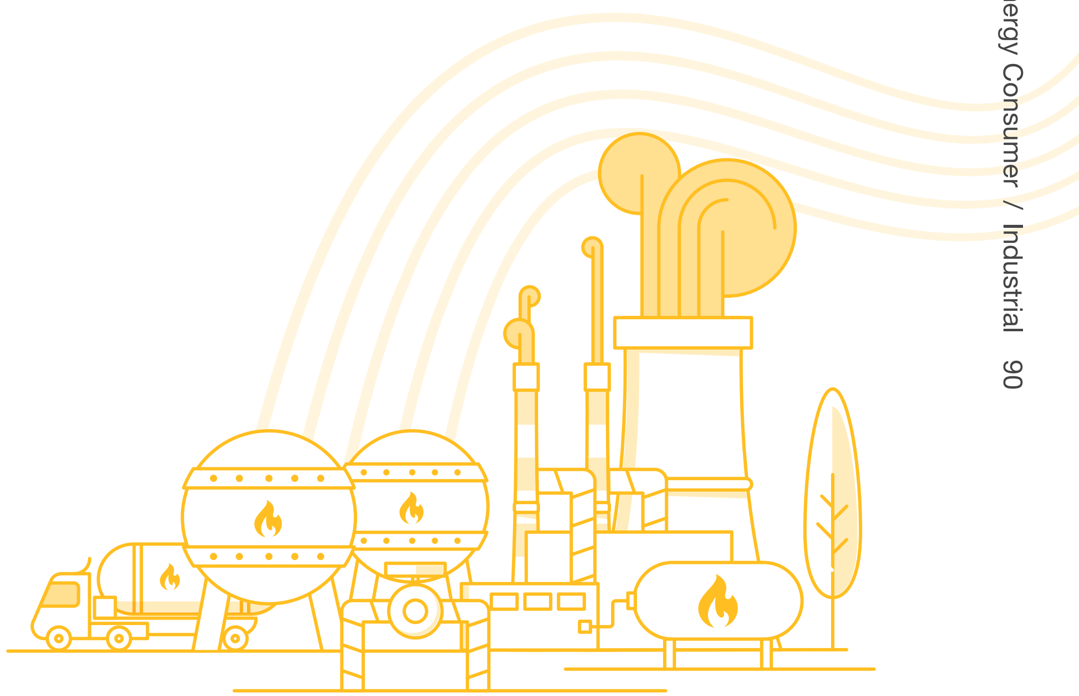
Similar to electricity demand, high energy prices and low economic growth have helped suppress gas demand. This decline is expected to continue as we start to see more industrial consumers move away from natural gas in our net zero scenarios. Post-2026 the decline becomes more dramatic as we start to see the impacts of industrial decarbonisation and fuel switching into the late 2020s.

Our scenario range is driven by a series of levers linked to each scenario's position on our scenario framework. In the short-term this leads to a narrow scenario range for industrial demand as the pathways look similar before diverging in the longer-term. Fuel switching to electricity or hydrogen has a larger impact post-2030.

Consumer Transformation starts to see rapid electrification in the 2030s. Strong carbon pricing in the 2030s encourages industrial consumers to switch away from unabated fossil fuels, primarily to using electricity.

In System Transformation and Leading the Way there is a more mixed picture, as while fuel switching picks up, there is a greater share of hydrogen use rather than solely electrification within industry. Gas demand is expected to drop furthest and fastest in Leading the Way as growth is seen in both hydrogen and electricity demand for industry, rapidly displacing fossil fuels in the 2030s.

In Falling Short the sector sees only very limited energy efficiency improvements. Electricity demand increases, driven by economic growth and assumed lower energy prices, with some contribution from electrification from the 2030s. Gas demand remains high into the 2030s, with consumers slow to switch away.



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Industrial

Figure EC.15: Industrial electricity demand (excluding hydrogen production)

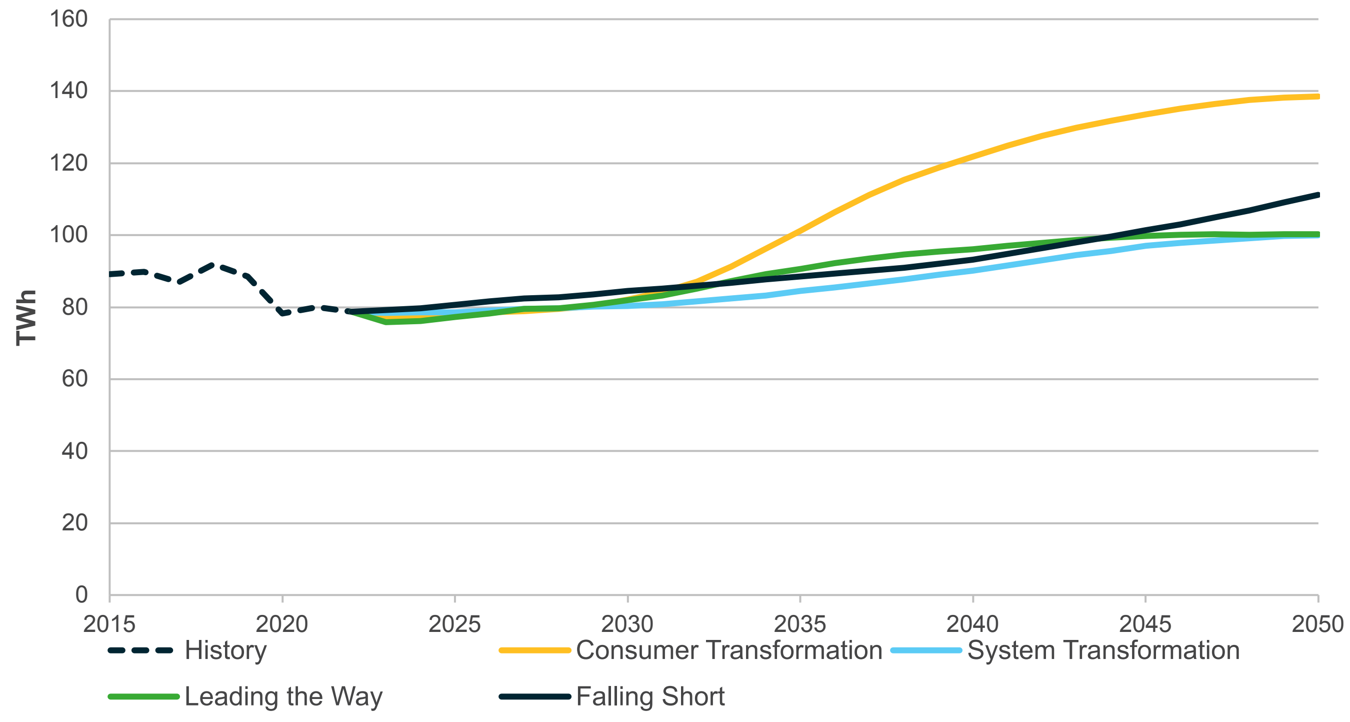
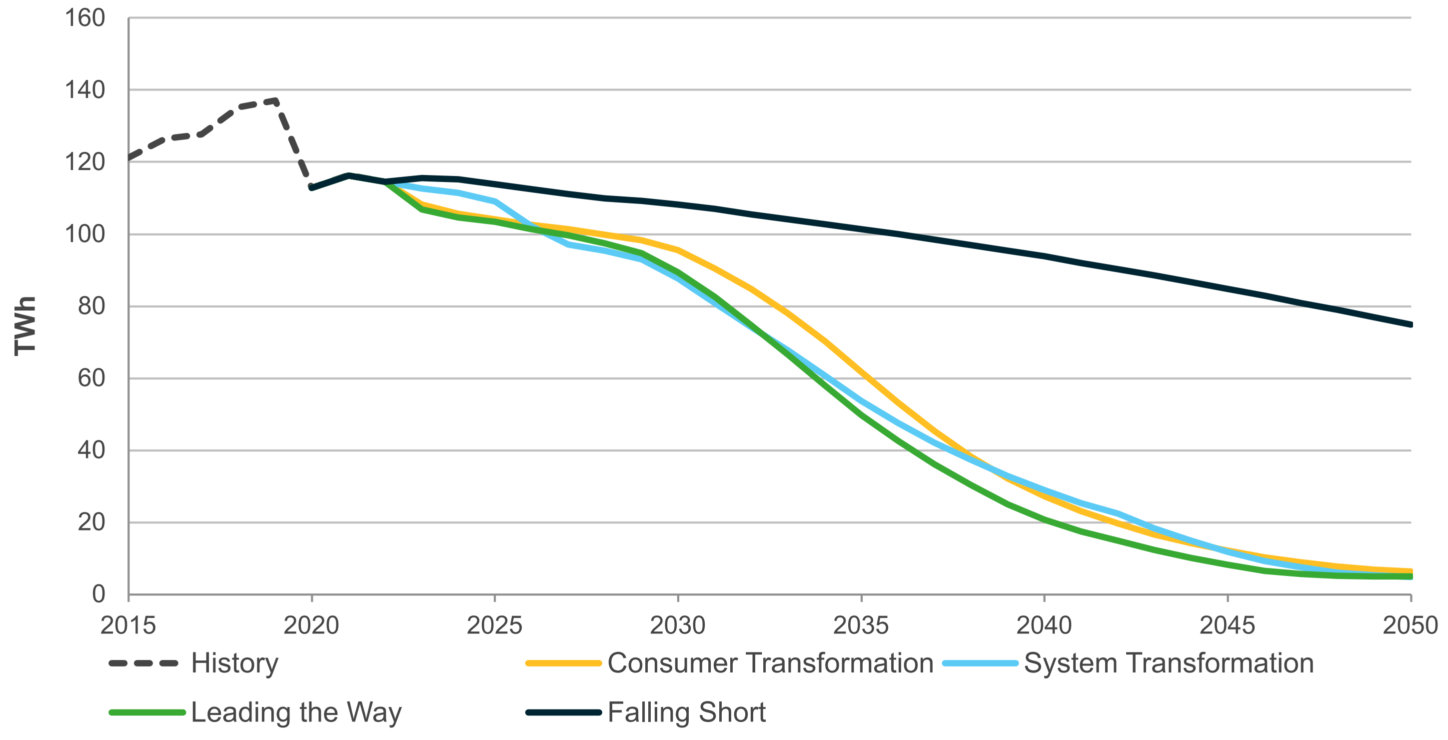


Figure EC.16: Industrial gas demand



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Hydrogen demand

Developments in policy and industry around hydrogen mean demand for low carbon hydrogen is expected to increase earlier.

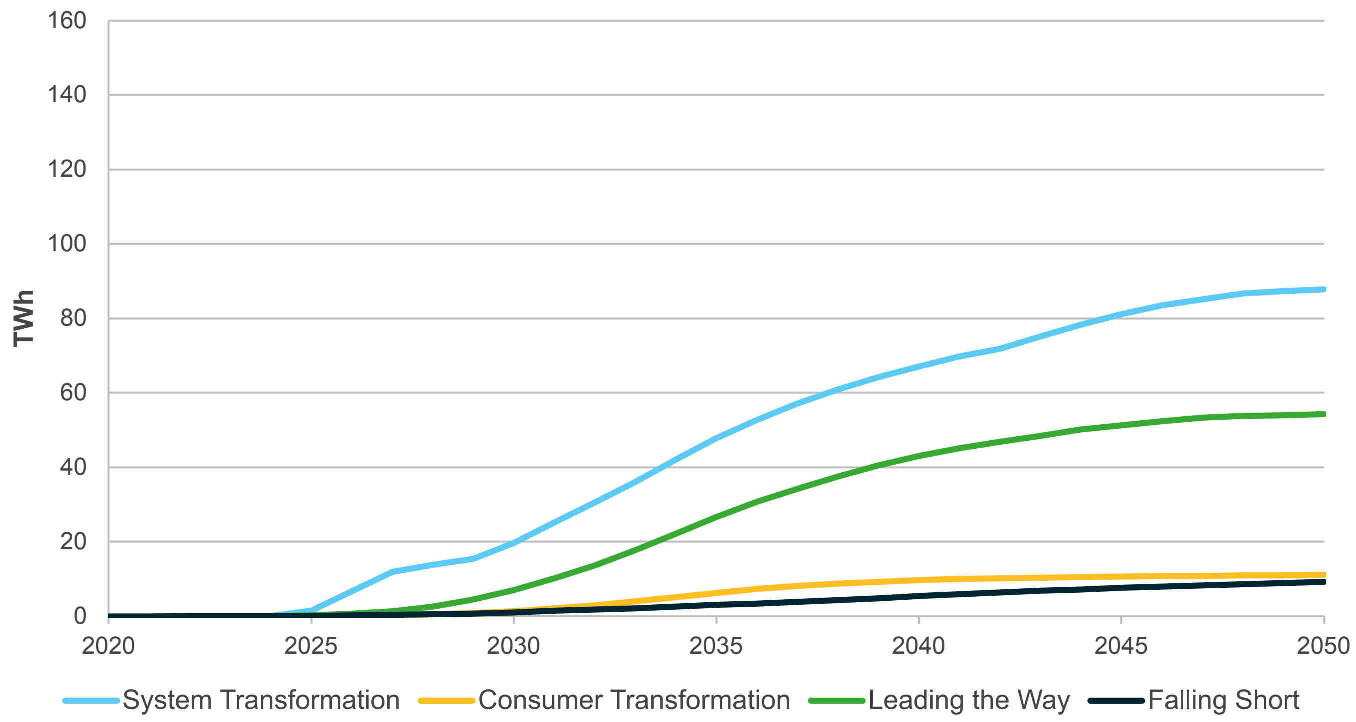
Within the past 18 months there have been significant developments in the hydrogen sector, with new targets set and policy put in place to drive hydrogen supply and demand within the industrial sector. These include commitments within the British Energy Security Strategy and Scottish Hydrogen Action Plan.

We now see growth in hydrogen demand for industry as early as 2025 in System Transformation. This is initially likely to be used to substitute some unabated fossil hydrogen use or fuel switching of processes away from natural gas to use hydrogen. We expect hydrogen demand to grow first in areas of industrial clusters, particularly the initial two clusters being developed around Hynet and the East-Coast Cluster.

Initially, clean hydrogen production is likely to be expensive, and so the potential government support schemes announced to subsidise industrial hydrogen use will be crucial to establishing it as a competitive option for consumers, particularly in the early stages.

In this section we only cover low carbon hydrogen demand, and do not include demand for unabated fossil hydrogen – without CCUS. The energy demand to produce existing unabated fossil hydrogen is captured within our industrial natural gas demands as this conversion typically takes place on-site.

Figure EC.17: Industrial low carbon hydrogen demand



In Leading the Way and System Transformation, growth of hydrogen demand within industry starts in the mid-2020s within industrial clusters, before spreading out beyond these hubs in the 2030s. In System Transformation further growth in the 2030s and 2040s is facilitated by the conversion of the gas network to deliver hydrogen. In Consumer Transformation and Falling Short growth in hydrogen demand is limited and solely within industrial clusters.

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Energy demand

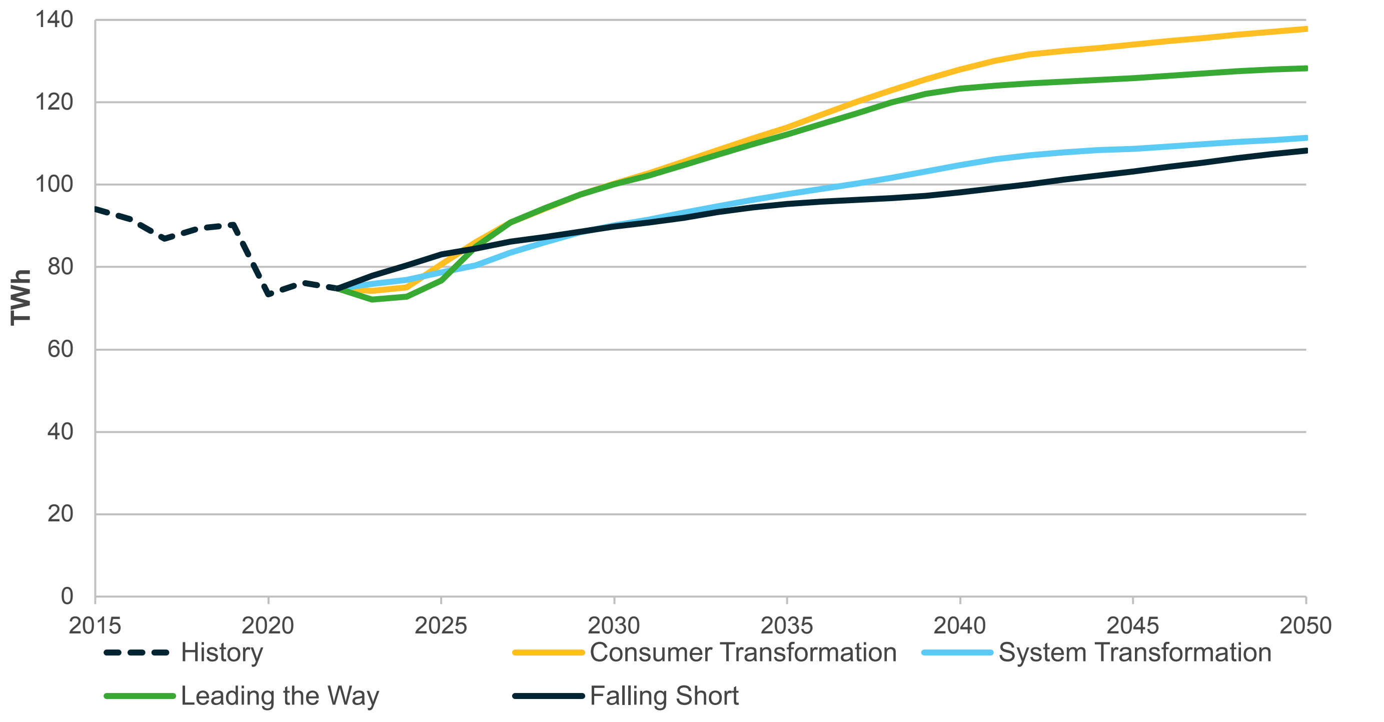
Electricity and gas demand in the commercial sector is likely to be suppressed in the short-term by the effect of high energy prices and challenging economic conditions. Hydrogen isn't expected to play a meaningful role until the 2030s at the earliest.

The very high energy prices seen over the last 18 months have had the effect of suppressing commercial electricity and gas demand, despite the government caps for business energy rates. Whilst prices have reduced since autumn/winter 2022, many businesses are still locked into high prices due to buying energy on longer-term fixed contracts.

We have seen some of the impact of increased energy costs passed on to consumers in the form of higher prices, rather than being absorbed by businesses or resulting in a reduction in demand. The Government's business energy price cap across the most recent winter also mitigated energy reductions. In 2024 price related demand suppression continues to be a factor, particularly in Consumer Transformation and Leading the Way, but this eases off from 2025 onwards and demand increases. In these scenarios, electricity demand is further supported by the growth of data centres and early electrification, whilst gas demands don't recover to previous levels as consumers switch away from natural gas to electricity.

In the late 2020s we expect commercial electricity demand to start to grow as fuel switching from natural gas to electricity picks up, particularly in the net zero scenarios. We assume that targets in the Government's net zero strategy for fuel switching and energy efficiency are met in the net zero scenarios. In the 2030s commercial electricity demand growth is also driven more strongly by the growth of commercial EV fleets and high levels of workplace charging. We also see increased electricity demands from increasing sources of demand such as data centres, as explored in our thought piece here.

Figure EC.18: Electricity demand in the commercial sector



Commercial

In the net zero scenarios, significant energy efficiency improvements are seen. These ramp up within the 2030s and help offset the increase in electricity and hydrogen demand for heat that would otherwise be seen as commercial consumers switch away from fossil fuels.

We don't expect hydrogen to play a role in the commercial sector until 2028 at the earliest, when in System Transformation some hydrogen is started to be used for commercial heat. Hydrogen starts to meet an increasing share of heating demands over time in System Transformation as it becomes more widely available, also playing a more limited role in Leading the Way. Commercial hydrogen use is expected to be almost exclusively for heat and hot water, with some additional small potential fuel switching to hydrogen in the catering sector.

Figure EC.19: Natural gas demand in the commercial sector

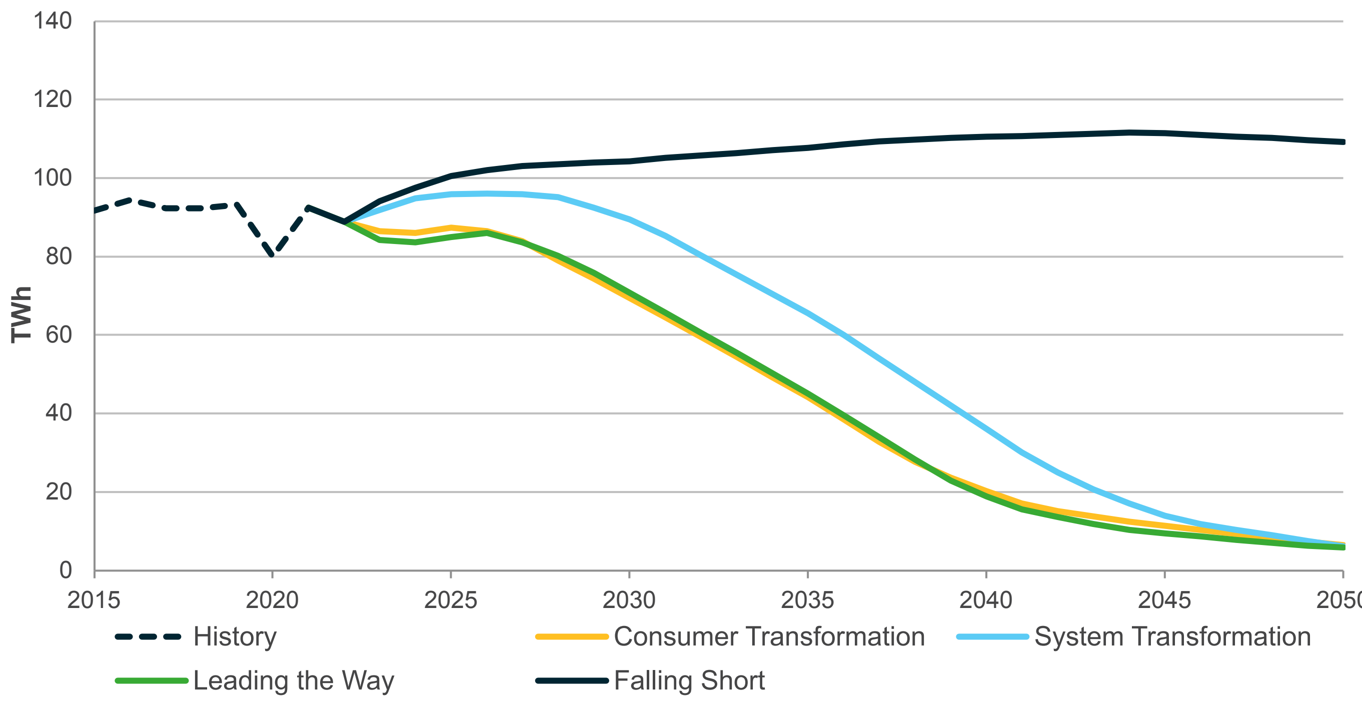
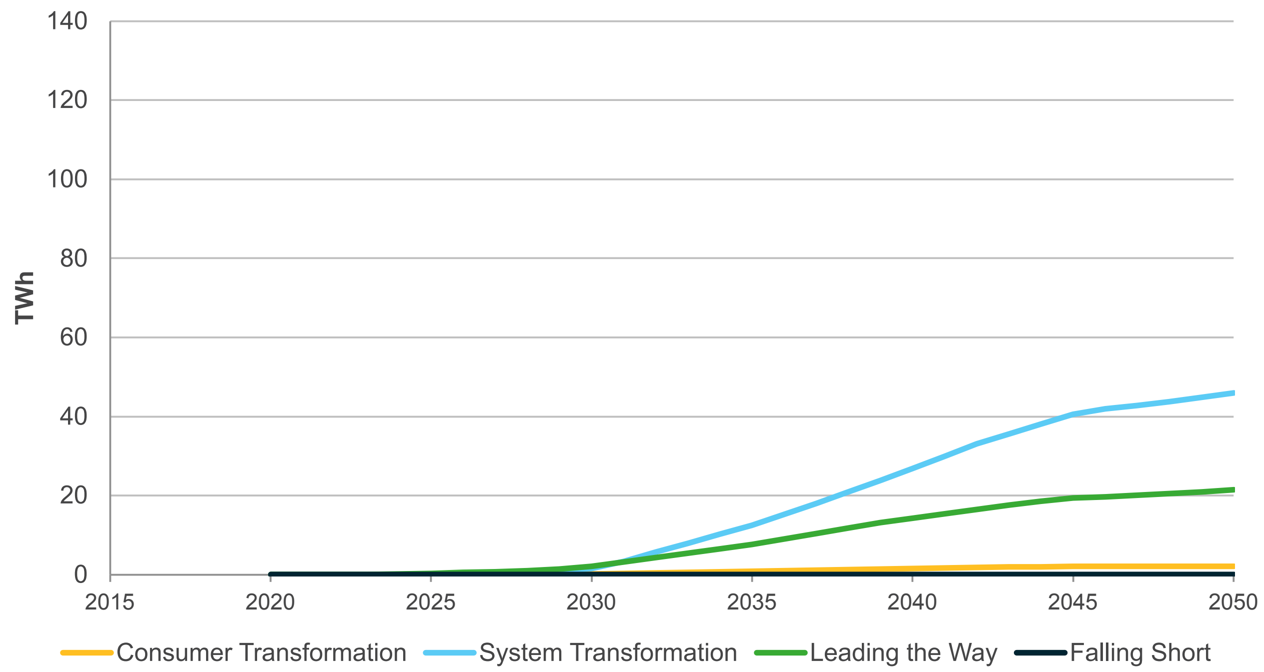


Figure EC.20: Low carbon hydrogen demand in the commercial sector



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Consumer archetypes

We have developed archetypes for different types of consumers to improve our modelling of their behaviour as part of our Consumer Building Blocks project.[6]

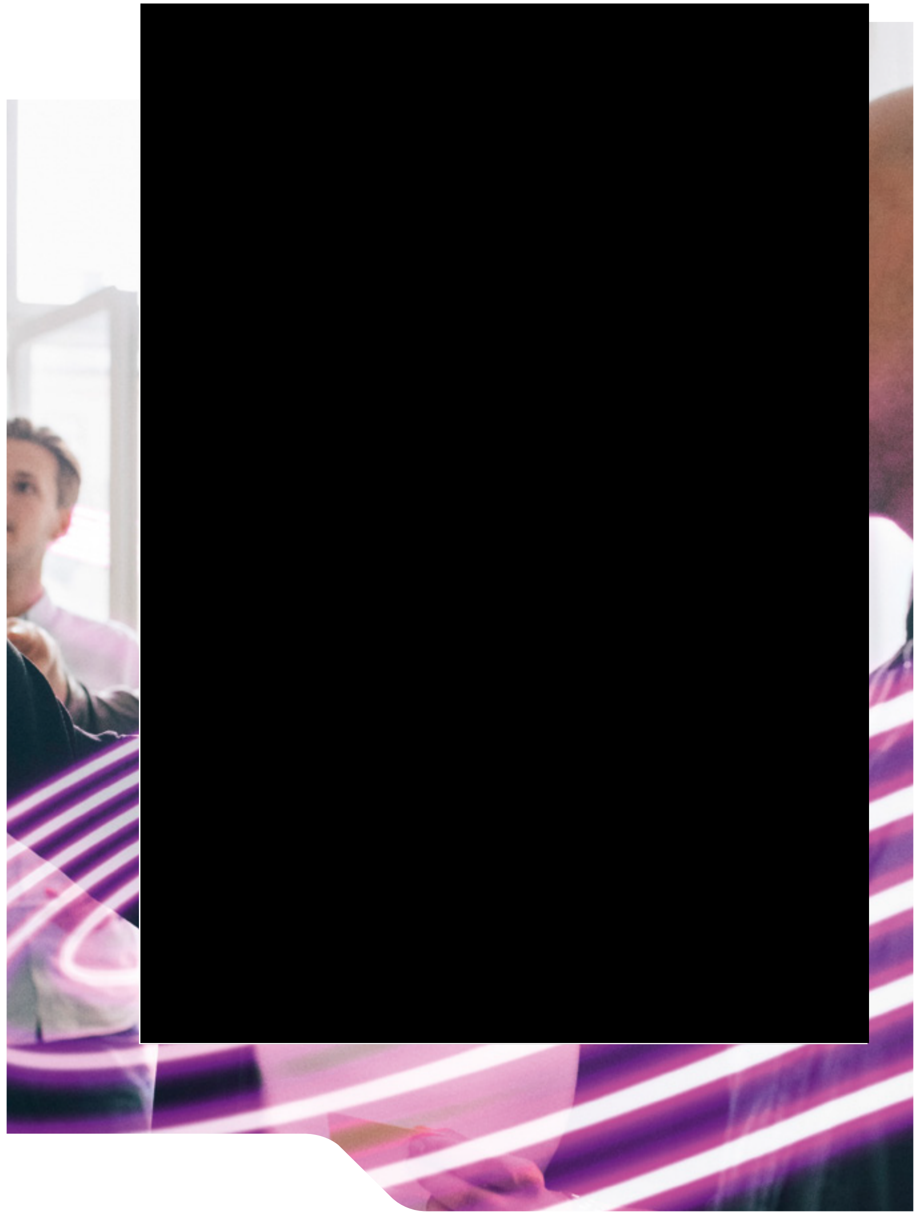
Consumers are critical to meeting net zero and are a fundamental part of the transition, not only as part of the energy picture but as part of their everyday lives and the running of their businesses. Our project developed a set of archetypes that segments different types of domestic and non-domestic consumers for use within the Future Energy Scenarios and across industry, improving collaboration and coordination within the energy sector. They have been developed in consultation with stakeholders across the industry to support their adoption.

We need to understand distinct types of consumers, the characteristics that drive their behaviour and what this means for their energy consumption.

This means considering factors such as:

- propensity for change
- adoption rates of technology
- ability and propensity to engage with Time of Use Tariffs
- whether their engagement will be proactive or passive
- the boundaries within which they would find flexing their demand acceptable.

Understanding the needs of consumers and what drives their decision making, whether it be financial reward or engagement in climate change, will enable the market to best engage with them and tap into the resource they hold. Understanding the level of trust consumers have with different organisations in energy and broader technology will help us understand how they might engage and with whom. We can use this information to inform engagement but also the development of propositions to the consumer to increase adoption.



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6 smarter.energynetworks.org/projects/nia2_ngeso026/

Consumer archetypes

Domestic archetypes

Using real world data we have developed a range of domestic archetypes through clustering of different variables.

The core dataset used to develop archetypes for domestic consumers is a set of smart meter data from the Smart Energy Research Lab (SERL).[7] This dataset includes:

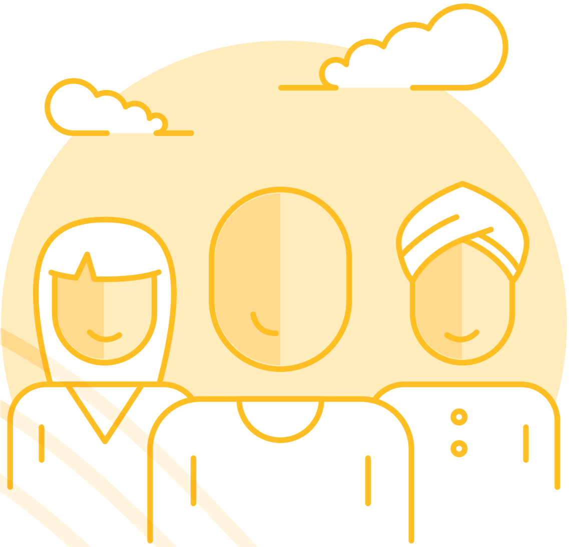
- daily and half-hourly electricity / gas data readings
- associated weather data variables
- survey data for each dwelling
- Energy Performance Certificate (EPC) data.

The sample includes over 7,000 households, which have then been clustered according to key variables to produce groups of similar households through which insights can be drawn into the fuel use, household types and behaviour of each cluster.

The first step is understanding the existing heating technology of each household, as this is a key determinant of behaviour. For example, a property with electric storage heaters that charge up overnight has a very different electricity demand pattern to a household with direct electric heating and different again to a household with a gas boiler that doesn't use electricity for heat.

Variables affecting consumer energy demand

Property and household	Energy	Attitudes and behaviour
• Property type	• Primary heating type	• Attitude towards different technologies
• Property age	• Secondary heating type and use	• Current efforts made to save energy
• Tenure	• Low carbon technology uptake	• Timing of peak and minimum demand
• Occupancy	• Magnitude of peak and minimum demand	
• Employment status		
• Financial stability		



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Consumer archetypes

Industrial & Commercial archetypes

Our Industrial & Commercial archetypes allow demands to be modelled in greater detail and with more granularity.

To create these archetypes, consumer characteristics within each subsector have been explored to understand their ability to engage with the energy market. The appropriateness of different technologies and energy offerings has been evaluated to determine the ability of different consumers to engage with each modelled technology.

A range of datasets have been used to understand the baseline of the non-domestic consumer population. These datasets are used to understand three principal areas for different organisations; how an organisation must have the “conditions, capacity and concern” to engage with an innovation.

Eleven different sectors were used as a starting point, ranging from education to heavy industry. To produce a set of archetypes that is both manageable and sufficiently granular, a nested approach was taken. To create the nested archetypes, a large number of organisational archetypes were used and then grouped together by sector and their engagement with different types of offers. Within each group are four archetypes which are consistent across sectors.

For each sub-archetype the level of engagement with each offer sub-category – i.e., energy efficiency, low carbon technologies, or flexibility has been scored from low to high.

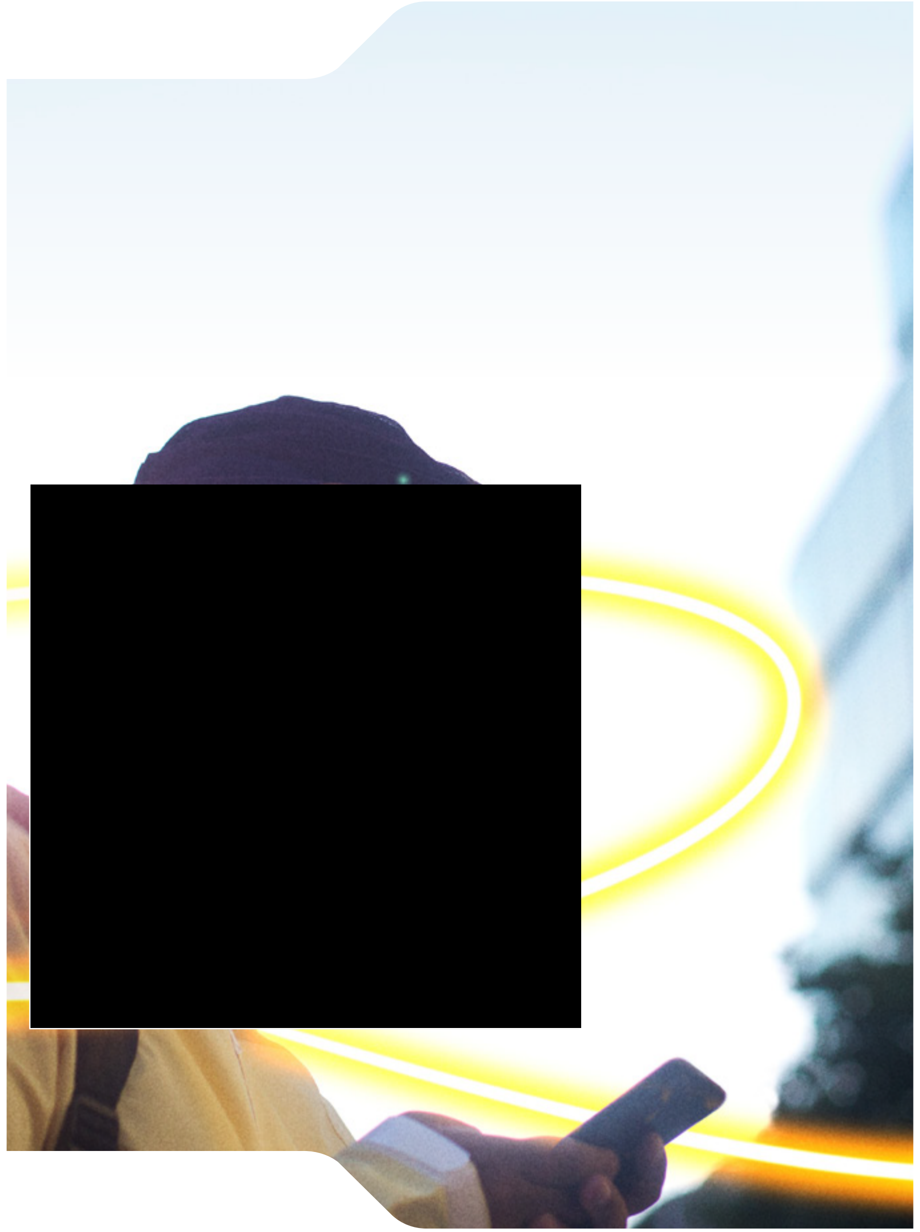
Heavy industrial sites required a more bespoke approach due to the diversity of energy needs and decarbonisation options and so was segmented by industrial sub-sector rather than engagement with particular technologies.

How does this improve our modelling?

For each archetype we have data on the attributes which are preventing them from engaging with more offers to help users to understand how each archetype may evolve under different modelled scenarios. This allows us to consider the evolution of different consumer segments over time within our scenarios according to the levers within our scenario framework.

This work will also help improve the regional granularity of our I&C demand modelling, as we can start from an LSOA (Lower Super Output Area) level picture of the split of the archetypes and consider how energy demand evolves from that point.

We are also able to use a bespoke load profile created for each archetype to model energy demand, today and in the future.



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Consumer archetypes

Businesses within each sector are grouped into one of four sub-archetypes below:

Green Dreamers	Mostly leased properties, half have an active energy management ambition and most have some sort of energy manager	Green Dreamers may be highly concerned but may lack the capacity and conditions to engage They are more likely to engage in scenarios where change is driven by system-wide enablers which reduce individual hurdles to engagement
Resourceful Innovators	Entirely owner-occupiers, just under half have an active energy management ambition and most have some sort of energy manager	Resourceful Innovators often have all resources necessary to engage These consumers have the conditions, capacity, and concern needed to engage but their ultimate engagement will depend on the options made available to them in a scenario
Constrained Sceptics	Mostly leased properties, and a lower percentage have high energy spend than the archetypes above. Less than half of these organisations have an energy manger and very few have an active energy management ambition. Mostly smaller businesses	Constrained Sceptics often lack conditions, capacity and concern This group will be the most difficult to mobilise and will be the last to engage across all scenarios
Renewable Realists	As in Resourceful Innovators these organisations are entirely owner-occupiers. Most of these organisations have no energy manger. Very few of these organisations have an active energy management ambition. Mostly smaller businesses	Renewable Realists may have the capacity to act but may not be sufficiently motivated to engage These organisations will be engaged in scenarios where policy forces consumers to shift or when it makes low carbon technologies cost-optimal

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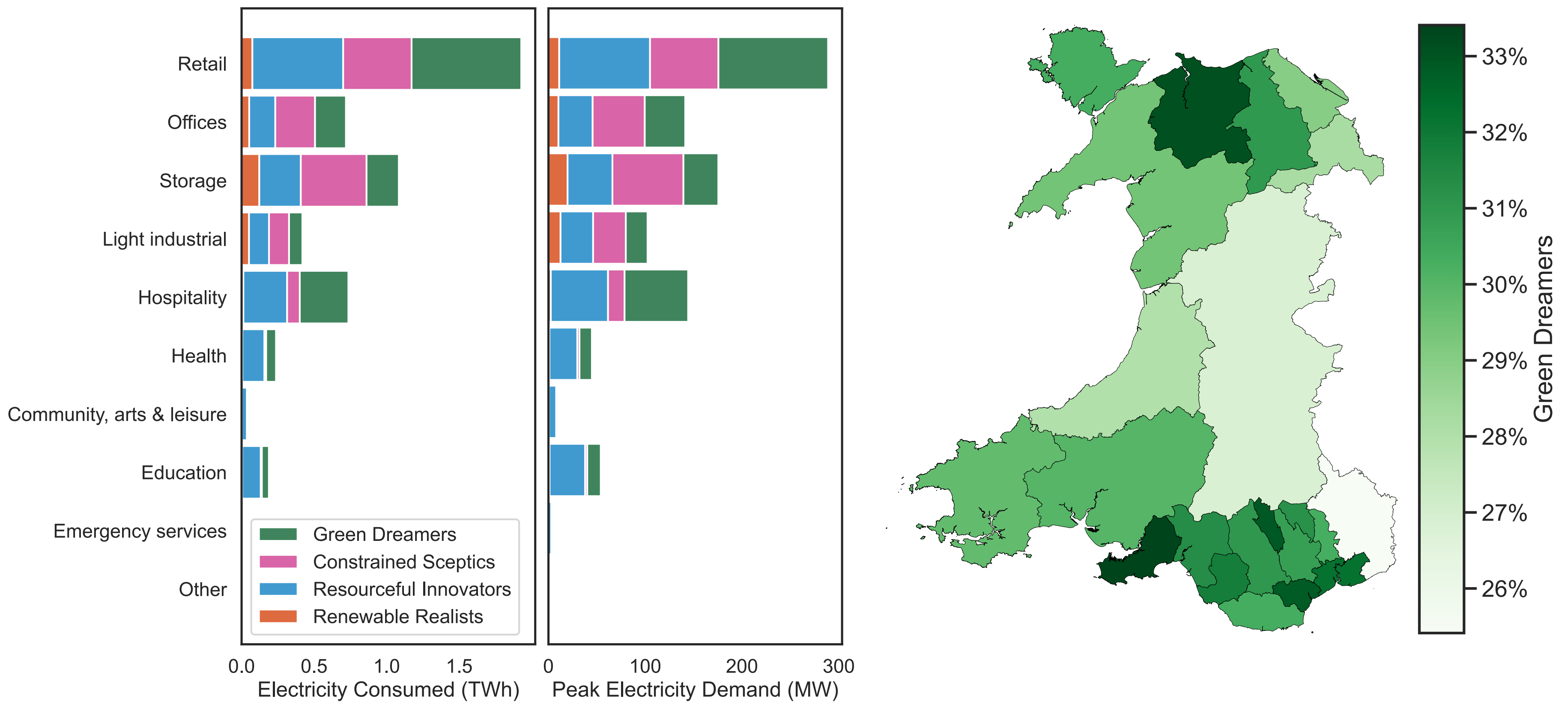
A regional perspective

The granular nature of this archetype development improves our understanding of Industrial & Commercial demand and how it might change over time.

Figure EC.21 shows the contribution towards both peak and annual demand for each of the sub-archetypes, and a breakdown of the share of Green Dreamers across all sectors within local authorities in Wales. Green Dreamers are consumers who would like to engage with the energy transition, but are unable to do so for one of a number of reasons. They are more likely to engage in scenarios where change is driven by system-wide enablers which reduce individual hurdles to engagement. Being able to look in detail at the share of different archetypes and sectors within local areas can help identify interventions that could enable consumers to engage with the energy transition and benefit from flexibility markets.

Figure EC.21: Peak and annual demand split by archetype and share of Green Dreamers by local authority in Wales



Hydrogen and electrification - residential focus

Heat pumps are likely to be more cost effective than hydrogen boilers for the most common housing archetype.

To meet net zero, carbon emissions from heat need to reach zero. There are a range of potential options for achieving this, including electrification, substitution of hydrogen for natural gas, and continued use of fossil fuels in industrial clusters with Carbon Capture, Usage and Storage.

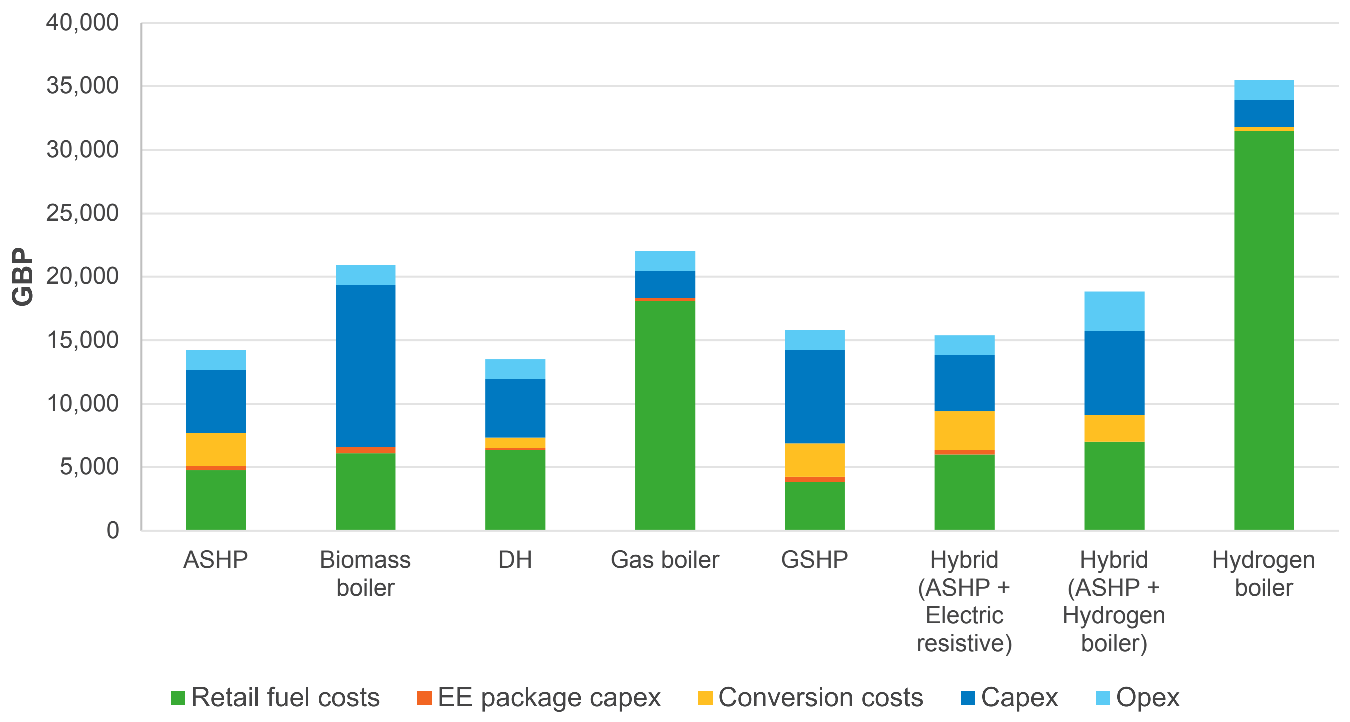
In this section we consider the economic case for different heating technologies, with particular focus on hydrogen and electrification. We also highlight the key uncertainties that affect these results.

Underpinning our analysis of heat in buildings is a technoeconomic model that considers:

- the economics of different technology choices
- the decision-making of individual consumers, and
- local infrastructure investment decisions.

Figure EC.22 shows the 15 year total cost (sum of capital and operational cost) for different heating technology types for the most common housing archetype in England in Leading the Way in 2030. This is a medium, semi-detached house with double glazing, cavity insulation and a gas boiler, representing around four million homes. Retail fuel costs represent the largest single driver of total costs across all technologies, although for some technologies, particularly heat pumps, capital expenditure (capex) costs make up a larger share than for gas or hydrogen boilers. Leading the Way assumes high gas prices, and a continued reduction in heat pump capital costs between today and 2030, which makes ASHPs cost competitive with gas boilers.

Figure EC.22: Average 15 year cost of selected heating systems in Leading the Way in 2030 for the most common housing type in England, excluding any grants or incentives



The unsubsidised hydrogen price in 2030 is high, over 30 p/kWh, driven by high production costs in this nascent market. This results in very high total costs for hydrogen boilers. The price paid by consumers will vary according to subsidies and grants available which are not included here, as well as due to underlying price assumptions.

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Hydrogen and electrification - residential focus

Heat pumps typically require additional expenditure for home energy efficiency improvements and conversion costs, such as larger radiators compared to hydrogen boilers. But while future capital costs for the up-front purchase of a hydrogen boiler are expected to be closer to that of a gas boiler, the total whole-life cost of the system is heavily dependent on the ongoing running costs. Retail fuel costs make up the largest share of total costs, and so the total cost is very sensitive to the price of hydrogen.

The relative operating costs of different heating systems are heavily affected by the fuel prices of each option. Figure EC.22 is based on fuel price assumptions in Leading the Way in 2030.

Hydrogen from electrolysis will always be more expensive to produce than the electricity used to produce it, as there are some efficiency losses in the conversion. This means that if the hydrogen is produced from electricity at average electricity retail prices, heat pumps will always be a more cost effective option to operate, due to the much higher efficiency, compared to hydrogen boilers. Consumers may see subsidies to equalise the cost of hydrogen and natural gas to ease the transition, but ultimately this cost will still end up being paid by consumers indirectly via taxes or energy bill levies.

While the efficiency of a gas or hydrogen boiler can never exceed 100%, the Coefficient of Performance of a heat pump can be several times this, indicating that for every unit of electricity used to power the heat pump, it supplies two or more units of heat to the property by extracting heat from the environment.

This analysis is based on an average Coefficient of Performance for an Air Source Heat Pump of 2.81 in 2030, indicating it produces 2.81 units of heat for every unit of electricity consumed.

It is possible, however, for hydrogen to be more cost competitive. Hydrogen that is produced by electrolysers operating flexibly to maximise the use of low cost renewable generation that would otherwise be curtailed, offers the potential to reduce the costs of the input generation and therefore of the hydrogen produced. However, electrolyser locations need to be carefully considered to minimise whole energy system costs. In System Transformation, hydrogen used for heating is mostly produced via methane reformation with CCUS. The price of this is sensitive to the input price of gas and the capital and operating costs of the methane reformation facilities. Our estimate for the retail price of hydrogen in this scenario is between 12 and 16 p/kWh.

Under Ofgem's Energy Price Cap, unit rates for gas and electricity between April and June 2023 are approximately 50 p/kWh for electricity and 12 p/kWh for gas. Under the Government's Energy Price Guarantee (EPG) these are reduced to 33 p/kWh for electricity and 10 p/kWh for gas. Going forward, rates for both electricity and gas are expected to fall over the next two years, reaching closer to the rates seen prior to 2022 which were around half of those seen under the EPG.

There are several other initiatives that are likely to affect the relative balance of electricity and gas prices. Currently electricity prices are affected by gas prices, as gas fired generation often sets the marginal price of electricity. Reform of the wholesale electricity markets could change this. There are also a range of levies that are placed on electricity bills and not gas bills. The Government's Heat and Buildings Strategy committed to rebalancing these policy costs to ensure heat pumps were no more expensive to buy and run than gas boilers. Both measures could make heat pumps more cost competitive.

The potential for heat pumps to operate more flexibly with thermal storage or smart control alongside a Time of Use Tariff presents another opportunity to reduce heat pump operating costs by minimising the use of more expensive peak-time electricity.

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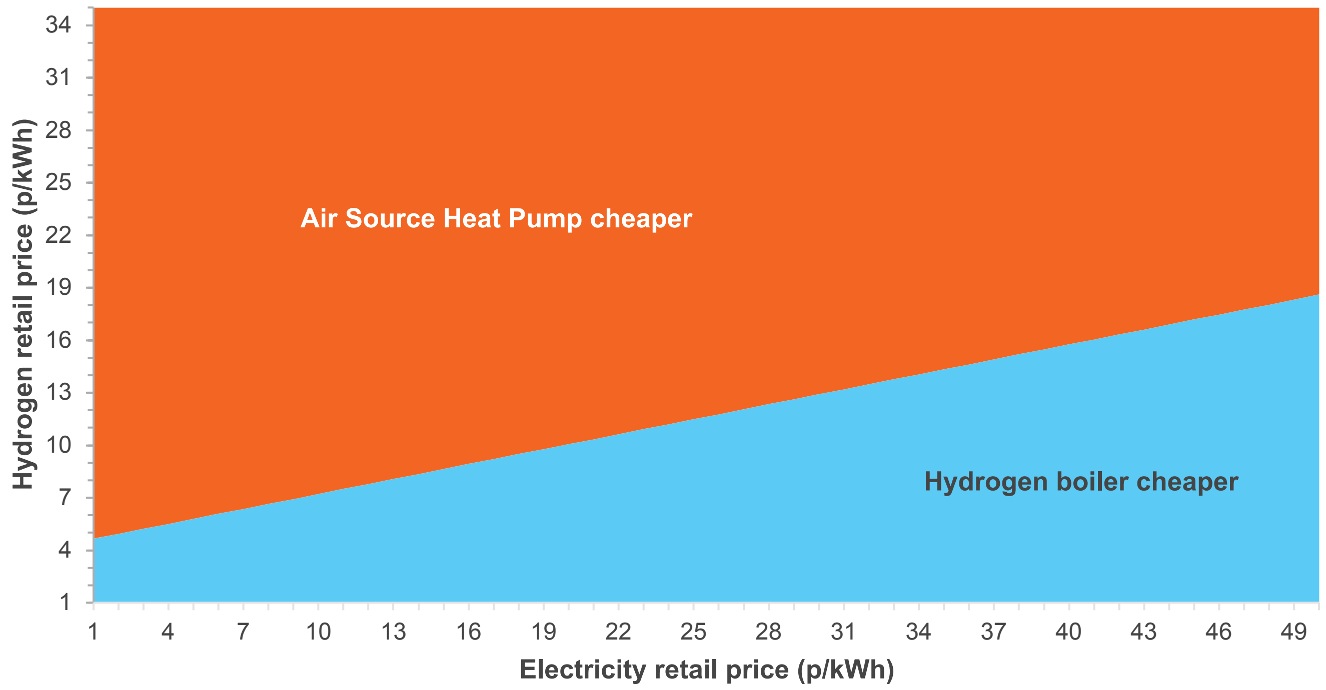
Hydrogen and electrification - residential focus

Figure EC.23 shows the cheapest 15 year cost per technology out of Air Source Heat Pumps or hydrogen boilers, including capital costs, conversion costs, operating costs and fuel costs. Our analysis shows that under current assumptions, the unsubsidised hydrogen prices in Leading the Way of over 30 p/kWh make heat pumps a more cost effective option. In System Transformation, which has the lowest consumer hydrogen prices of between 12 and 16 p/kWh, this would have equivalent costs to an electricity price of between 27 and 41 p/kWh respectively. While this is lower than the peak unsubsidised electricity prices seen during winter 2022/23, it is much higher than prices seen before Autumn 2021. Heat pumps are likely to often be the most cost effective option for residential heat decarbonisation, even after accounting for higher capital costs. However this result is sensitive to changes in input assumptions for fuel costs and capital costs, and the break even point will vary across the scenarios. Figure EC.23 is before considering any subsidies, grants or incentives, such as capital grants towards heat pumps available through the Boiler Upgrade Scheme or potential hydrogen adoption incentives, which can change the balance of the options considerably.

However, as mentioned above, ultimately these policy costs need to be borne by taxpayers or energy consumers, so while the cost to individual consumers can be changed by these, the relative total system costs are not.

Figure EC.23: Relative cost of hydrogen vs electrification for residential consumers for the most common archetype in England, based on Leading the Way 2030, excluding subsidies and incentives



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The Energy System

ESO

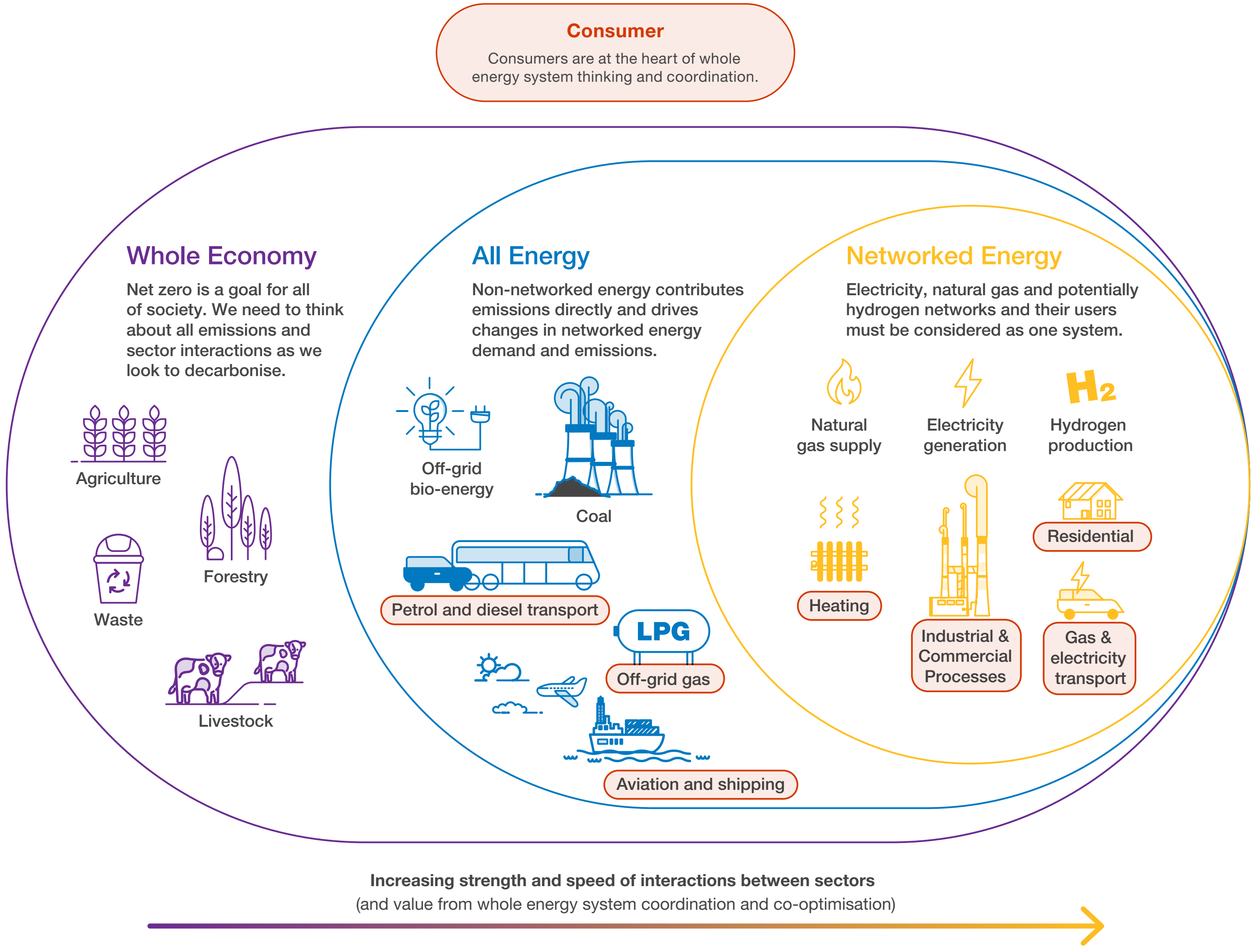
Introduction

The energy system is the backbone of modern society. To deliver on the transition to net zero whilst continuing to deliver for consumers, a whole energy system approach and strategic change is required across all fuels, including low carbon hydrogen and bioenergy.

Consumers require energy that is clean, secure, affordable, and fair. This is achievable but relies on strategic development of whole energy networks, markets, and technologies to make the most of the abundant renewable energy available in Great Britain. We have already seen the energy system evolving as new technologies and innovations emerge, and the electricity system has decarbonised rapidly.

The power sector must be fully decarbonised, and in order to offset other sectors which cannot decarbonise it needs to reach a point of negative emissions. Therefore, **renewable sources emerge as the dominant source of electricity generation in Great Britain** between now and 2050. By 2030, wind and solar generation will have risen to at least 66% in Falling Short (from 31% in 2022[1]) and by 2050, it will meet 71% to 84% of annual electricity demand.

Emissions from some other sectors, like aviation and shipping, will be hard to abate and therefore, achieving net zero by 2050 across the whole economy will require **Greenhouse Gas Removal (GGR) to offset emissions**. The energy sector is well placed to deliver this through technologies such as Bioenergy with Carbon Capture and Storage (BECCS). Direct Air Carbon Capture and Storage (DACCS) will also have a large role to play.



1 Britain's Electricity Explained: 2022 Review | ESO (nationalgrideso.com)

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Introduction

Flexibility from demand and supply will be needed to maximise the generation output from weather dependent sources, ensure supply is reliable and minimise cost to the consumer. Our scenarios demonstrate the importance of utilising low carbon technologies and fuels, such as hydrogen and CCUS (Carbon Capture, Usage & Storage), alongside electricity storage, interconnection, and demand side flexibility, to deliver a balanced whole energy system.

This chapter explores in detail the energy system: how it works today and how it could change as we transition to a net zero energy system. Carbon emissions across the whole economy, including the energy system are covered in the Net Zero chapter.

We consider electricity, hydrogen, natural gas and bioenergy supplies and in each scenario, we match annual supply and demand using an unconstrained network. For more information on constrained modelling, please see our Electricity Ten Year Statement (ETYS) and Network Option Assessment (NOA) documents. This is shown in our energy flow diagrams. We also ensure that the energy system can meet peak demand in all scenarios in line with reliability standards (1-in-20 gas peak and Average Cold Spell (ACS) peak electricity demand), including flexibility needs.

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Introduction

Policy timeline / key comparison chart

CT Consumer Transformation
LW Leading the Way
ST System Transformation
FS Falling Short
Policy

This chart contains a selection of recent policy targets and ambitions in relation to net zero and energy security and highlights how they compare to the different scenarios. Analysis for FES 2023 commenced before the publication of several key policy documents and does not signify that any individual targets cannot be met across the range of scenarios.

		2022	By 2025	By 2030	By 2035	By 2040	By 2045	By 2050	Maximum potential by 2050
Emissions	Meets 2050 net zero target							CT LW ST (Policy)	
	Meets 5th carbon budget	446 $MtCO_2e$ emissions[2]		CT LW ST (Policy)	FS				Net zero by 2046 LW
	Meets 6th carbon budget				CT LW ST (Policy)			FS	-34 $MtCO_2e$ in 2050 LW
Electricity Generation	50 GW of offshore wind	13 GW		LW (Policy)	CT ST	FS			110 GW CT
	Up to 5 GW floating offshore wind	0 GW			CT LW ST (Policy)	FS			20 GW CT
	Up to 70 GW of solar	14 GW			(Policy)	LW		CT	91 GW LW
	No unabated natural gas-fired generation capacity (subject to security of supply)	36 GW			(Policy)	LW	ST	CT	LW reaches this target in 2036 LW
	Up to 24 GW nuclear generation capacity	6.1 GW						(Policy)	16 GW CT
Hydrogen	10 GW low carbon hydrogen production capacity in operation or construction	<1 GW		LW (Policy)	ST		CT		83 GW ST
	5 GW hydrogen production from electrolysis	<1 GW		LW (Policy)	ST	CT			55 GW LW
	Up to 2 GW of low carbon hydrogen production capacity in operation or construction[3]	<1 GW	(Policy)	ST LW	CT				83 GW ST
Natural Gas	40% reduction in gas consumption			LW (Policy)	CT	ST			97% reduction CT
Bioenergy	*Strategy expected this year – bioresource supply consistent with CCC Carbon Budget 6*								

2 2021 emissions, latest data available
3 FES scenarios on this chart represent operation rather than construction as well as a mix of CCS enabled and electrolytic hydrogen

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Key insights

This key to achieving net zero whilst reducing whole energy system costs and ensuring security of supply is strategic coordination and whole energy system thinking across all sectors.

Whole energy system

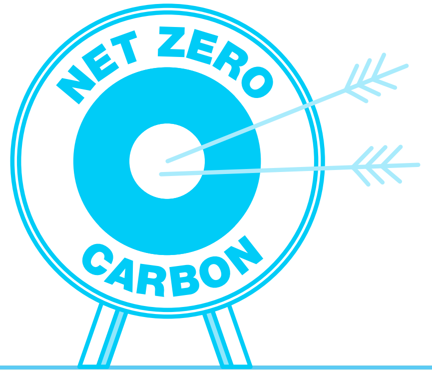
- Strategic and timely investment across the whole energy system is critical to achieving decarbonisation targets and minimising network constraints. Coordinated planning and delivery of strategic, whole energy system investment through Centralised Strategic Network Planning (CSNP) will require continued collaboration and engagement with the Government, Ofgem, local communities, industry, and the supply chain. Strategic network investment should be enabled through reforms to the planning system, while also balancing social and environmental impacts.
- Connections reform is required to facilitate quicker, more coordinated, and efficient connection to the GB electricity system to deliver net zero. Continued collaboration between Government, Ofgem and industry is critical. The process must be future proofed to facilitate potential prioritisation of connections for delivery of whole energy system benefits and net zero in line with strategic network planning.
- New large electricity demands, including electrolysers to convert electricity to hydrogen, will be required for net zero. These demands have significant potential to deliver whole energy system flexibility and reduced network constraints alongside decarbonisation. A cohesive strategy is required to ensure large electricity demands are located where they provide the biggest benefit to consumers and reduce whole energy system costs. This needs to be enabled by market reform.

Electricity supply

- Total generation capacity is expected to increase rapidly through the 2020s, with between 42% and 85% increase by 2030.
- Offshore wind makes up the largest share of growth in electricity supply in the 2020s and becomes the largest source of generation in all scenarios by 2035.
- Capacity Market (CM) contracts awarded to a range of new gas and storage projects drive additional growth and reduce the role of other technologies in the supply mix in the short-term.

Gas supply

- Events over the past year have had a significant impact on the UK picture for natural gas. Despite price rises, we have seen an increase in gas demand due to an increase in exports to the continent as they looked to replace Russian gas. Supply from UKCS (UK Continental Shelf), imported gas via pipeline from Norway and shipped LNG (Liquified Natural Gas) have all increased in the past year to match demand.
- There is sufficient gas supply between now and 2050 to ensure security of supply. This is partly due to the diverse sources of natural gas available to GB, and because we expect natural gas demand to decline through fuel switching, energy efficiency improvements and increased renewable generation.
- The most effective way to ensure energy and climate security and reduce dependence on imported fossil fuels is the swift transition to clean energy and increased energy efficiency.



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Key insights

Hydrogen supply

- Gas and hydrogen infrastructure: the gas network is still being used in 2050 in System Transformation and Falling Short, albeit with modifications to transport hydrogen in the former. In Leading the Way, the network required is not as extensive and, in Consumer Transformation, it is much reduced by 2050 due to reduced demand and lower levels of hydrogen.

- Low carbon hydrogen will play a vital role in the future energy system, but the breadth of application is very wide across our scenarios. This reflects the differing views on how hydrogen will be used to meet our energy needs.

- There is only enough hydrogen in the pipeline to meet the government target of 10 GW. We believe all the projects coming online and in time is less likely and therefore only seen in Leading the Way. More capacity and more projects would give greater confidence in meeting this target.

  In order for this to happen, policy support and consistency is required. All hydrogen projects rely on funding mechanisms which form part of the Energy Security Bill.

- Before 2030, demand for low carbon hydrogen will be dictated by proximity to a hydrogen production project, supported with government funding.

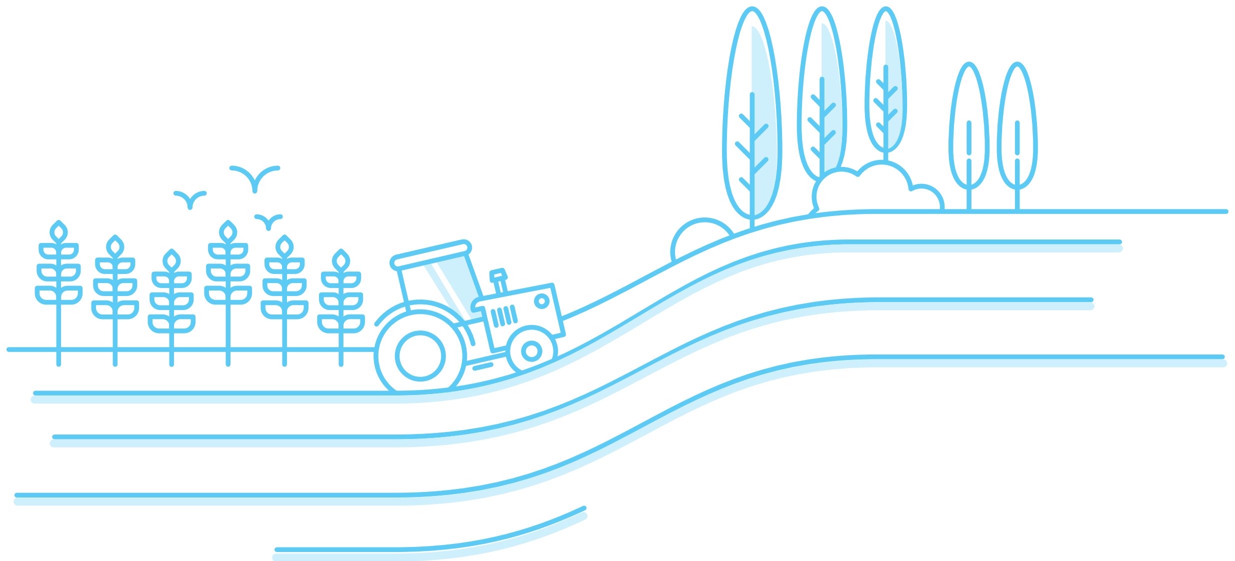
- Further clarity is needed on how and when track 2 industrial clusters will be delivered, alongside the expansion of track 1 clusters to reduce investment uncertainty and enable greater optionality for consumers.

- Electrolytic hydrogen production has the potential to deliver whole energy system benefits, and hence lower costs of energy, but only if it is in the right place. A cohesive strategy is required for technology which considers the proximity to network constraints, end users and transportation and storage of hydrogen.

Bioenergy supply

- Bioenergy can play a role in the decarbonisation of all sectors of the economy, but resources are limited so it is critical to ensure it is being used for the most optimal applications.

- Robust sustainability criteria are essential in ensuring maximum contribution to net zero from bioenergy, which is easier to assess for domestic supply chains. Reduced reliance on imports also reduces scope three emissions and strengthens security of supply.



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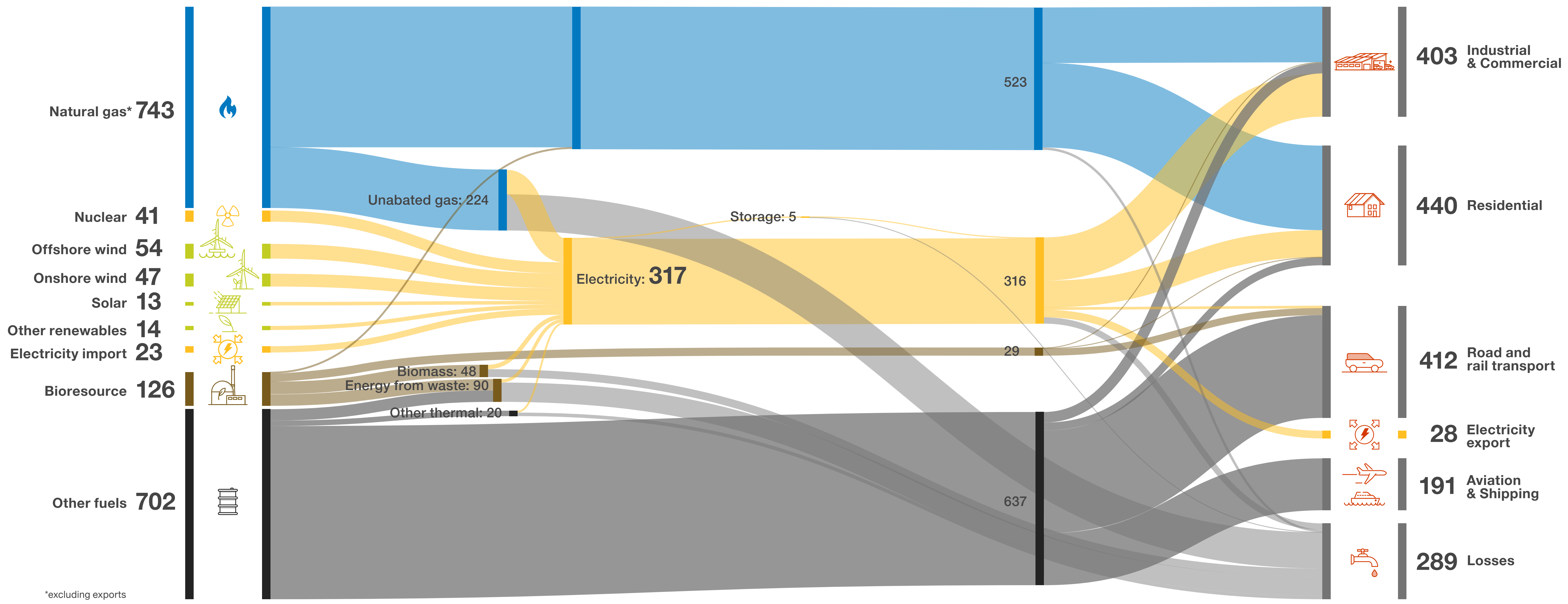
Energy supply and demand

2022 (1763 TWh)

- Fossil fuels make up 82% of total energy supply in 2022
- Petroleum supplies 93% of road transport demand and 100% of aviation and shipping demand
- Interactions between different fuels are low, demonstrating limited whole system thinking



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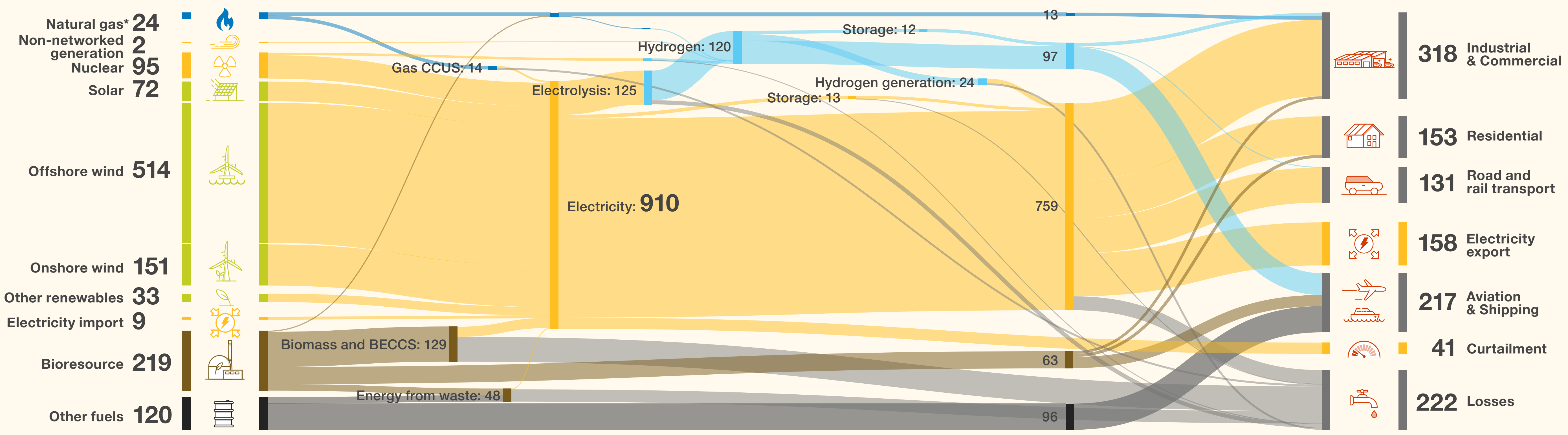
Energy supply and demand in 2050

Consumer Transformation (1239 TWh)

- Home heating, transport and industry largely electrified
- High levels of energy efficiency combined with large-scale electrification lead to lowest consumer energy demands across the scenarios excluding aviation
- High levels of renewable generation with low hydrogen production leads to the highest levels of electricity curtailment and export of any of the scenarios
- Two thirds of hydrogen produced is used in aviation, with another 20% used for electricity generation, to help meet security of supply



*excluding exports

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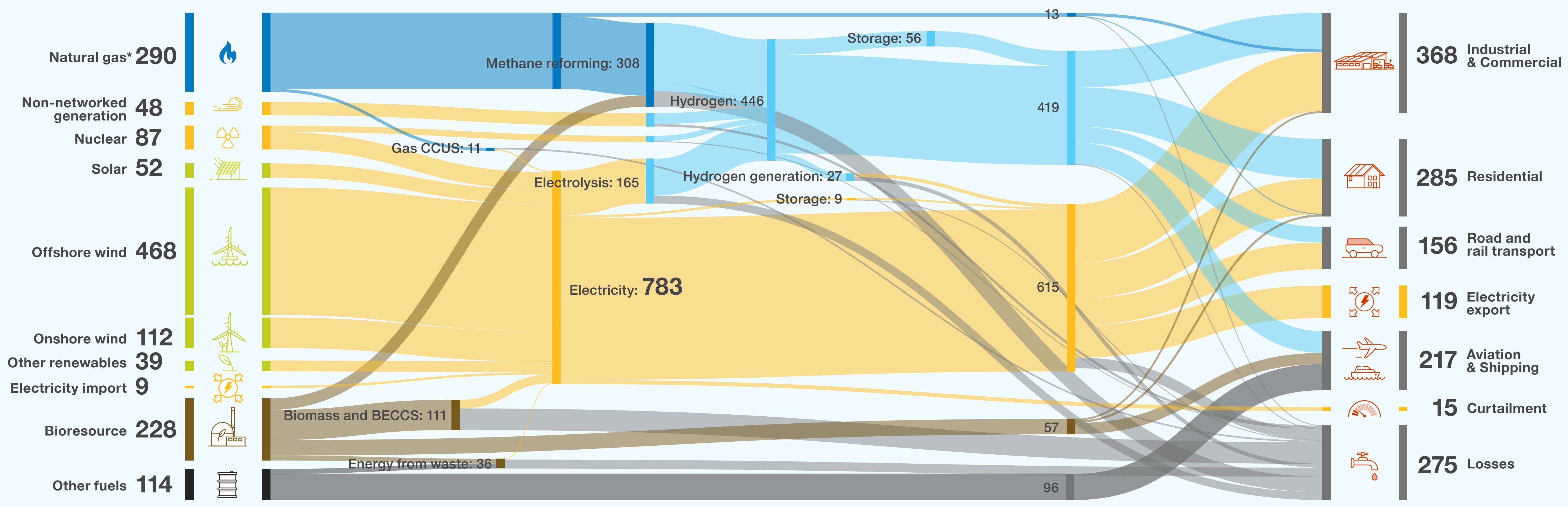
Energy supply and demand in 2050

System Transformation (1447 TWh)

- Highest proportion of hydrogen across the scenarios with widespread use for home heating, industry and HGVs
- High natural gas use for hydrogen production from methane reformation
- Highest level of bioresource use - bioenergy used to produce both hydrogen and electricity, mostly alongside CCUS for negative emissions
- Electricity production more than double that of today, partly to meet highest demand for electrolysis



*excluding exports

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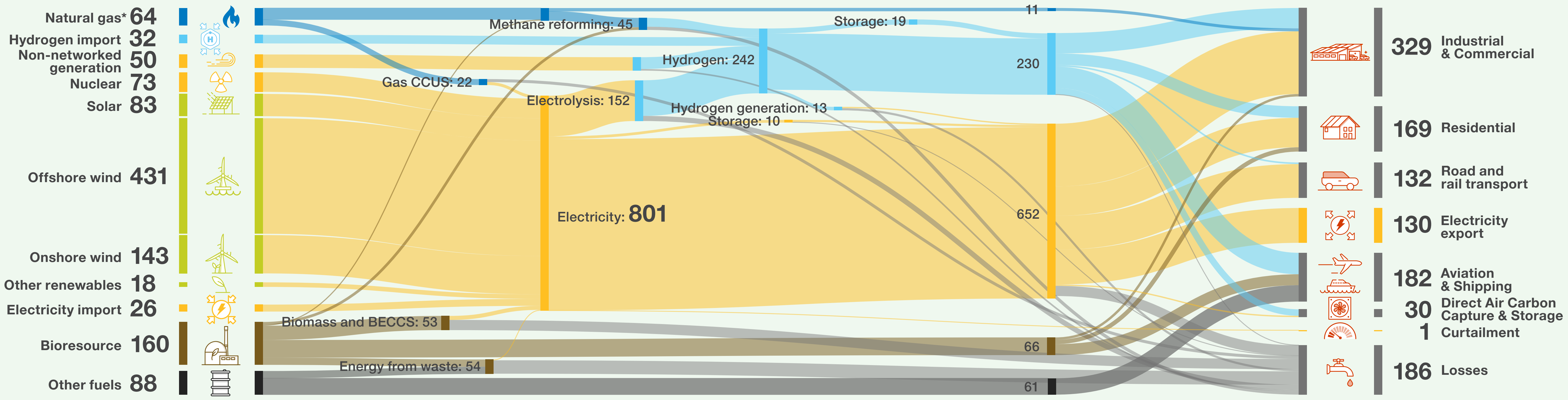
Energy supply and demand in 2050

Leading the Way (1167 TWh)

- Combination of hydrogen and electricity used in industry and to heat homes
- Lowest level of electricity curtailment across the scenarios, due to the highest level of flexibility
- Lower bioresource use for negative emissions due to emissions reduction from land use change and Direct Air Carbon Capture and Storage (DACCS)
- Zero carbon fuels meet two thirds of aviation demand



*excluding exports

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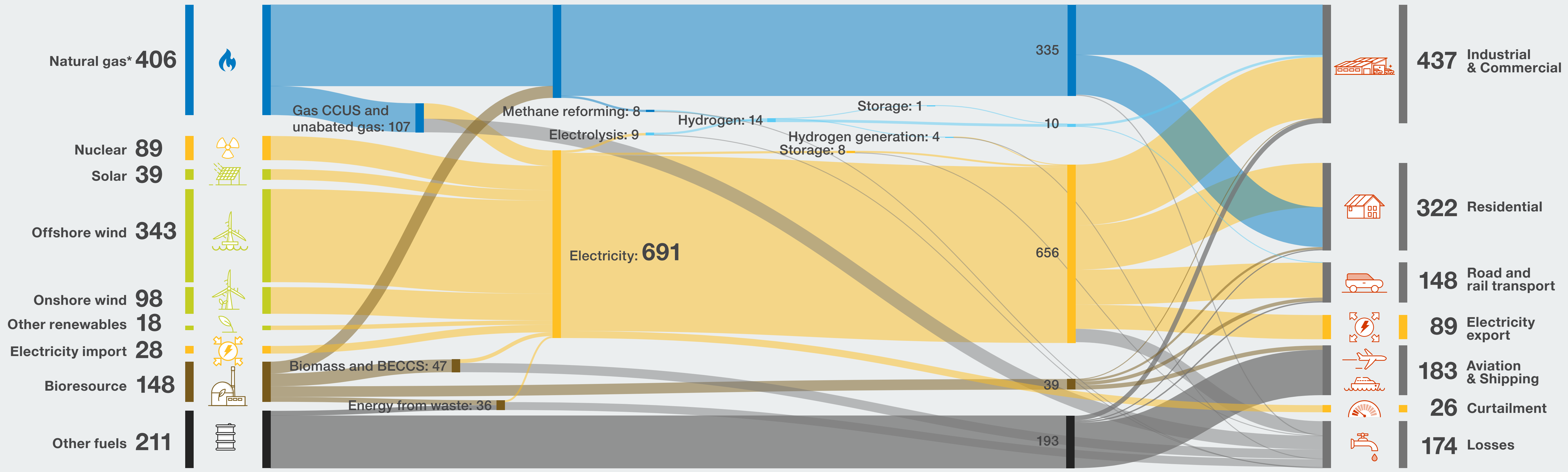
Energy supply and demand in 2050

Falling Short (1380 TWh)

- Continued high usage of natural gas, particularly for domestic heating and industry
- Small private vehicles fully electrified (including some plug-in hybrids) whilst HGVs rely on fossil fuels
- Low use of hydrogen as production isn't decarbonised
- Highest total end-user energy demand due to minimal increase in energy efficiency measures and reliance on inefficient fossil fuels



*excluding exports

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Supply and demand

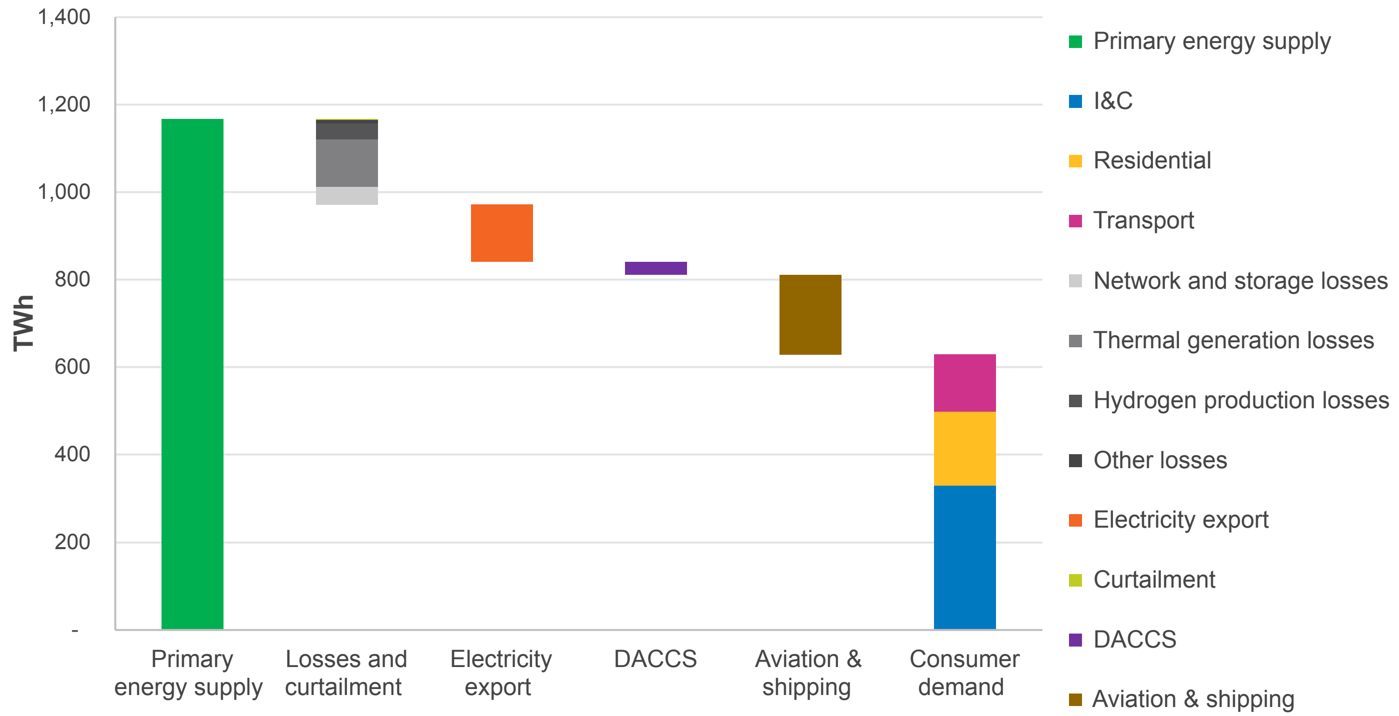
Transformation energy demand

Demand for residential, transport and industrial & commercial consumers represents 58% of total energy demand in Leading the Way in 2050, down from 88% today.

Total consumer demand in Leading the Way in 2050 is 630 TWh, down from 1386 TWh in 2022. This is partly driven by significant increases in energy efficiency, but primarily from much higher efficiencies of some electrified processes compared to combustion equivalents. While underlying residential heat demand falls by 28% in 2050 due to energy efficiency improvements and behaviour change, the energy demand for heating falls by 61%, with the difference due to the greater efficiency of heat pumps compared to gas boilers.

Figure ES.01 also highlights some new forms of demand, such as demand for Direct Air Carbon Capture and Storage, non-kerosene demand for aviation and shipping[4] and net electricity export. We also see higher levels of losses, while thermal generation losses fall as the electricity sector shifts away from gas generation, losses increase on the electricity networks as they carry higher volumes of energy, and there are additional losses involved in producing new fuels such as hydrogen. We also see higher levels of curtailment of renewable generation at times.

Figure ES.01: Demand components contributing to total primary energy



4 Today or future kerosene demands are not included in this analysis

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Primary energy demand

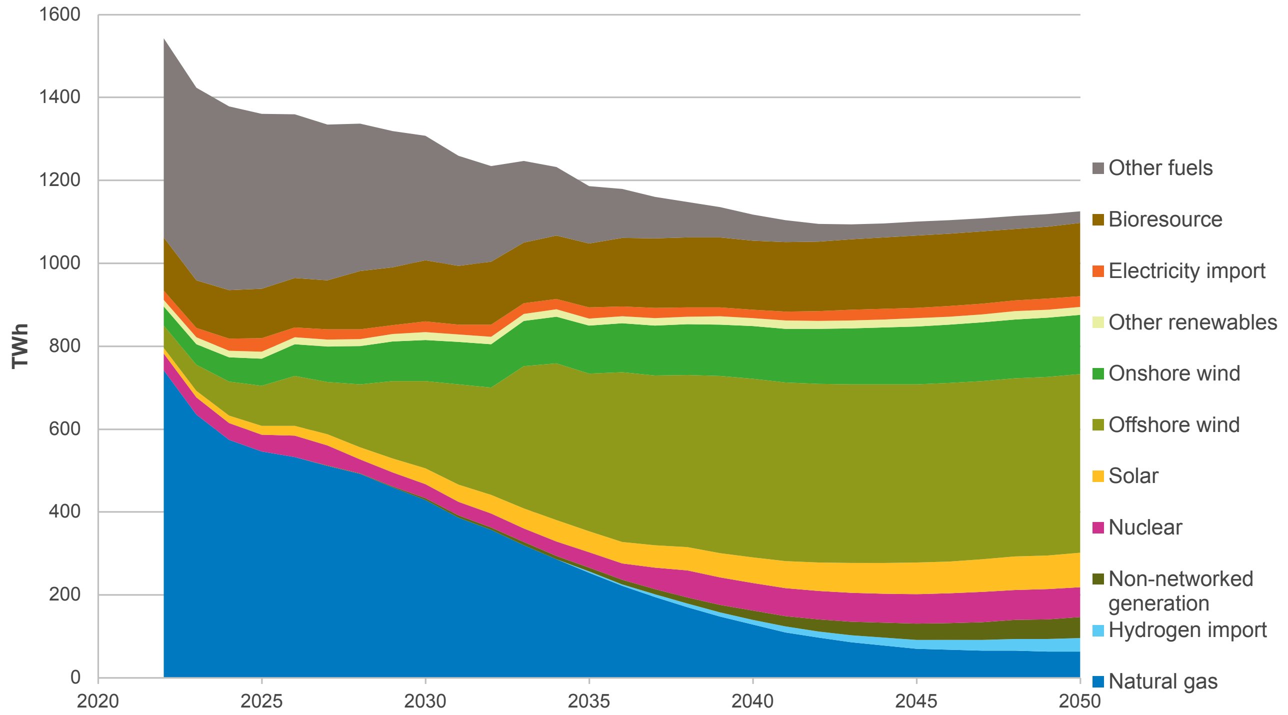
Total primary energy demand falls across all scenarios between today and 2050.

Our energy flow diagrams show how much energy is needed for a given year in each scenario, by end consumer (on the right-hand side) and where that energy comes from, by primary energy type (on the left-hand side). Here we look in more detail at how that primary energy type changes over time in Leading the Way.

In 2022 electricity from nuclear and renewables represents 13% of total primary energy input, with over three quarters met by fossil fuels. Electricity produced from fossil fuels or bioenergy is not considered primary energy. This is likely to change rapidly as the economy decarbonises, with oil and natural gas use falling sharply through the 2020s and 2030s.

The shift from petrol and diesel to EVs has the largest impact on oil use, resulting in a corresponding increase in electricity demand, while the largest single contributor to natural gas use is residential heating. This highlights the key challenges that face the country in reaching net zero: the switching away from fossil fuels. Many energy demands can be electrified, but this results in an increase in electricity demand that needs to be met from new sources of low carbon generation. Switches from fossil fuels to other sources of energy require either sufficient resource availability of e.g. bioresource or, in the case of hydrogen, additional electricity or natural gas to produce it. The role of fuel switching is explored in more detail in the Net Zero chapter. Energy efficiency also has a key role in helping reduce total consumer demand, thereby limiting the need for additional electricity generation, this is explored in the Energy Consumer chapter.

Figure ES.02: Primary energy demand in Leading the Way in 2050



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Security of supply and peak demand

As we move away from gas generation to renewables, alternative methods for managing peaks in demand will be required.

Traditionally, risks to meeting electricity security of supply,[5] have been at times of high demand, particularly peak demand. In the future, these risks will also be driven by periods of over-supply and/or supply and demand mismatch. Flexibility is used to help manage these periods. In the past, this was normally in the form of dispatchable gas plants being switched on, with relatively small contributions from pumped storage and (mainly industrial) Demand Side Response (DSR). In the future, storage, DSR and other forms of flexibility will play a key role in managing the system.

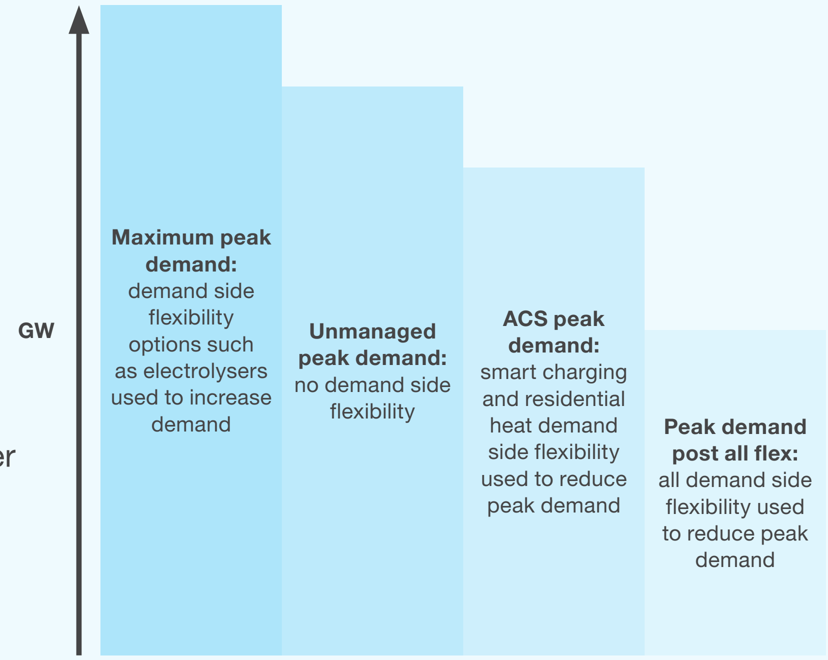
As we move away from gas generation to renewables, alternative methods for managing peaks in demand will be required; these could include replacing natural gas power plants with equivalent hydrogen power plants, Long Duration Energy Storage (LDES), DSR, and batteries for shorter, less sustained peaks.

In the future, high demand will not be the only risk to security of supply as increased renewable generation will result in supply determining periods of risk. For example, low demand during periods of high renewable supply will pose equal risk to periods of higher demand but with much lower levels of renewable generation. These periods of undersupply are typically short (hours or a few days) and can be managed by options including several flexible technologies: interconnectors, DSR and Electric Vehicle (EV) smart charging (or Vehicle-to-Grid (V2G)).

Peak electricity demand definitions

There are several types of peak electricity demand referred to in this chapter:

- **Maximum peak demand:** as well as using demand side flexibility to reduce demand, it can also be used to increase demand when electricity supply is very high, for example by running electrolysers when it is windy. In this report this is referred to as maximum peak demand.
- **Unmanaged peak demand:** refers to the maximum electricity demand before any demand side flexibility takes place to reduce demand. This does include a degree of natural diversity.
- **ACS peak demand:** this is the maximum electricity demand over an average winter after smart charging and residential heat demand side flexibility have been applied.
- **Peak demand post all flex:** this refers to the maximum electricity demand after all demand side flexibility has been applied.



5 **Security of supply** refers to meeting all electricity demand at any given time. Risks include loss of supply due to operability issues/overloaded network

Security of supply and peak demand

More extreme but rare extended periods of low weather-dependent generation (often referred to as dunkelflaute periods), possibly lasting up to several weeks, also have the potential to pose a security of supply risk, since a combination of flexible technologies will be needed to ensure security of supply as these periods could cause storage options to be exhausted. There is still considerable uncertainty around the length and regularity of these periods. Their level of impact will be determined by how low renewable generation is and how much it fluctuates relative to demand.

To manage dunkelflaute periods, dispatchable thermal power plants (gas and/or hydrogen), depending on the scenario and year, are likely to be required. A combination of LDES (e.g. Compressed Air Energy Storage (CAES), Liquid Air Energy Storage (LAES), Pumped Hydro Storage (PHS)) and interconnectors will be required to manage the network during these periods. Further analysis on dunkelflaute periods is presented in the Flexibility chapter. We continue to work with industry experts to improve our understanding of the potential impact of dunkelflaute periods in future FES iterations.

At times of high renewable generation and low demand, oversupply also needs to be carefully managed with the need for additional energy to be consumed (either by increasing demand or using energy storage) to prevent the need to curtail generation. As with undersupply, oversupply can occur daily or last for a longer period. Flexible demand sources, such as electrolysers, may be particularly useful for managing longer periods of electricity oversupply as when utilised they increase demand, for example by using electricity to produce hydrogen which can then be stored for the duration of the period of oversupply.

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Security of supply and peak demand

Electricity peak demand

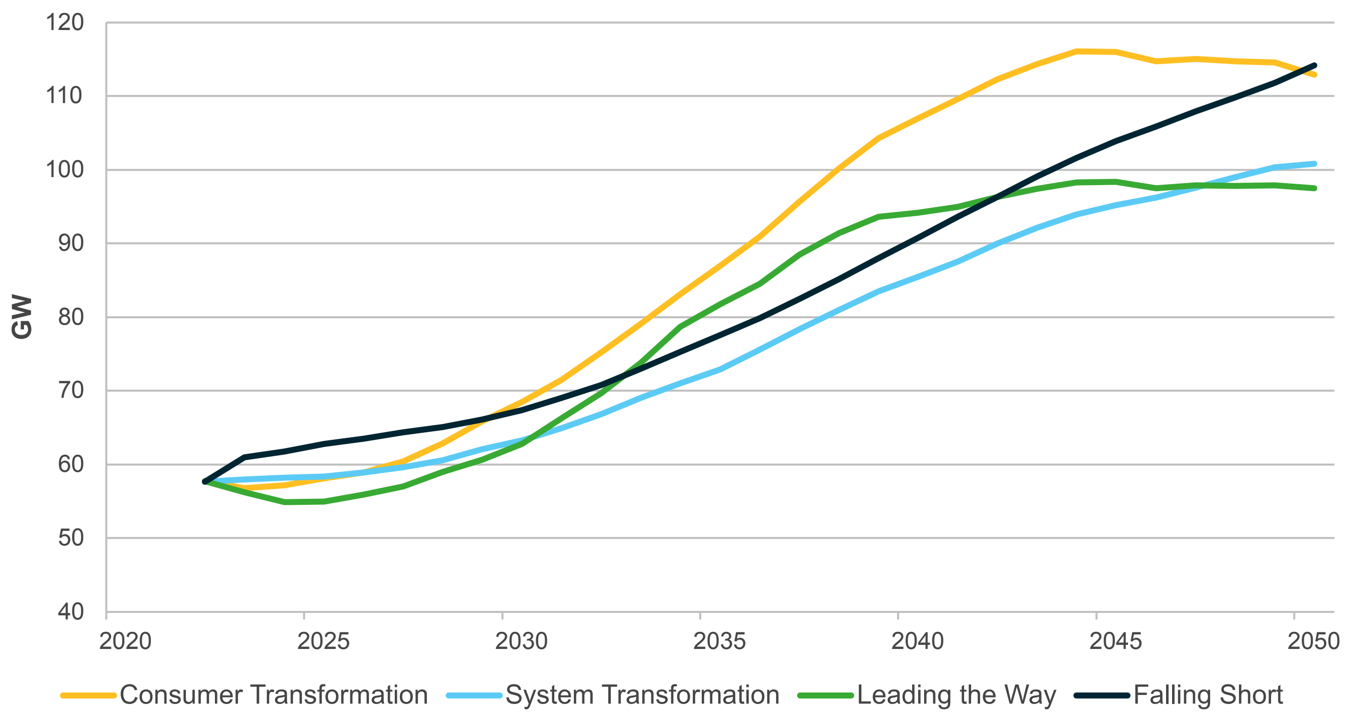
We expect electricity peak demand to increase in all scenarios as electrification of the economy continues, particularly heat and transport. Figure ES.03 shows the electricity demand projections out to 2050, which assumes the Average Cold Spell (ACS[6]) definition of demand.

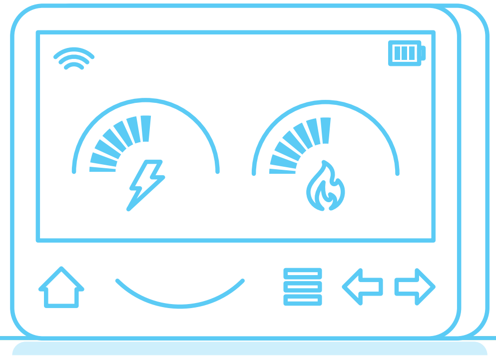
Consumer Transformation is the most electrified scenario and the peak demand for electricity increases rapidly from the late 2020s and then stabilises during 2040s. This is slower in the other scenarios where many sectors, but particularly heat, experience lower levels of electrification.

Compared to FES 2022, this year's electricity peak and annual demands are marginally lower out to 2030 due to the forecast higher energy prices and slower economic growth which impact demand. Post-2030, peak demand in System Transformation rises at a similar rate to FES 2022, but does not exceed FES 2022 peak demand until 2047, due to the lower starting point (i.e. lower peak demands through the 2020s).

For the other scenarios, electricity peak and annual demands from the early 2030s up to 2050 are higher than FES 2022, reflecting stakeholder feedback and policy announcements. The changes to electricity peak and annual demands are primarily due to a combination of increased fuel switching away from natural gas in the Industrial & Commercial (I&C) sectors, reflecting the Industrial Decarbonisation Strategy, and the increased electrification of Heavy Goods Vehicles (HGVs). I&C electrification increases peak and annual demands, while fuel switching to hydrogen produced from electrolysis increases annual electricity demand only, as electrolysers typically don't operate at peak. In Falling Short, an increased level of electrification compared to FES 2022 is seen, although without the efficiency measures seen in some of the other scenarios.

Figure ES.03: ACS Electricity Peak Demand





6 ACS demand for electricity is the maximum demand over an average winter and is consistent with the treatment of demand in the electricity Capacity Mechanism. As an average it has a 50% chance of being exceeded in any given year

Security of supply and peak demand

Electricity peak demands have historically occurred on winter weekday evenings when demand for Industrial & Commercial premises overlaps with heating, lighting and cooking in homes. The nature and timings of peak demand are likely to change as the country decarbonises. As the share of renewable electricity supply increases, we may see peak demands at other times of the day or year. Distributed generation connected to the distribution network will meet an increasing share of local demand at times, changing the demand profile seen on the transmission network. Beyond this we will start to see more forms of flexible demand such as electrolysis that change operation patterns according to market conditions. For example, in Leading the Way in 2050, a typical daytime demand could be increased by up to 38 GW from electrolysers alone. This could be encouraged to happen at times of high renewable output by low market prices or other incentives and would be in addition to 'ordinary' demands on the electricity system, for more information please refer to our Flexibility chapter.

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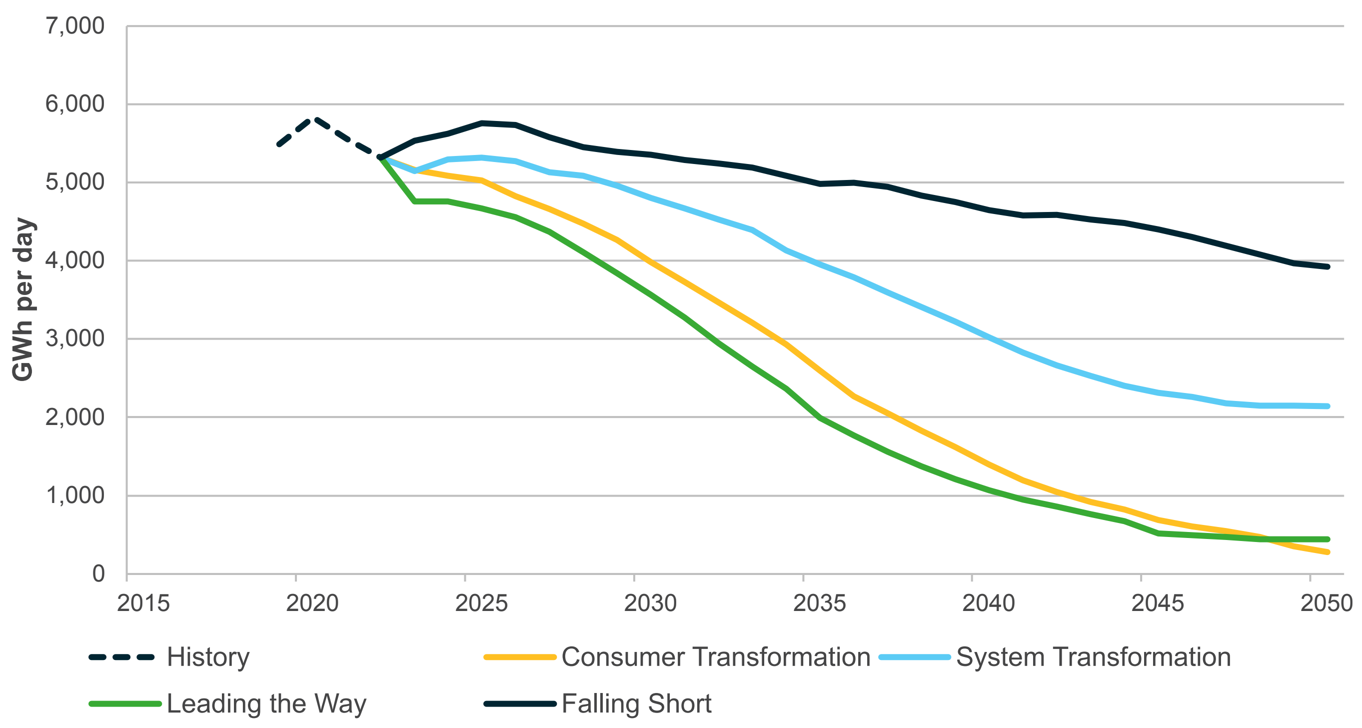
Natural gas peak demand

Natural gas peak demand is expected to decline in line with the reduced use of natural gas in the net zero scenarios, this can be seen in the data workbook under ES.04. Peak demand for natural gas is linked to heat demand for residential homes. On cold winter evenings this will continue to be high while large numbers of homes still rely on gas boilers. As the heat sector decarbonises in the net zero scenarios with greater use of heat pumps and hydrogen boilers, the peak demand for natural gas will reduce. Falling Short shows similar progress in decarbonising heat by 2050 as in FES 2022, with 147 TWh of natural gas being used for residential heating by 2050 in this year's results compared to 142 TWh last year. However, this still represents just over 50% of total residential heat demand. This, alongside some gas still being used in the power sector, results in gas peak demands reducing more by 2050 than in last year's results but remaining higher than our other scenarios.

In Consumer Transformation and Leading the Way, natural gas peak demand declines to nearly zero by 2050 as unabated gas is phased out completely, with only limited residual uses in the energy system. In System Transformation natural gas is still used to produce hydrogen via methane reformation with CCUS. However, the peak demand is lower than today as methane reformation to produce hydrogen takes place throughout the year.

Figure ES.04: Natural gas peak demand



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Consumer Transformation

The route to 2050

- Consumer Transformation sees rapid electrification through the 2020s and 2030s. To meet this there is high growth in renewable generation, particularly offshore wind and solar. The Government's 2030 offshore wind target is narrowly missed, reaching 50 GW in 2031, but with continued growth after this point – all the way to 116 GW in 2050.
- Gas generation output reduces rapidly through the 2020s but is still used to support security of supply. Its capacity declines in the 2030s, offset by continued increases in renewable and nuclear generation, including significant numbers of Small Modular Reactors (SMRs), growth in hydrogen generation capacity and BECCS. The power sector reaches net negative emissions in 2031. Interconnectors play an increasingly important role, to provide flexibility for weather dependent generation, and to make greater use of installed wind generation capacity by avoiding curtailment.
- Consumer Transformation has the lowest hydrogen supply of the three net zero scenarios because electricity is prioritised for heating. The focus is instead on using hydrogen to help operate the whole energy system by using excess renewable electricity.
- By 2030, only 1 GW of hydrogen production capacity is built and there are no imports or exports of hydrogen. Production of hydrogen increases from 2040 as hydrogen demand increases to help decarbonise hard to abate sectors.

What does 2050 look like?

- Electricity dominates overall energy supply, providing over 74% of primary energy. Wind, solar, nuclear and BECCS provide 93% of electricity, supplemented by many technologies delivering small amounts of energy.
- Total electricity generation capacity is 301 GW, plus a further 67 GW of electricity storage and interconnection. Electricity generation output is over three times that of today at 886 TWh, with 149 TWh exported.
- Despite high levels of electrification, hydrogen is used to decarbonise hard to abate sectors. Network-connected electrolysis is by far the most common method of production, utilising renewable generation at times where supply exceeds demand.
- Some limited repurposing of the existing natural gas system is assumed to transport hydrogen between clusters. As there is only minimal hydrogen network, electrolysers are located close to demand or are grouped with hydrogen storage and generation.
- High levels of hydrogen generation capacity, interconnection and storage provide flexibility to help meet peak demands, while there is a large net export of electricity over the interconnectors.
- Consumer Transformation sees our lowest natural gas demands by 2050. Natural gas is replaced in most cases by electricity for heating homes and buildings.

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System Transformation

The route to 2050

- Growth in renewable generation is fast through the 2020s, although slower than the other net zero scenarios, with more limited growth in decentralised technologies such as onshore wind and solar. However, the Government's 2030 offshore wind target is missed, 50 GW is reached in 2032 but continued growth is seen after this point as electrification increases electricity demand. Interconnection capacities increase steadily but provide a smaller share of flexibility over time compared to the other net zero scenarios.
- From the mid-2020s, strong support and clear direction from the Government help hydrogen supply and demand grow quickly over the 2030s.
- Hydrogen is blended into the gas grid from 2028 to 2043, after which dedicated hydrogen networks take over. Hydrogen producers and storers have much more flexibility in locating and sizing their assets, as they can rely on the gas network for offtake and distribution.
- We assume a strategy for rolling out hydrogen to the rest of the gas network is developed, beginning with some distribution networks converting in the 2030s for later connection to the NTS. Most of the conversion work has been completed by 2045.
- Methane reformation becomes the dominant form of hydrogen production initially, but growth slows in the mid-2040s, and electrolysis takes over.

What does 2050 look like?

- System Transformation has the highest level of hydrogen demand, hydrogen meets 42% of end consumer demand particularly in residential heat, industry and transport. It also sees the highest natural gas demand in 2050 of all our net zero scenarios which is primarily used for low carbon hydrogen production.
- Around 49% of hydrogen is produced through methane reformation with CCUS. Although electrolysis accounts for 60% of production capacity, it only supplies 39% of all hydrogen as load factors are relatively lower than methane reformation. This scenario also sees the highest levels of production from nuclear and biomass gasification, with the latter providing almost 5% of all hydrogen produced in 2050.
- Total electricity generation capacity is 268 GW, plus a further 49 GW of electricity storage and interconnection. Electricity generation output is well over twice that of today at 796 TWh, with 110 TWh exported. Wind, solar, nuclear and BECCS provide 92% of generation output. Gas CCUS and hydrogen provide less than 3% of generated electricity but play an important role in meeting security of supply. The power sector reaches net zero emissions in 2032 and delivers 36 $MtCO_2e$ of negative emissions through BECCS.
- As hydrogen is used for heating, significant seasonal storage is needed to ensure sufficient supply for winter peak by storing hydrogen produced by baseload methane reformation. We expect 56 TWh of stored hydrogen to be available by 2050 (equivalent to over 10% of annual demand) – primarily in salt caverns.

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Leading the Way

The route to 2050

- Leading the Way sees the most ambitious growth in renewable technologies in the 2020s and 2030s, reaching the Government's target of 50 GW of offshore wind by 2030 including networked and non-networked capacity and continuing to grow. It also sees high levels of solar and onshore wind growth. The power sector reaches net zero emissions by 2030.
- Natural gas generation is phased out rapidly, with no capacity remaining after 2035. Alternative flexible generation technologies including hydrogen need to be ramped up rapidly ahead of this date.
- Leading the Way correspondingly sees the fastest reduction in natural gas demand with most demand between 2020 and 2050 being met by gas from the UKCS and Norway.
- Hydrogen is a key enabler for rapid decarbonisation in all sectors. In tandem with high levels of renewable electricity generation, electrolysis capacity is built quickly over the 2020s and early 2030s, which in turn gives confidence to investors, businesses, and homeowners to invest in assets and appliances which use hydrogen where appropriate.
- With clear direction and significant support from the Government, the UK meets its ambition for up to 10 GW of hydrogen capacity by 2030. Almost all of this is through networked electrolysis, though the Government has provided some specific support to methane reformation capacity.
- Electrolysers are built near sources of renewable generation and can mitigate congestion on the electricity network. This is possible as these facilities are connected to a local hydrogen transmission network so that the hydrogen can be transported to where it is required. Offshore electrolysers will also be built alongside wind farms in the 2030s, so that hydrogen is transported to shore rather than electricity.

What does 2050 look like?

- Total electricity generation capacity is 269 GW, plus a further 79 GW of electricity storage and interconnection, meeting lower annual and peak demands than the other net zero scenarios. Electricity generation output is three times that of today at 779 TWh, with 104 TWh exported.
- Wind, solar, nuclear and BECCS provide 95% of generation output; these are supported by high levels of interconnection and storage and some flexible hydrogen generation to meet peak demands. The power sector delivers 17 $MtCO_2e$ of negative emissions through BECCS.
- Demand for hydrogen comes from a mix of heating and industrial needs as well as road transport, shipping and aviation.
- This scenario makes maximum use of electrolysis, either onshore or offshore. Hydrogen will also be produced from a limited amount of biomass gasification, with most bioresource used for electricity. Hydrogen production from nuclear is minimal.

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Falling Short

The route to 2050

- Falling Short sees more gradual decarbonisation of the power sector.
- Growth in offshore wind continues, with 31 GW installed by 2030, but with more limited growth of onshore wind and solar. After 2035, there is limited phase-out of gas generation, offset by some growth of gas with CCUS and large scale new nuclear in the 2040s.
- Emissions from the power sector fall below 36 $MtCO_2e$ by 2030 and decline gradually after this point driven by the shift away from unabated gas, reaching net zero by 2048. Interconnection capacity continues to grow up to 2030 while storage continues to gradually increase.
- Natural gas continues to play a central role in this scenario so there is little-to-no conversion of the gas network to transport hydrogen. Production facilities are mostly located close to areas of industrial demand.
- This hydrogen initially only comes from networked electrolysis. It is later joined by methane reformation with CCUS, with the first production and storage facility being built in the mid-2030s.

What does 2050 look like?

- Natural gas demand reduces steadily to about 65% of 2021 levels. Though natural gas is still widely used in the UK to heat homes and buildings and for industrial applications, we also see increased energy efficiency in homes and buildings, as well as increased electrification for heating.
- Increased electricity demands are driven by electrification of transport and some electrification of heat.
- Total electricity generation capacity is 243 GW, plus a further 38 GW of electricity storage and interconnection. Electricity generation output is over twice that of today at 639 TWh, with 61 TWh of net exports.
- Wind, solar, nuclear and BECCS provide 87% of generation. The electricity system is dominated by renewables, particularly offshore wind, but fossil fuels still play a key role, with gas generation, along with interconnectors, providing flexibility to support renewable generation and CCUS generation the highest across the scenarios. The power sector delivers 15 $MtCO_2e$ of negative emissions through BECCS.
- This scenario sees the smallest hydrogen demands as natural gas is still used for residential heat and industry, with electricity meeting most of the remaining energy demand.

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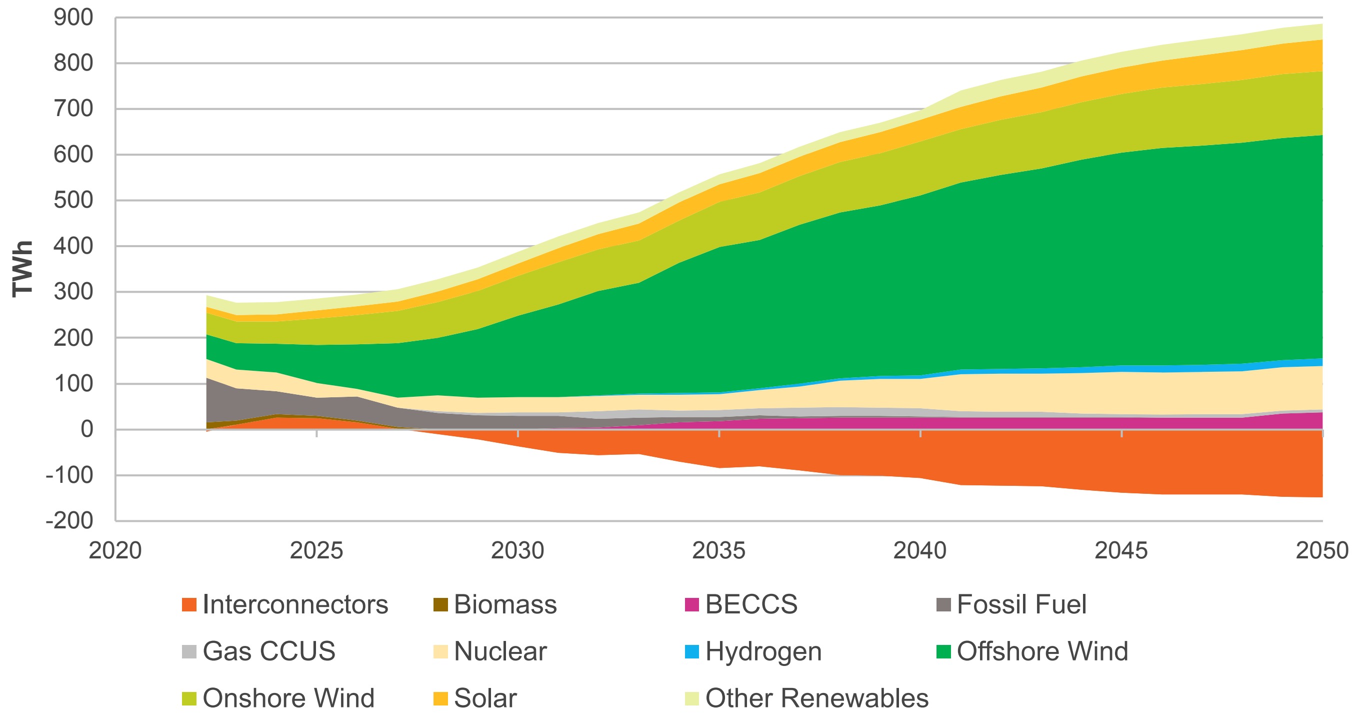
Electricity supply - total generation output

The energy crisis driven by the Russian invasion of Ukraine has changed the electricity supply balance in Great Britain over the last 18 months, with the country becoming a net exporter of electricity in 2022 from being a significant net importer of electricity in 2021. This resulted in higher fossil fuel generation to help support this level of exports. As the energy crisis eases we expect GB to return to a position as a net importer, driven by price differentials between GB and continental Europe, until the late 2020s when the growth of renewable generation leaves us with an energy surplus.

Consumer Transformation

Consumer Transformation shows the highest levels of electricity generation by 2050 with the majority output being offshore wind, a consistent result across the scenarios. Fossil fuel generation output falls by two thirds by 2030, as gas becomes increasingly used for system balancing, and annual supply is dominated by renewables. We also see the highest levels of negative generation in Consumer Transformation with interconnectors moving from net importing, to exporting by 2028.

Figure ES.05: Electricity output by technology in Consumer Transformation



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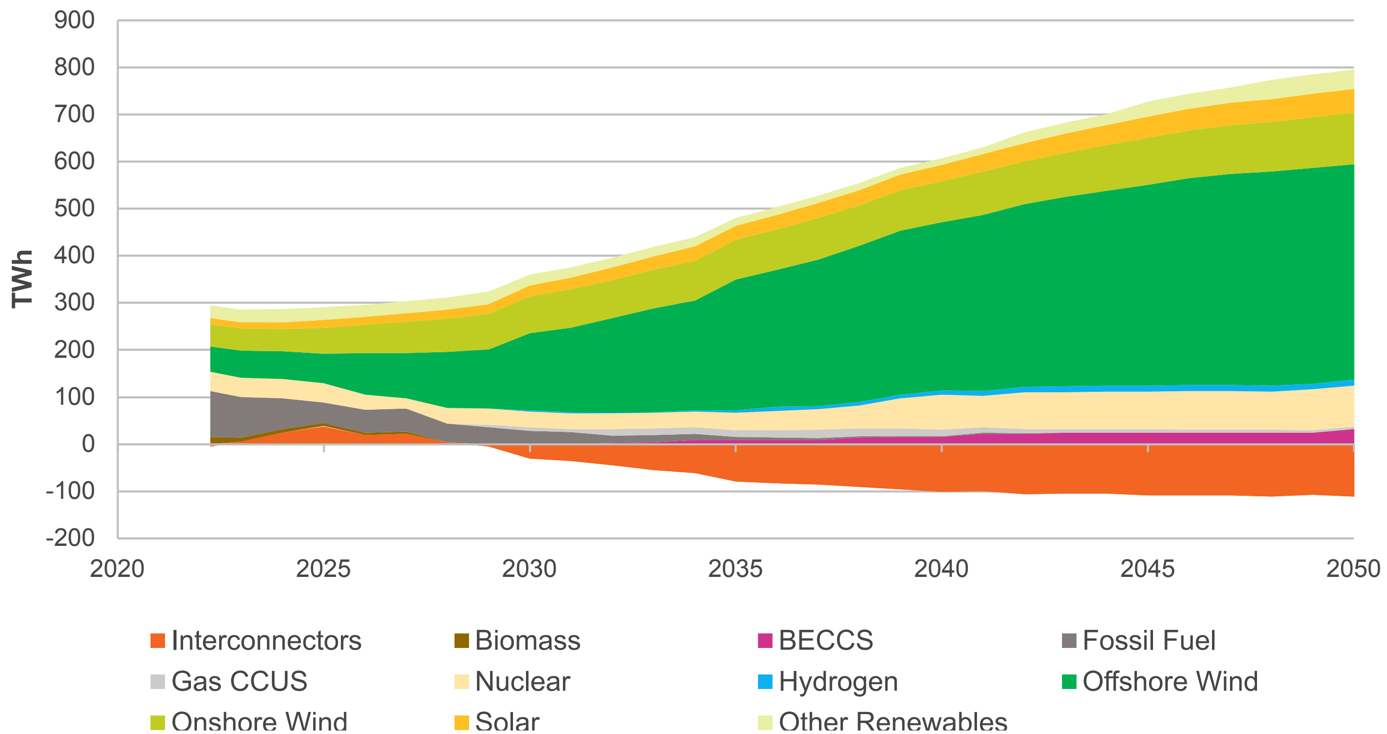
Electricity supply - total generation output

System Transformation

System Transformation shows a similar result overall to Leading the Way though with a slower move away from fossil fuels.

As with all scenarios, electricity generation increases out to 2050 with the majority being made up of offshore wind.

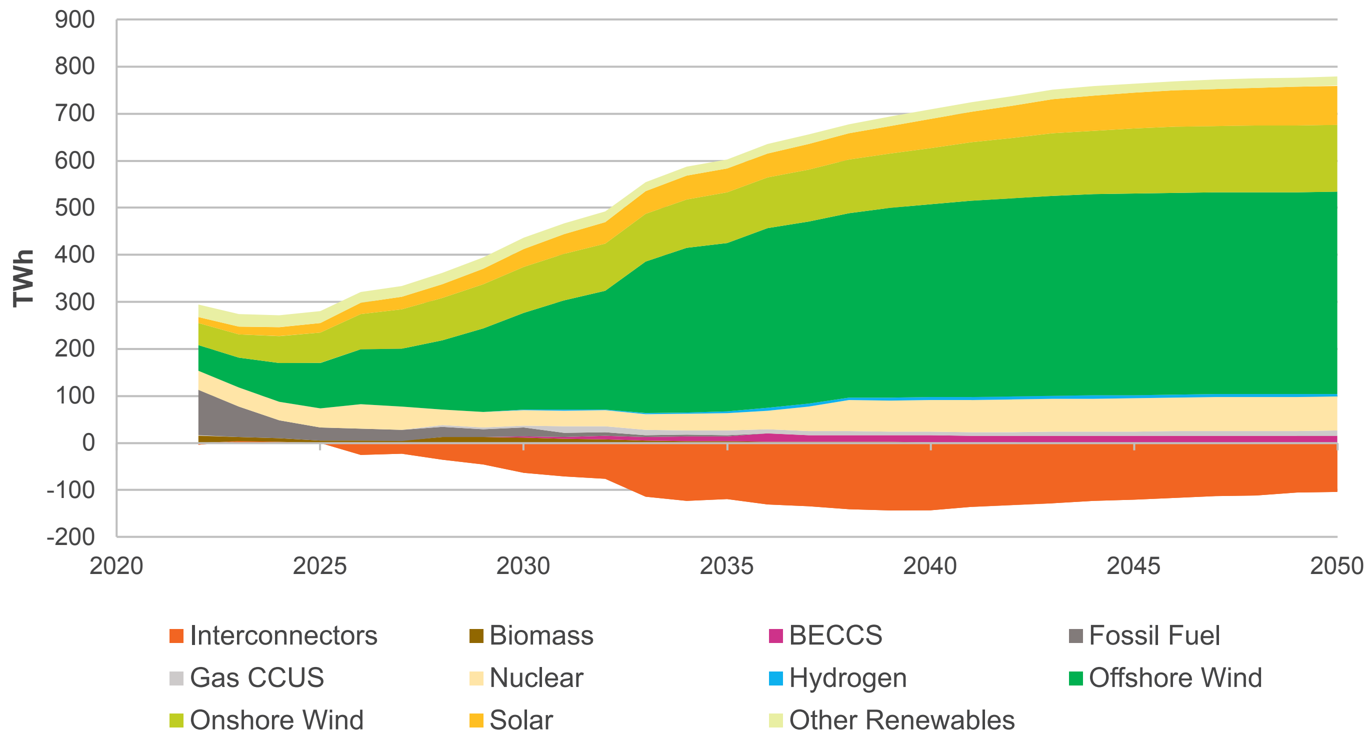
Figure ES.06: Electricity output by technology in System Transformation



Leading the Way

Leading the Way shows the sharpest decline in fossil fuel use with these being phased out by 2035 and the highest uptake in solar compared to other scenarios.

Figure ES.07: Electricity generation output by technology in Leading the Way



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Electricity supply - total generation output

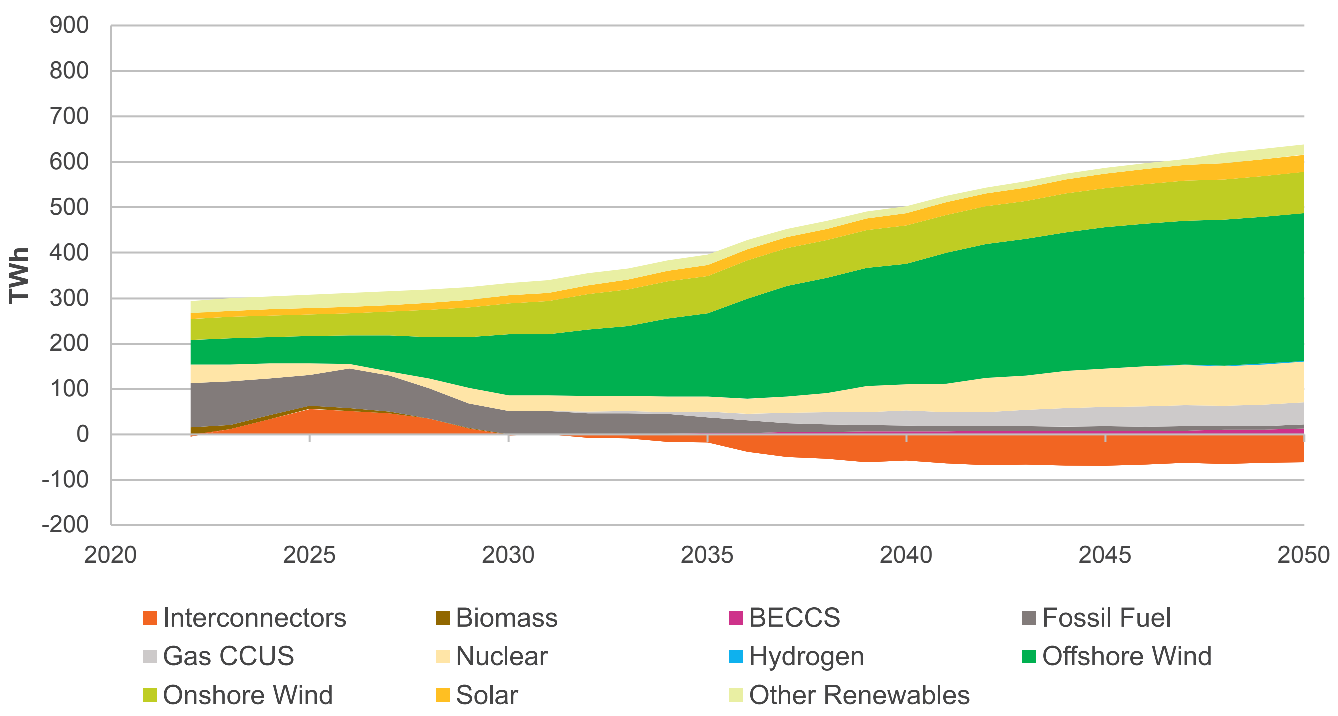
Falling Short

Falling Short results in the lowest electricity generation overall with the slowest move away from fossil fuels with low levels still present in 2050.

Interconnectors continue importing until 2030, when low levels begin to be exported.

Gas CCUS is utilised most heavily in this scenario, beginning in the early 2030s.

Figure ES.08: Electricity generation output by technology in Falling Short



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Total generation capacity

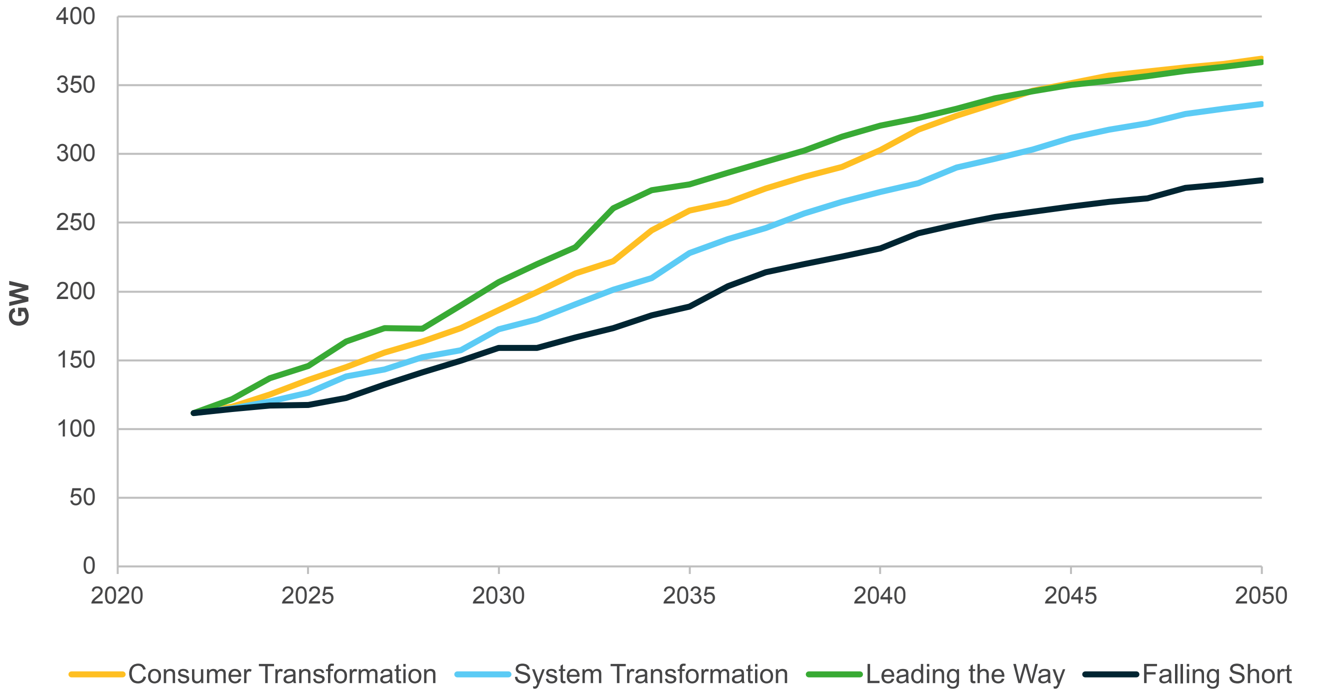
Generation capacity is expected to increase rapidly through the 2020s, with a between 42% and 85% increase by 2030 when compared to 2022.

Growth in total installed generation capacity is seen across all scenarios through the 2020s, the primary driver of this short-term capacity growth is new renewable generation. This is most rapid in Leading the Way, which sees up to 37 GW more offshore wind, 15 GW more onshore wind and an additional 27 GW of solar installed by 2030. Between 2030 and 2035 across the scenarios, offshore wind is expected to have the highest installed capacity of any technology.

There is a wide range of outcomes across our scenarios, with barriers such as grid connection availability, and supply chain growth, project financing and pipeline development all presenting potential barriers to growth in new capacity. This section explores the generation technologies that see the most change between now and 2030. A breakdown of all generation types and how capacity changes in each scenario can be found in our data workbook.

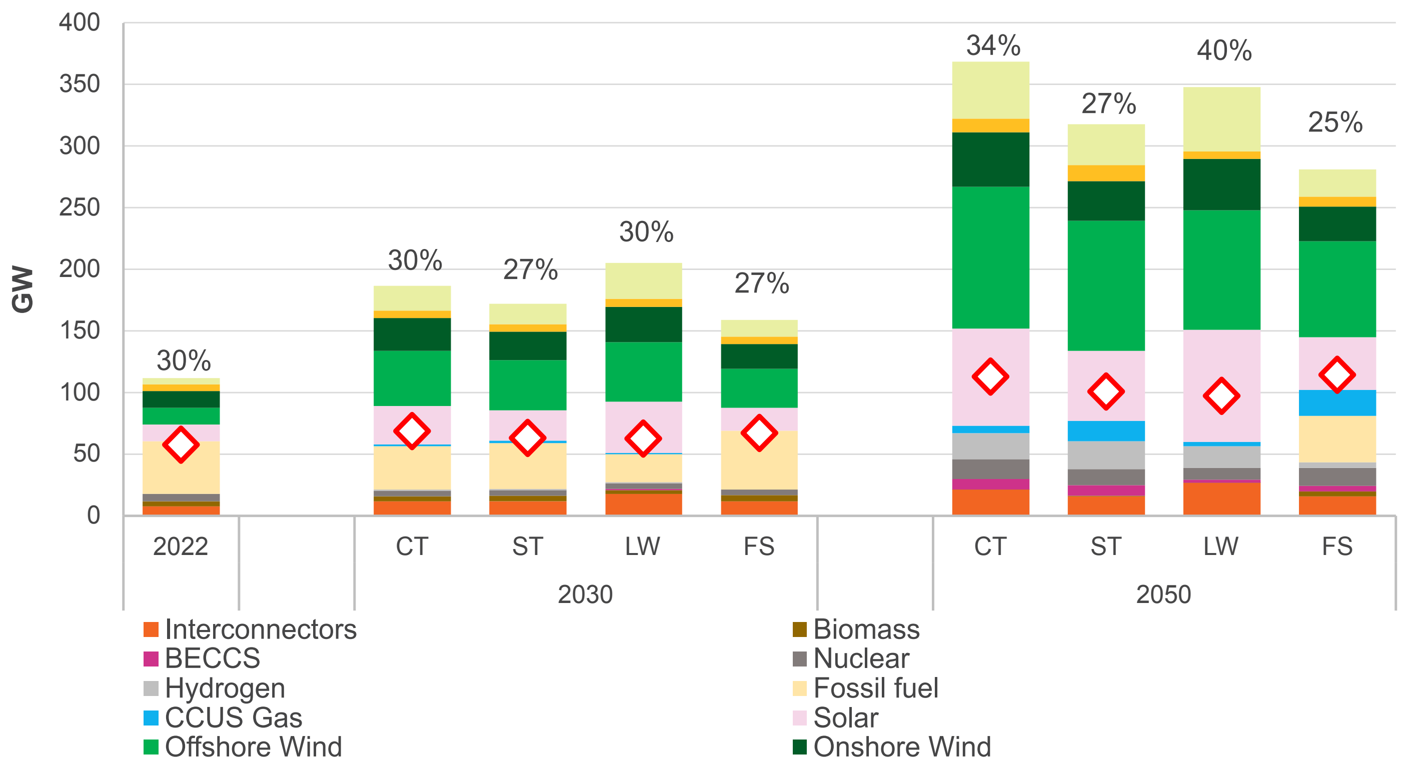
Recent Capacity Market auctions have had an influence on our modelling. New gas fired generation capacity have given additional certainty to the short-term prospects of fossil fuel generation. Storage capacity is expected to increase rapidly in the 2020s with additional short-term growth driven by a strong project pipeline and successes in this year's Capacity Market auctions. Energy storage growth is considered in detail in the Flexibility chapter. Both developments have had an impact on the overall generation mix of other technologies.

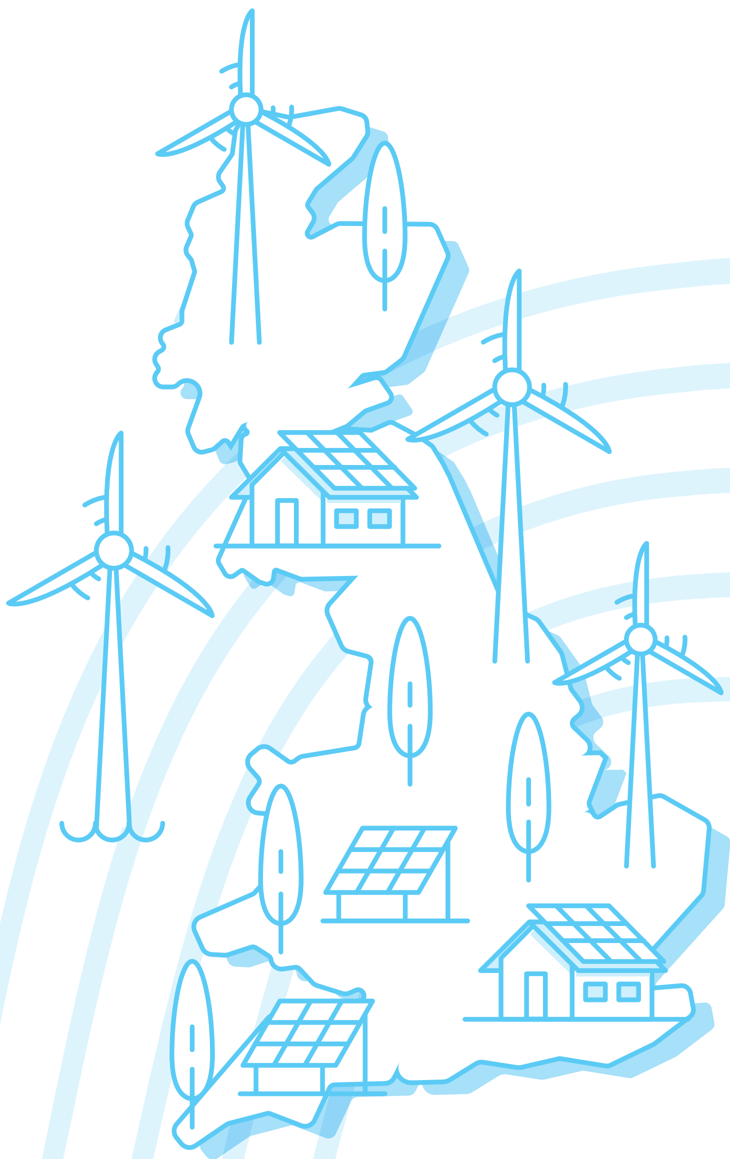
Figure ES.09: Installed capacity in GW



ES.09 shows total generation capacity in each scenario, while ES.10 on the following page shows the breakdown of different technologies in 2022, 2030 and 2050.

Figure ES.10: Installed generation capacity, peak demand and percentage of decentralised generation (GW)





Offshore wind

Wind generation capacity growth is expected to accelerate in the late 2020s, with offshore wind making up the largest share of growth.

We expect offshore wind generation capacity to continue to increase rapidly throughout the 2020s. Even in our slowest decarbonising scenario, Falling Short, we expect a rapid and large increase in wind capacity which will require significant network investment. Offshore generation requires infrastructure to bring the power onshore and to move it from coastal landing points to demand centres. Offshore wind locations and growth pipelines have been aligned with the ESO's work on Holistic Network Design (HND) that aims to deliver an integrated approach to connect new wind to GB.

The Government's target for 50 GW of offshore wind to be installed by 2030 is met only in Leading the Way, including non-networked and networked wind. The challenges to be overcome in areas such as grid connection, turbine size, physical constraints, supply chain capacity and the length of the planning process mean it is credible that this target is not met.

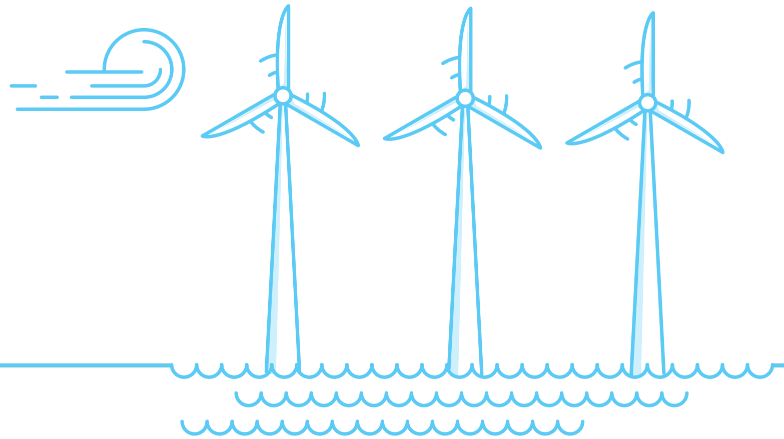
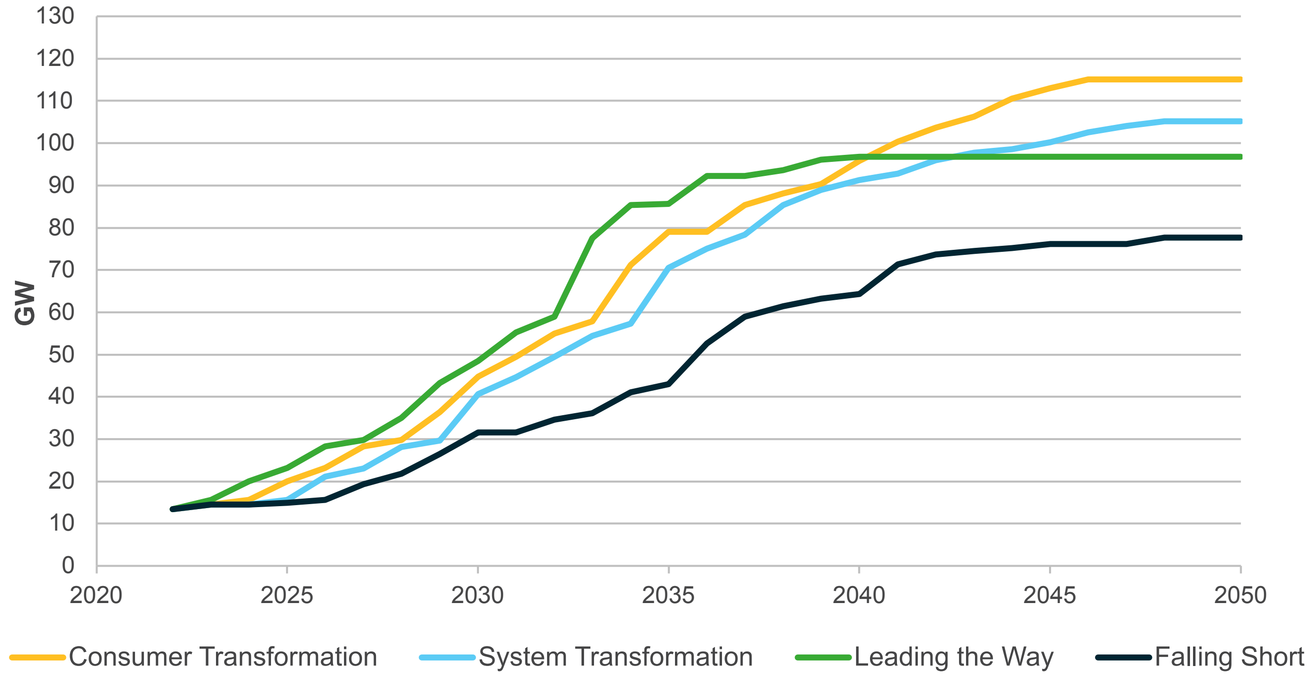


Figure ES.11: Offshore wind capacity in GW, excluding non-networked wind



Electricity supply

Onshore wind

Onshore wind capacity grows significantly in Leading the Way, which assumes that planning reform has a significant impact in unlocking growth in this sector. However, short-term growth in other scenarios is more limited, reflecting the uncertainty in the timescales and effect of any changes to planning rules and the other barriers that need to be overcome including network connections and high levels of inflation increasing materials costs and pushing up the cost of capital.

In System Transformation and Falling Short, lower levels of societal change result in greater local opposition and increased difficulty gaining planning permission.

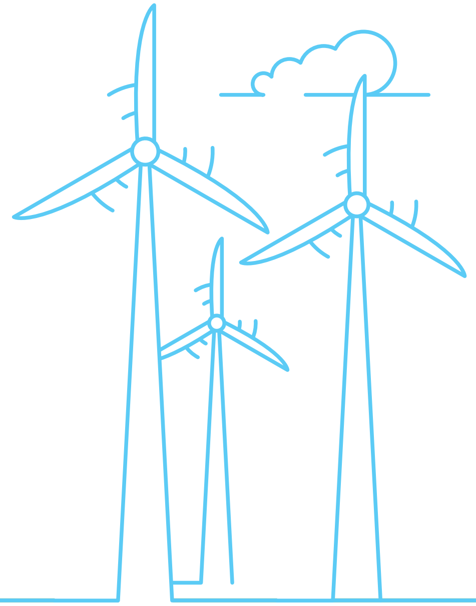
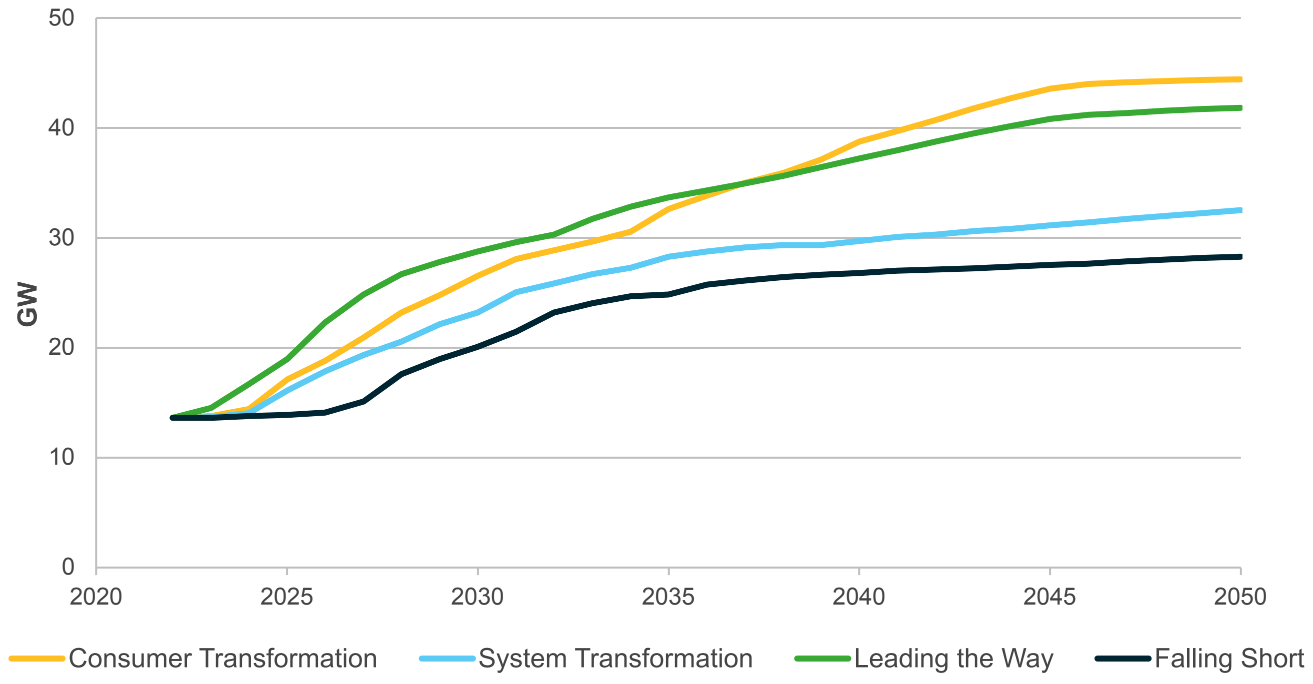


Figure ES.12: Onshore wind capacity in GW



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Solar

We expect continued price reductions, such as the recent removal of VAT on domestic energy efficiency measures, to increase the uptake of solar panels through the late 2020s, although this growth is more limited in Falling Short. There are a wide range of outcomes for solar development across our scenarios, depending on factors including price reductions of solar panels and electricity network capacity.

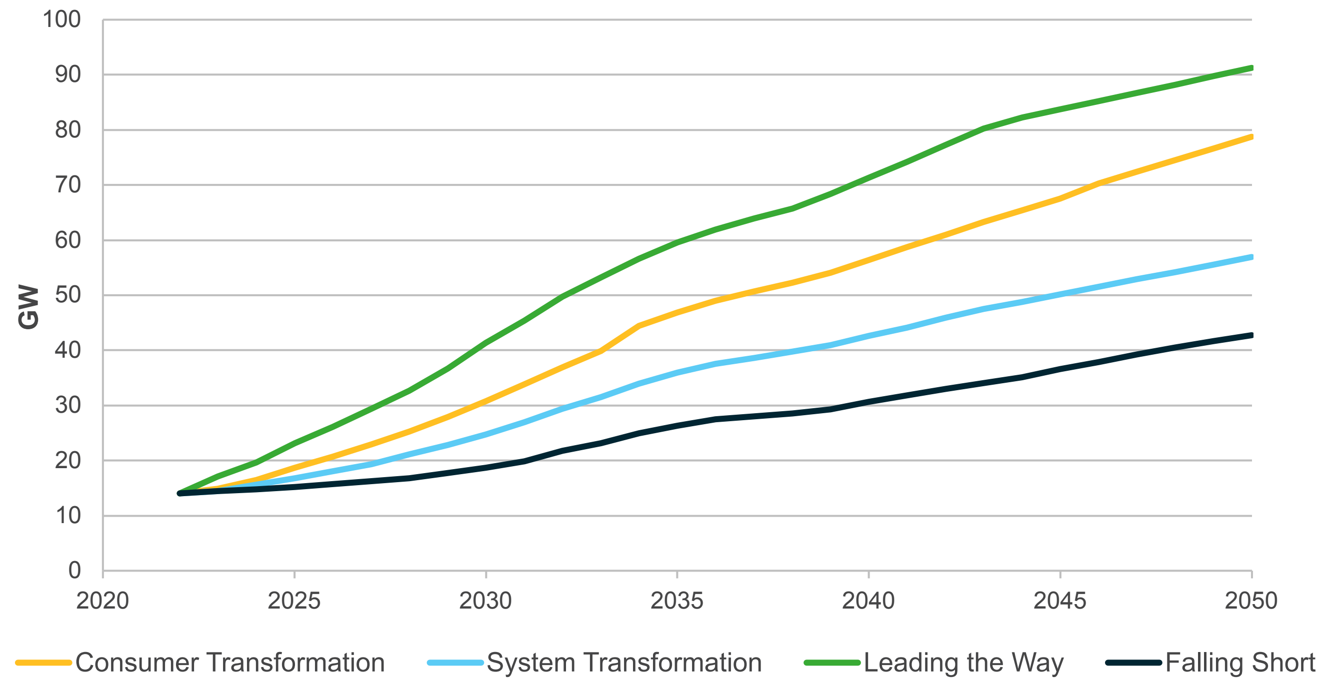
In Leading the Way, our maximum solar generation scenario, solar generation is co-located with flexible technologies at different connection voltages (i.e. with electrolysis or grid-scale battery storage for solar farms and with domestic batteries for roof-top solar). There is also co-location of solar with electrolysis to produce hydrogen as well as high uptake of domestic solar. Co-location is seen in other scenarios to varying degrees.

There is day-to-day uncertainty due to weather but in general, solar generation is quite predictable over the course of a year and the position of the sun and its expected radiation levels over the year are well known. This means it can be a great asset for meeting annual demand levels, especially when coupled with suitable storage. The case for homeowners, builders and businesses to install rooftop solar generation is growing. This is partly due to the rising cost of energy shortening payback periods but also higher energy efficiency standards for new homes.

The British Energy Security Strategy expects a five-fold increase in deployment of solar generation between today and 2035, with up to 70 GW installed. This aligns with our modelling for solar generation but is slightly higher than we see in Leading the Way.

Potential blockers to further development include grid capacity and connections, land and planning, skills and the supply chain of solar panels. If an installer/operator can overcome these, the business case for solar generation is currently strong because of recent high electricity prices.

Figure ES.13: Solar capacity in GW

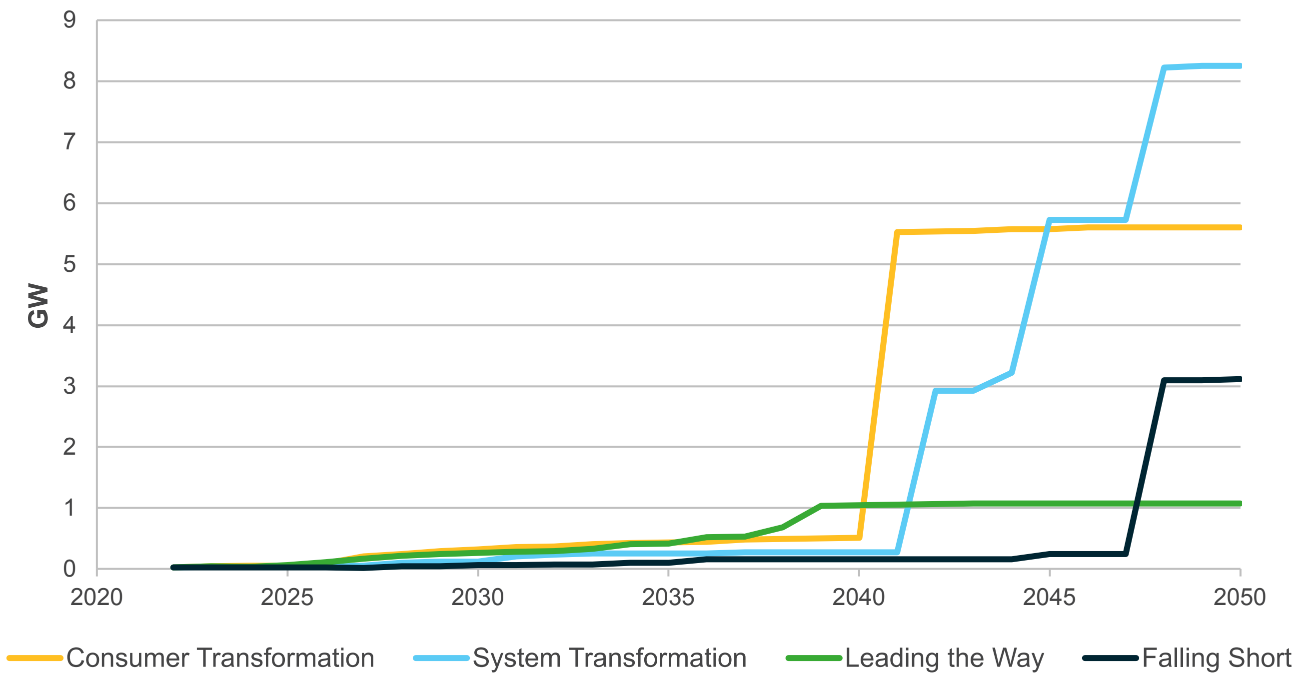


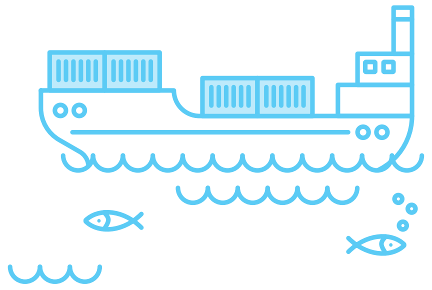
Marine

Marine energy generation uses the natural movement of water to produce electricity. This is a highly predictable form of generation, particularly for tidal generation. Though generation output varies through the course of a given day, total daily generation is very dependable. Tidal range works in a similar way as a hydroelectric dam, converting potential energy from water as it moves between high and low tide. This can be done by building artificial lagoons or by siting tidal barrage generation in natural choke points, such as the entry to a bay or estuary. Tidal stream uses turbines underwater to generate electricity directly from tidal flow, in much the same way as wind turbines do above the surface. The UK has some of the highest tidal ranges in the world with estimates of potential generation capacity ranging from 30 to 50 GW for all wave and tidal energy. The British Energy Security Strategy has committed that £20 million per year will be ringfenced for tidal stream projects to bring costs down.

While marine generation technology is mature and assets can have a long life, it is typically very expensive to install, which limits its deployment in our scenarios. Leading the Way sees the lowest installed capacity in 2050 as demand is met by cheaper alternatives. In all scenarios we see many small tidal stream installations as well as wave generation. In Consumer Transformation, successive tidal range projects in the early 2040s bring capacity up to just over 5 GW by 2041. The same projects are completed slightly later in System Transformation, but they reach a greater capacity (just over 8 GW by 2050) to meet security of supply standards. The first tidal lagoon in Falling Short is operational just before 2050.

Figure ES.14: Marine capacity in GW





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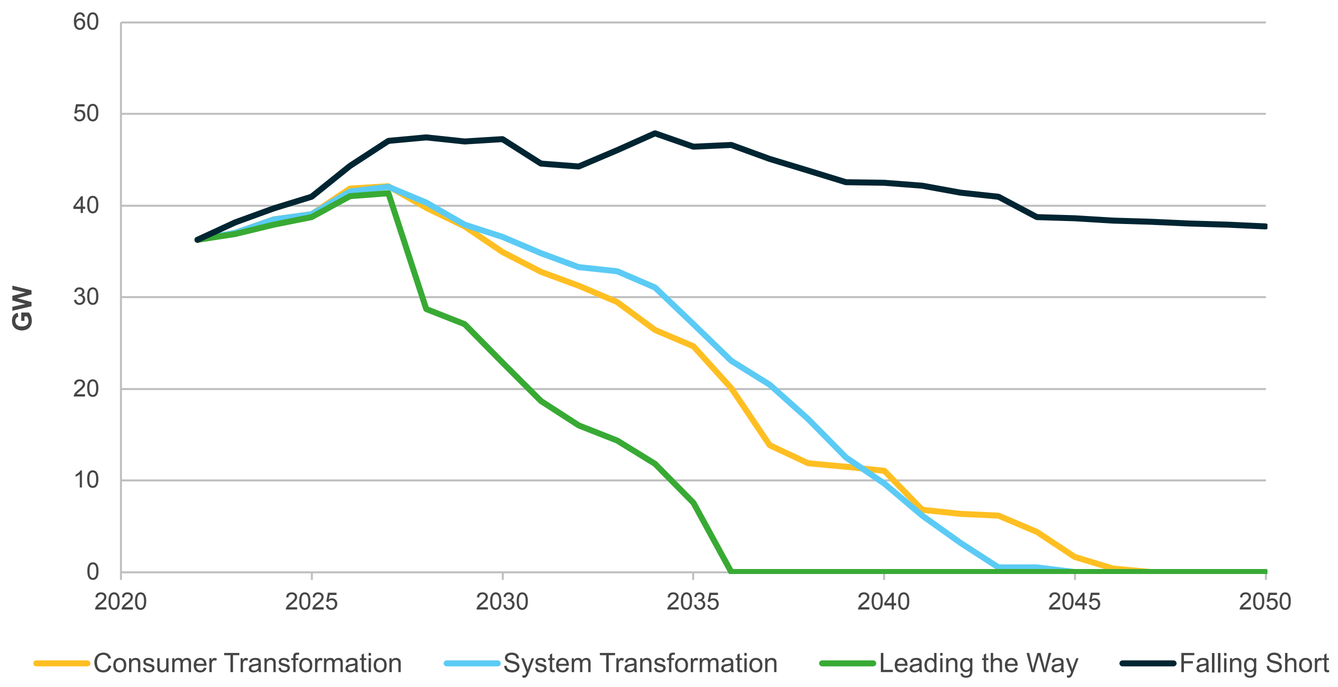
Unabated gas generation

Gas generation capacity is expected to grow in the short-term, with new plants being supported by Capacity Market contracts to help meet security of supply.

Recent Capacity Market contracts awarded to gas fired generators, including some new-build gas generation, has given added certainty around short-term growth in gas generation capacity. In the net zero scenarios we expect gas generation capacity to start to fall in the late 2020s as it is displaced by increasing renewable generation and growth in low or zero carbon dispatchable technologies. In Falling Short, gas capacity is expected to continue increasing resulting in emissions reduction targets being missed.

New build gas generation has been awarded a 15 year Capacity Market contract. This new generation plant is likely to still be on the system in 2035 when the government has targeted the power sector to reach net zero. This means that new generators, alongside existing gas generators, need to consider how they would convert to low or zero carbon operation through the adoption of Carbon Capture, Usage and Storage (CCUS) technology or a shift to using hydrogen rather than natural gas. Policy is likely to be needed to meet this target, through the tightening of emissions limits for generators, or mandating unabated gas comes off the system.

Figure ES.15: Unabated gas capacity in GW



Low carbon dispatchable power

Low carbon dispatchable power capacity is expected to grow sharply beyond 2028 in our net zero scenarios. This aligns with the development of CCUS transport and storage networks.

Low carbon dispatchable power includes gas generation with CCGT and hydrogen CCGTs and CHPs. It does not emerge in the short-term due to the need for the development of CCUS transport and storage networks. Figure ES.16 shows the growth of low carbon dispatchable power out to 2050.

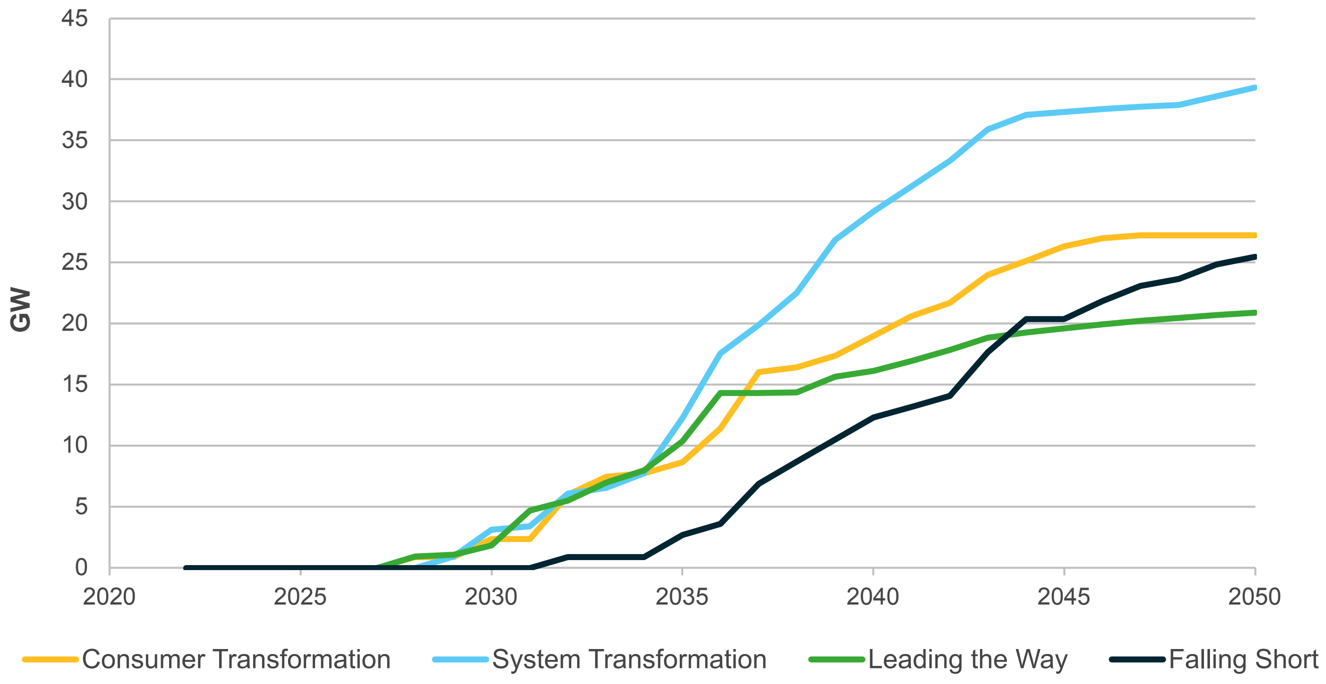
Revenue support from Government for gas CCUS generation will be available through Dispatchable Power Agreements (DPAs). The producer of the hydrogen would receive the revenue support for hydrogen CCGTs via the Hydrogen Production Business Model (HPBM).

System Transformation sees overall highest levels of low carbon dispatchable power in 2050 which is made up of 23 GW gas CCUS and 17 GW hydrogen CCGT/CHP. Falling Short sees the slowest development of low carbon dispatchable power which is due to greater reliance on unabated fossil generation.

Across the scenarios, Leading the Way has the lowest levels of low carbon dispatchable power, with just over 4 GW of gas CCGT and 18 GW hydrogen CCGT/CHP. This is due to lower peak demands and higher levels of flexibility and storage capacity.

The low carbon dispatchable power plants of the future could play a greater role than just supplying MW to the grid as they also provide stability.

Figure ES.16: Dispatchable low carbon generation capacity in GW



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Bioenergy and BECCS

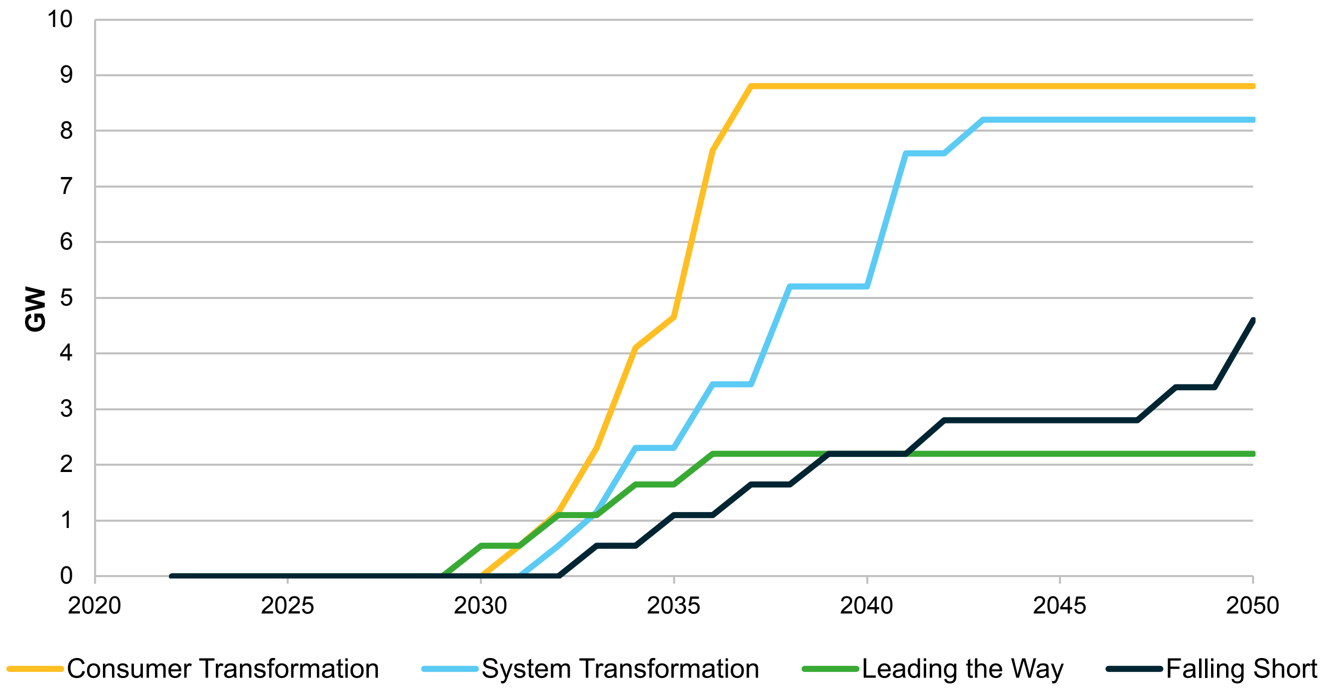
Bioenergy with Carbon Capture and Storage plays an important role in helping the power sector reach net zero in all scenarios.

In FES, BECCS is primarily included to help decarbonise the economy by providing negative carbon emissions which offset residual emissions in sectors which are difficult to fully decarbonise. Leading the Way has the lowest levels of BECCS because it prioritises emissions reductions through behavioural change and Direct Air Carbon Capture and Storage, an emerging technology which is made viable by the presence of excess renewable capacity and a way to access it at a competitive price. Negative emissions delivered from different sources and some of the specific challenges of emissions reporting of BECCS are explored in more detail in the Net Zero chapter.

BECCS is expected to run with a high load factor to maximise the level of negative emissions generated. Bioenergy plants provide a source of synchronised generation and ancillary services: essential to the reliable operation of future energy systems which are dominated by renewables.

Following the announcement of successful projects within the first industrial clusters, we don't expect large scale BECCS to be delivered before 2030 and have revised our scenarios to reflect this. We see the development of BECCS across the net zero scenarios in the early 2030s, after Carbon Capture, Usage and Storage technology has been scaled up. There continues to be some biomass generation without CCUS, however this is minimal in the net zero scenarios due to the competition for limited bioresources from a range of sectors. The bioenergy section explores the different sources of bioresources and the sustainability of the supply chain.

Figure ES.17: BECCS generation capacity in GW



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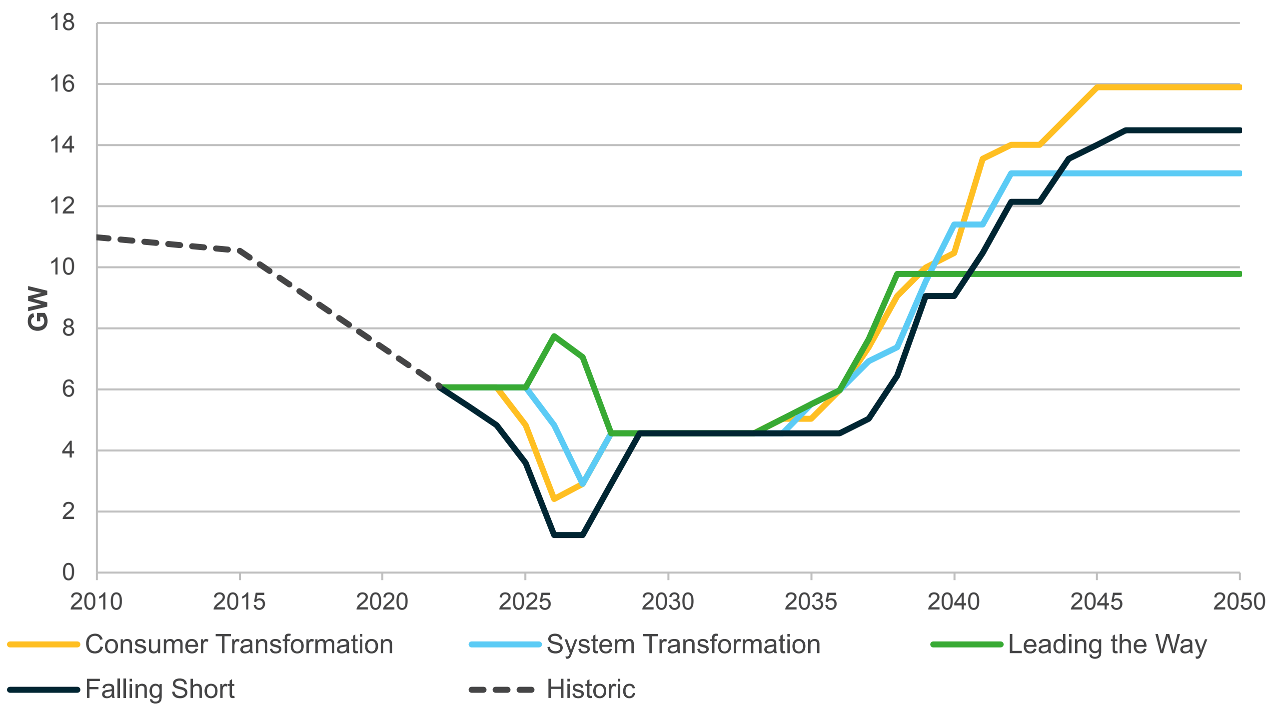
Nuclear

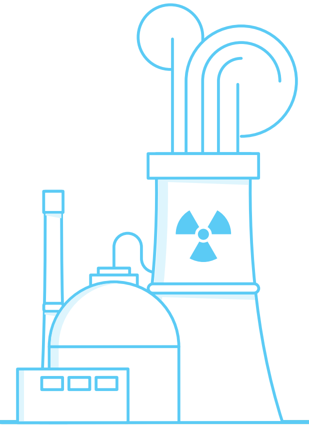
Hinkley Point C is the only new nuclear capacity expected ahead of 2033, but this new capacity will be more than offset by closures of existing nuclear stations over this time period.

Some delays in closures of existing nuclear plant have increased capacity expectations for nuclear generation in the 2020s. The existing nuclear fleet is ageing, and by 2030 the only reactors on the system are expected to be Sizewell B and the newly built Hinkley Point C in all scenarios. There is the potential for Small Modular Reactors to start coming online in the early 2030s. All scenarios reach 8 GW of traditional nuclear plant capacity ahead of 2050, this includes projects already in development, life extensions and expected new build capacity. Consumer Transformation has the highest take-up of Small Modular Reactors (8 GW), with the first of these deployed in 2033, but all scenarios see some growth in SMR capacity in the 2030s and 2040s. These are significantly smaller than the GW-scale traditional nuclear reactors and are designed to be more easily replicable and scalable and operate more flexibly than large-scale plant. The lower energy demands in Leading the Way mean there is only limited new nuclear development after Hinkley Point C.

The maximum nuclear capacity in any of our scenarios is 16 GW in Consumer Transformation by 2050, which is below the government ambition of up to 24 GW of nuclear capacity in the 2022 Energy Security Strategy. In this scenario, with high levels of renewable capacity, significant levels of baseload generation can be challenging as they contribute to curtailment issues at times of low demand and high renewable output.

Figure ES.18: Nuclear generation of existing plant





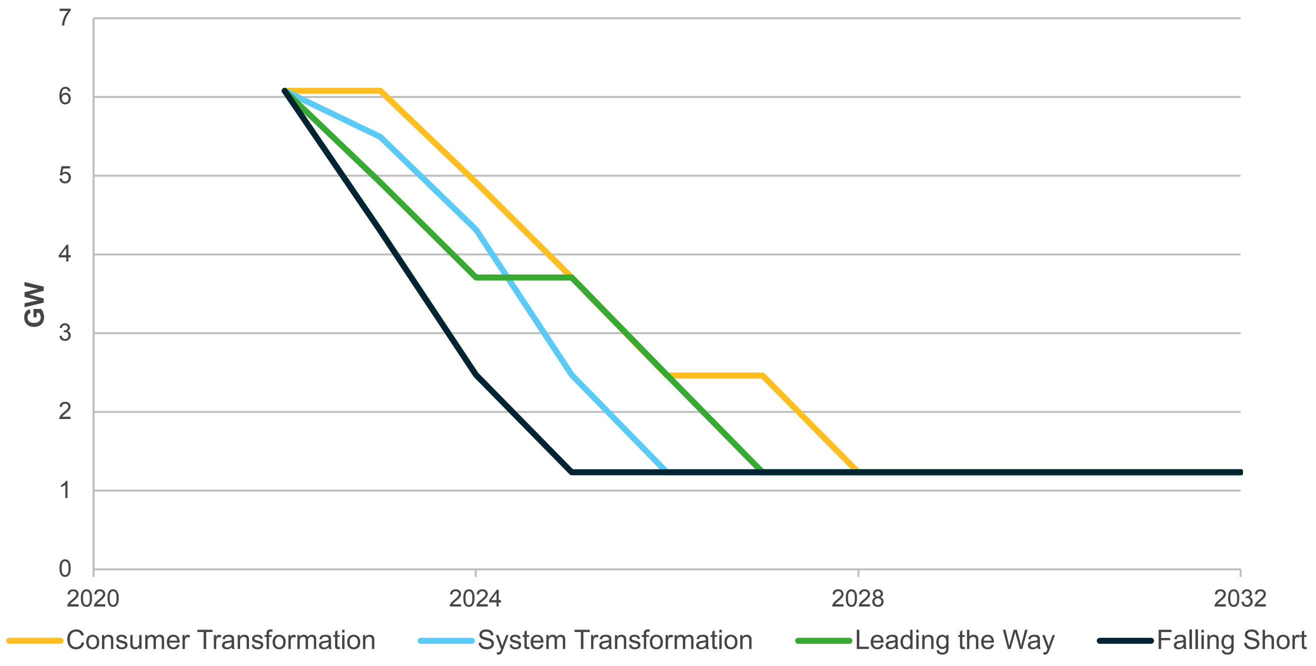
Nuclear: uncertainty and trade-offs

Despite high nuclear targets and significant policy announcements, greater progress of other low carbon technologies, as well as challenges around system operation at times of minimum demand, could limit nuclear deployment.

Across our 2023 scenarios we have a range of between 10 and 16 GW of nuclear generation capacity installed in 2050, up from around 6 GW today. The UK's current nuclear fleet contains a large share of ageing reactors, with all but one of those in use today currently scheduled to shut down by 2030, and only one new plant under construction in Hinkley Point C. This is expected to leave nuclear capacity at 4.6 GW in 2030, not recovering to current levels ahead of 2035. Beyond this, increases in capacity depend on decisions made today and in the near future on investment in new nuclear and technological developments to deliver new, more cost-effective reactors in future.

In 2022, the government set an ambition of up to 24 GW of nuclear generation capacity to be installed by 2050 in its Energy Security Strategy, this was reaffirmed in 2023's Powering Up Britain publication. This section explores the factors affecting nuclear generation capacity in our scenarios and what would need to happen to reach that stretch target of 24 GW. Consumer Transformation sees the highest growth in nuclear generation capacity across our scenarios and so we focus on that scenario in this analysis.

Figure ES.19: Nuclear capacity of existing plant



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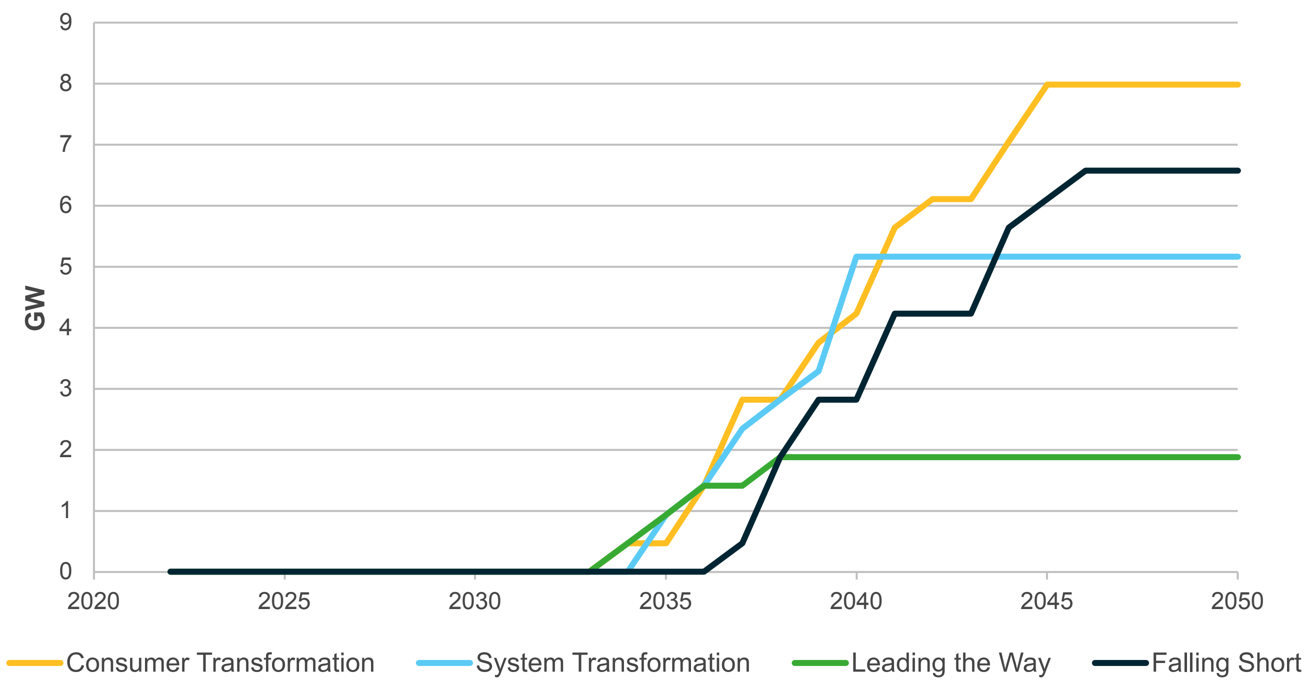
A traditional nuclear power plant provides around 1-3 GW of capacity. Small Modular Reactors offer an alternative approach to delivering nuclear power generation. SMRs are less than half that at 300-500 MW but at this size, they are roughly equal to a gas generation plant. These could be delivered by a range of competing designs, though none are yet operational. They are assumed to be connected to the transmission system and located on existing sites of nuclear generation, but their smaller footprint does make them potentially easier to locate elsewhere. Their location will depend upon several factors such as land availability, proximity to suitable water supply, environmental and social factors and skills and capabilities in the local area. Multiple SMRs working together can also provide greater flexibility through some load following capability or the ability to close some units.

Based on our stakeholder engagement, within our scenarios the earliest date we see SMRs connected to the system is 2033, after which point Consumer Transformation sees 8 GW installed over the subsequent ten years, at a build rate of approximately two per year. Alongside an additional large-scale nuclear reactor delivered in the 2030s, this is a total of approximately 16 GW of capacity from the mid-2040s. To reach the 24 GW target would likely require the acceleration of SMR deployment and/or the delivery of additional large scale reactor(s).

Consumer Transformation sees the highest deployment of nuclear generation partly because as a highly electrified scenario it also sees the highest electricity demands. Leading the Way deploys only half the level of nuclear generation due to much lower electricity demands reducing the need for additional capacity from the mid-2030s. This is driven by higher levels of energy efficiency and greater use of hydrogen, partly from methane reformation, both of which reduce electricity demand compared to Consumer Transformation.

Figure ES.20: Small Modular Reactor capacity across our scenarios



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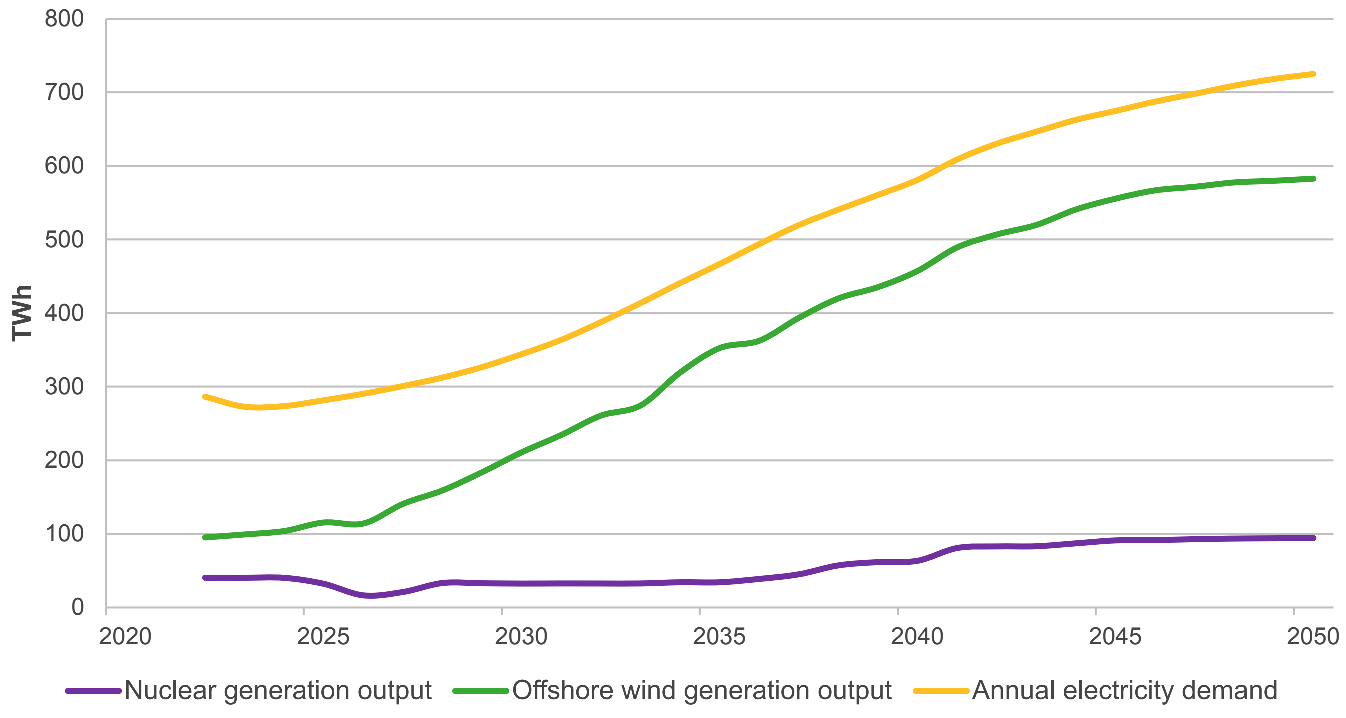
Offshore wind is the largest generation source by 2025 and makes up over 50% of the generation mix by 2031 in Consumer Transformation. This is driven by a rapid expansion of capacity throughout the 2020s to meet the government's target of 50 GW of offshore wind, which it achieves in 2031. By 2033, when the first SMR comes online, there is a well-established supply chain for offshore wind delivering significant growth in capacity – the rolling 3 yearly average of additional installed capacity is over 5 GW per year between 2030 and 2035. This rate of growth of offshore wind capacity is unlikely to come to a halt when new nuclear starts to come online, and so nuclear generation will be competing with an increasing share of offshore wind generation.

As turbines have got larger, offshore wind load factors have increased to around 50%, meaning that 1 GW of offshore wind generates over 4 TWh of electricity annually. Within our modelling we assume large-scale nuclear typically operates as baseload, operational constantly other than for maintenance, with a load factor across the fleet of around 82%. SMRs however, are assumed to operate more flexibly, they achieve typical load factors between 50% and 55% when dispatched within our hourly dispatch model.

One of the challenges of a system based around significant levels of offshore wind is reliably meeting winter peak demand. While wind output is typically higher in winter than summer, the capacity is not firm, so a portfolio of generation and storage needs to be in place to ensure security of supply can be met during low wind periods, particularly in the winter. This is discussed further in the dispatchable flexibility and dunkelflaute sections of our Flexibility chapter.

Nuclear generation offers firm capacity outside of scheduled maintenance and is likely to be fully available to help meet demand during winter peak. However, one of the major challenges, particularly of large-scale nuclear, is how to operate the system at times of minimum demand.

Figure ES.21: Annual electricity demand compared to nuclear and offshore wind in Consumer Transformation



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Electricity supply

Summer minimum demand on the transmission system has fallen as low as 14 GW in recent years, and this represents an operational challenge when there are high levels of nuclear generation connected. As shown in our embedded generation regional spotlight we expect this trend to continue as more generation is connected to distribution networks. Unlike renewables, nuclear generation cannot be curtailed easily, and so generation would need to be stored. SMRs that can operate more flexibly offer the potential to mitigate this risk, however the lower the load factor they operate under, the more challenging the economic case for delivering them becomes.

One avenue for the operation of an increased level of nuclear generation would be co-location of electrolysis with nuclear assets such that the nuclear generators can run constantly as baseload, but with electrolysers which ramp up and down according to the needs of the grid and the level of nuclear power required on the system. It is not yet clear whether nuclear connected electrolysis produced like this would be cost competitive, as while the electrolysers will be able to operate with relatively high load factors, the electricity they use is likely to be higher cost directly from nuclear generators than the low cost system electricity at times of high renewable output. This will be explored further through Centralised Strategic Network Planning (CSNP).

We will continue to keep the levels of nuclear generation within our scenarios under review and reconsider the case for higher levels of capacity in future.

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Distributed generation

Generation connected to distribution networks will play an increasingly important role as growth continues through the 2030s.

Today generation connected at distribution level includes a wide range of technologies, from household rooftop solar PV (Photovoltaic) panels to onshore wind turbines, solar farms, local hydroelectricity schemes and fossil fuel peaking plants. We have around 13 GW of solar, 6 GW of onshore wind and 11 GW of small dispatchable generators (including Combined Heat and Power units, (CHPs) currently connected to the distribution network. A breakdown of all generation types and how capacity changes in each scenario can be found in our data workbook.

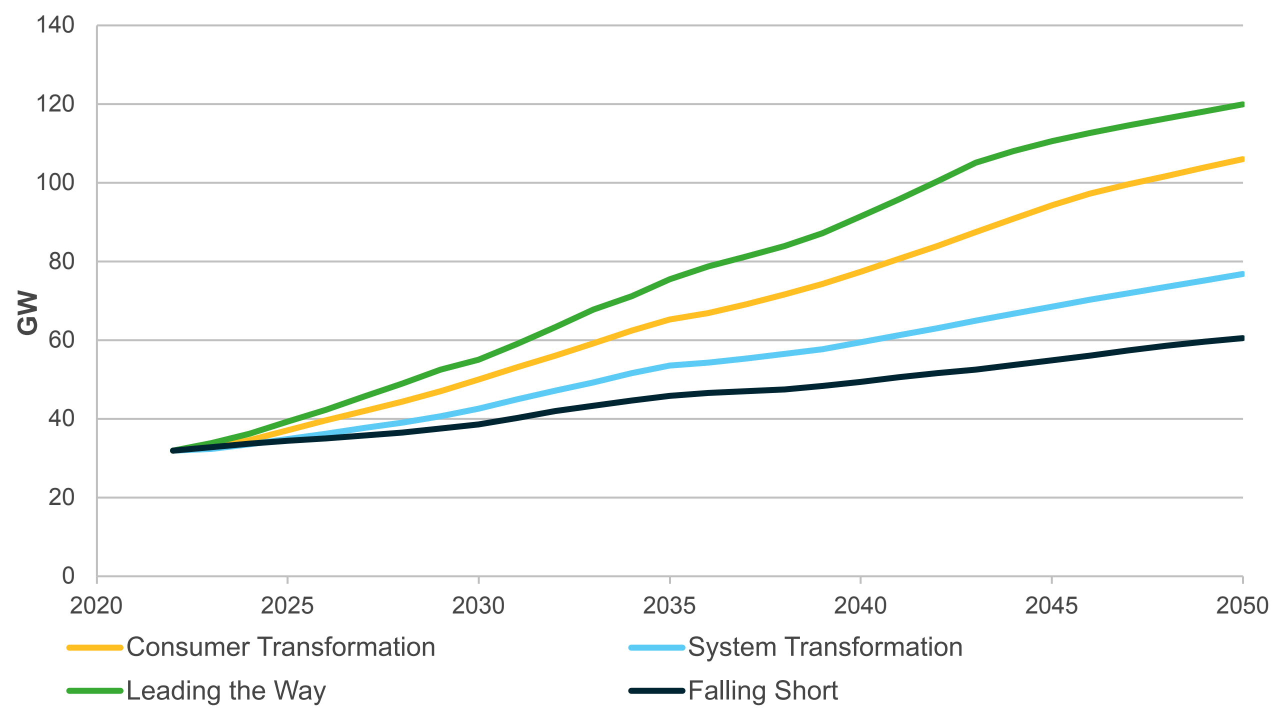
Onshore wind is expected to grow slowly in the 2020s in the scenarios with lower levels of societal change, System Transformation and Falling Short. Higher growth rates are seen in Consumer Transformation and Leading the Way as we assume greater relaxation of planning constraints and progress on connection issues.

Solar generation grows most rapidly in Leading the Way in the 2020s, with capacity more than doubling by 2030, while Falling Short sees only limited growth. The project pipeline in the scenarios with lower levels of societal change is affected more by barriers such as access to grid connection, land availability, planning permission and supply chain constraints. We expect an increasing share of projects to be coming forward co-located with battery storage or electrolysis, particularly in Leading the Way, to help mitigate connection issues.

Small fossil fuel plant capacity is expected to grow out to 2027 in all scenarios other than Leading the Way, with reductions in diesel generators being offset by growth in gas reciprocating engines.

Beyond 2027 we expect to start to see zero carbon options play more of a role, with the growth in hydrogen reciprocating engines and CHPs, and a decline in gas generators across the net zero scenarios.

Figure ES.22: Distribution connection generation



Distributed generation - regional spotlight

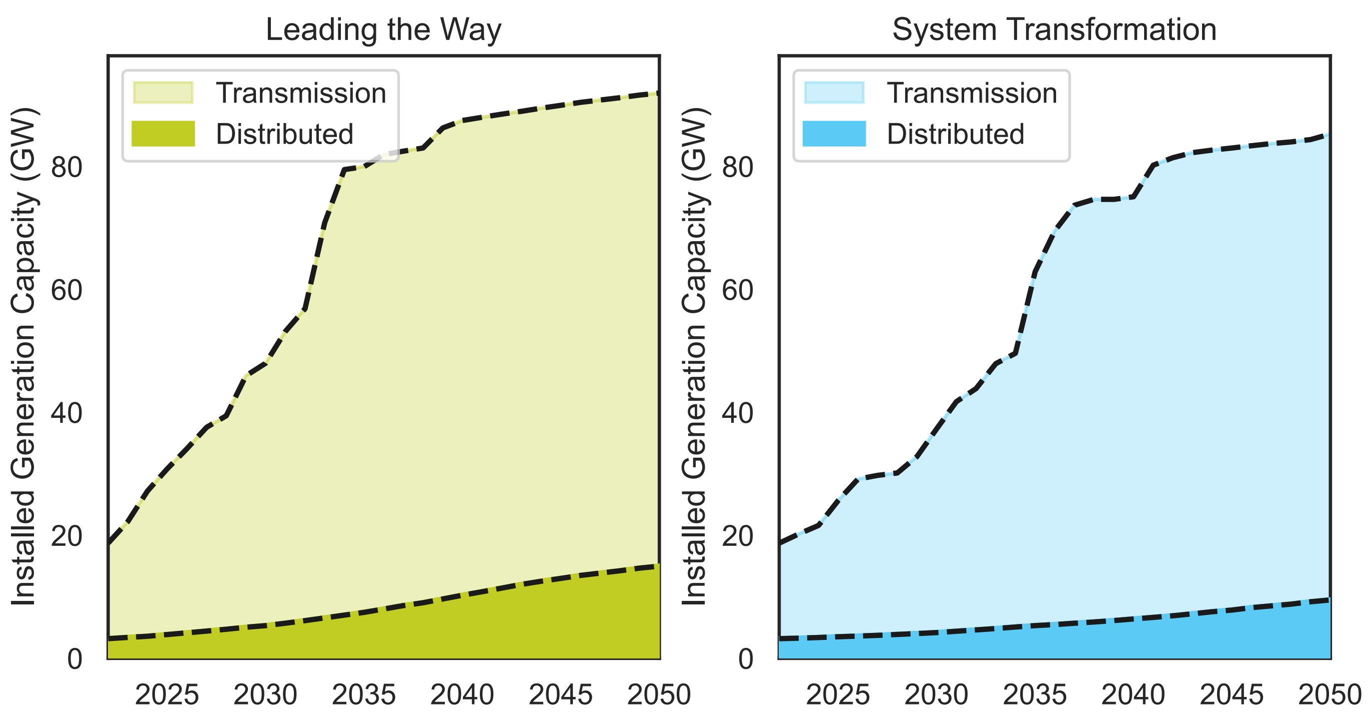
Distributed generation will increase in all of our scenarios and across our regions. This increase is less pronounced than the growth of capacity connected to the transmission system but is still crucial in a robust, diverse energy mix.

The growth of distributed generation will allow local areas to have greater choice in the way their energy is generated and stored via local authorities. Initiatives such as Energise Barnsley have shown the ability of local communities, led by local authorities, to develop partnerships and directly engage with low carbon technology. This opens our energy markets and the opportunities presented by net zero to a wider range of participants. In an increasingly interlinked system, it will also allow communities to make the right choices in technologies that benefit them and align with their local area plans, for example in grouping generation assets near to transport or industrial centres.

Many areas have discussed ambitions to enable their people to benefit from the expansion of renewable energy, for example the Welsh Government consulted on a goal of 1.5 GW of community owned renewable energy generation by 2035 and organisations such as UK100[7] are promoting a greater role of communities in the solutions we need to transition to a low carbon energy system. Although it is difficult for us to quantify this degree of local ownership within FES, we believe the growth in distribution-connected generation provides this opportunity.

Figure ES.23 shows the growth of Scottish transmission and distribution connected generation capacity in System Transformation and Leading the Way. Both scenarios have similar overall growth of generation capacity, but Leading the Way has higher proportion of smaller-scale generation representing the greater societal change in this scenario.

Figure ES.23: Installed transmission and distributed generation capacity in Scotland



7 uk100.org/UK100membership

Distributed generation - regional spotlight

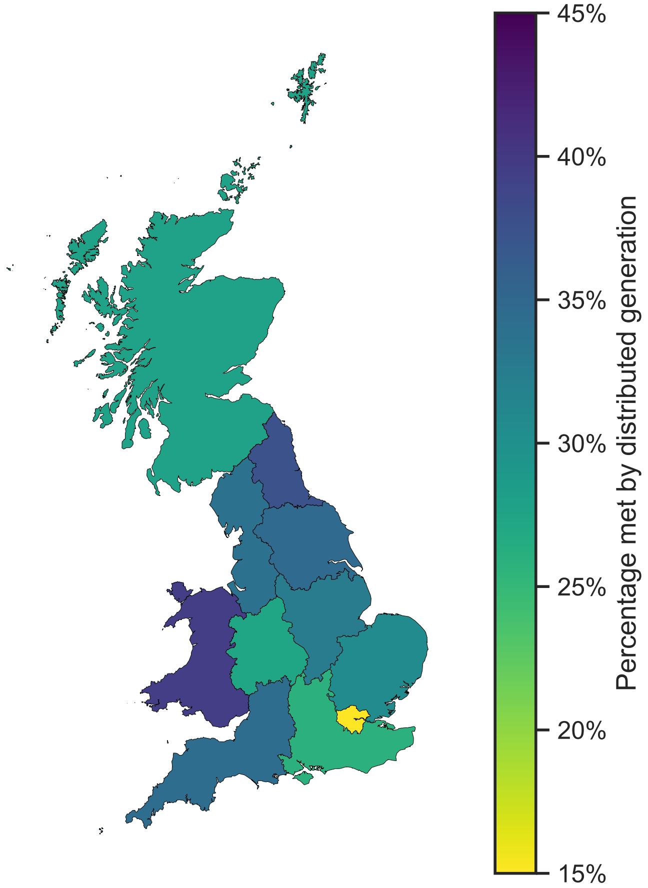
Higher levels of renewable distributed generation help empower consumers and increase local self-sufficiency but also bring challenges in operating a fair and efficient system with many smaller participants.

In our future scenarios, electricity flows will be higher and increasingly complex. These balances may shift in different regions and at different times of the day or year and it will become increasingly important to consider the effects of these local peaks on both the transmission system and the regional mix of technologies, particularly in Consumer Transformation and Leading the Way which have higher levels of distributed generation.

Solar generation is a major contributor with an ambitious pipeline of development for distributed generation in several regions. In our scenarios, some areas of the country may be able to meet their own summertime peak electricity demands solely through renewable distributed generation, but this capability will reduce on days where there is less sunshine and across the whole of the winter. Solar use can be maximised locally when it is able to meet demands that peak in summer, such as in areas with higher air conditioning demand.

There are technological and market solutions to many of these challenges, but different solutions are appropriate for different areas depending on their generation portfolio. As we discuss in the Flexibility chapter, there are future opportunities for different types of consumers to participate in reducing their peak electricity demands. This will work well for regions with large and variable electricity demands, but for other regions there may be a greater need to invest in storage technologies or reinforcement of network infrastructure. The map on the right shows the percentage of distributed generation that meets regional demand at the time of overall peak GB demand in the Winter of 2040 in our Consumer Transformation scenario. These generation data do not include larger distribution connected sites that have separate transmission agreements, the threshold for these sites is also lower in the Scottish transmission owner regions.

Figure ES.24: Proportion of demand met by distributed generation at winter peak in Consumer Transformation



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Interconnectors

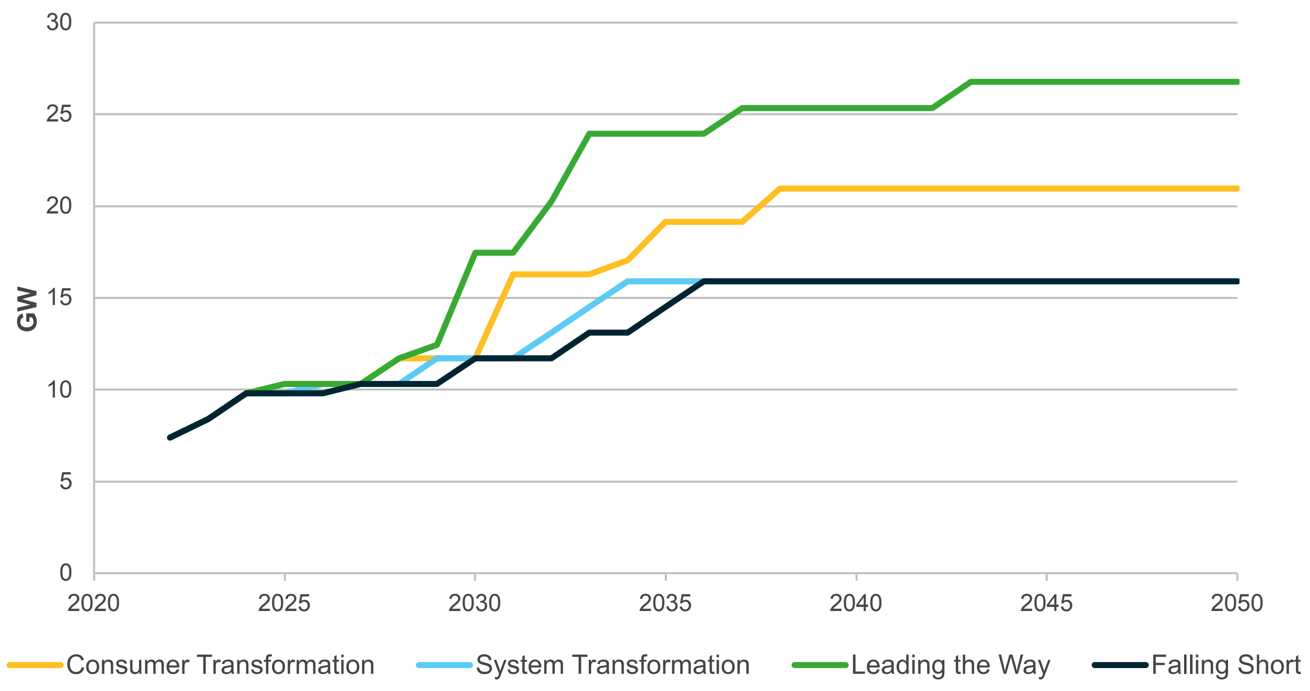
We expect growth in interconnection capacity in the short-term, based on a pipeline of projects that are close to, or already under construction.

In the late 2020s there is more divergence in interconnector capacity across the scenarios. Interconnector growth is highest in our scenarios with high levels of societal change which see greater levels of flexibility from both consumers and supply-side sources such as interconnectors. The longer-term outlook for increased levels of interconnection remains uncertain, countries on both sides must be confident that projects will be beneficial for the consumers for them to progress. Leading the Way sees a significant acceleration of connections.

Interconnectors are used in all scenarios for trading electricity with continental neighbours. We expect interconnector flows to follow price signals which will also help avoid curtailment of excess generation. By connecting grids in different countries, we can share some of the benefits and characteristics of our generation mixes with each other. The role that interconnectors can play in exporting renewable generation at times of high output or importing to meet peak demand depends on a range of factors, including weather patterns and the generation mixes of our interconnected markets. Interconnector flows are explored in more detail in the Flexibility chapter.

Multi-Purpose Interconnectors (MPIs) have been considered this year within Leading the Way and Consumer Transformation as we have seen new projects under development to connect offshore generation with more than one country. A range of countries are considering development of these projects, which has helped boost the likelihood of development of new interconnector capacity.

Figure ES.25: Interconnector capacity



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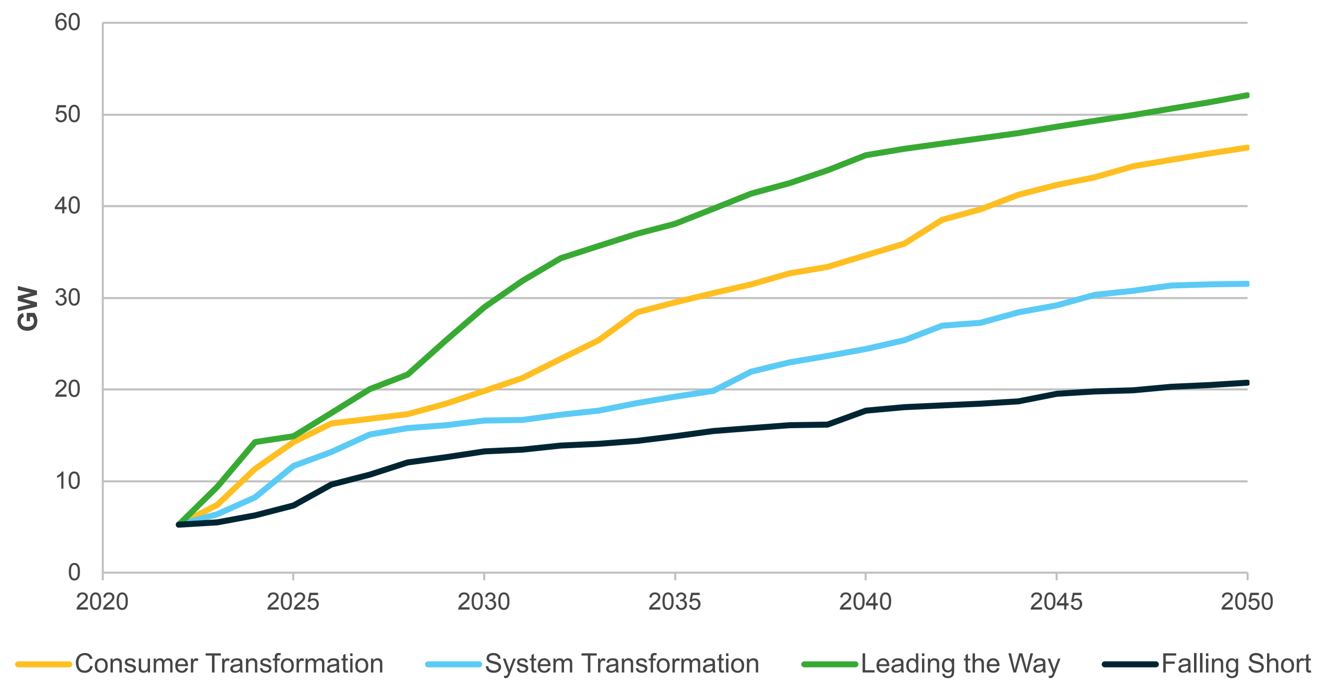
Electricity storage capacity

Electricity storage is needed to reinforce security of supply and efficiently manage supply and demand. Installed capacity and volume need to increase significantly to support the decarbonisation of our electricity system as we transition to net zero.

Electricity storage is a rapidly developing sector. In our FES, we consider battery storage, pumped hydro storage (PHS), Compressed Air Energy Storage (CAES) and Liquid Air Energy Storage (LAES). More information can be found in our Flexibility chapter. This year, we have seen a significant change in electricity storage capacity based on the latest Capacity Market auctions. Around 18 GW of electricity storage is expected to connect into the system by 2028. This has pushed up the scenario range in the short-term across all our net zero scenarios. System Transformation sees less installed electricity storage deployment compared to Consumer Transformation and Leading the Way, representing the upper barriers of supply chain issues, planning considerations and connection delays; with the last being underway for the short and long-term.

Figure ES.26: Electricity storage installed capacity (excluding Vehicle-to-Grid and Hydrogen)



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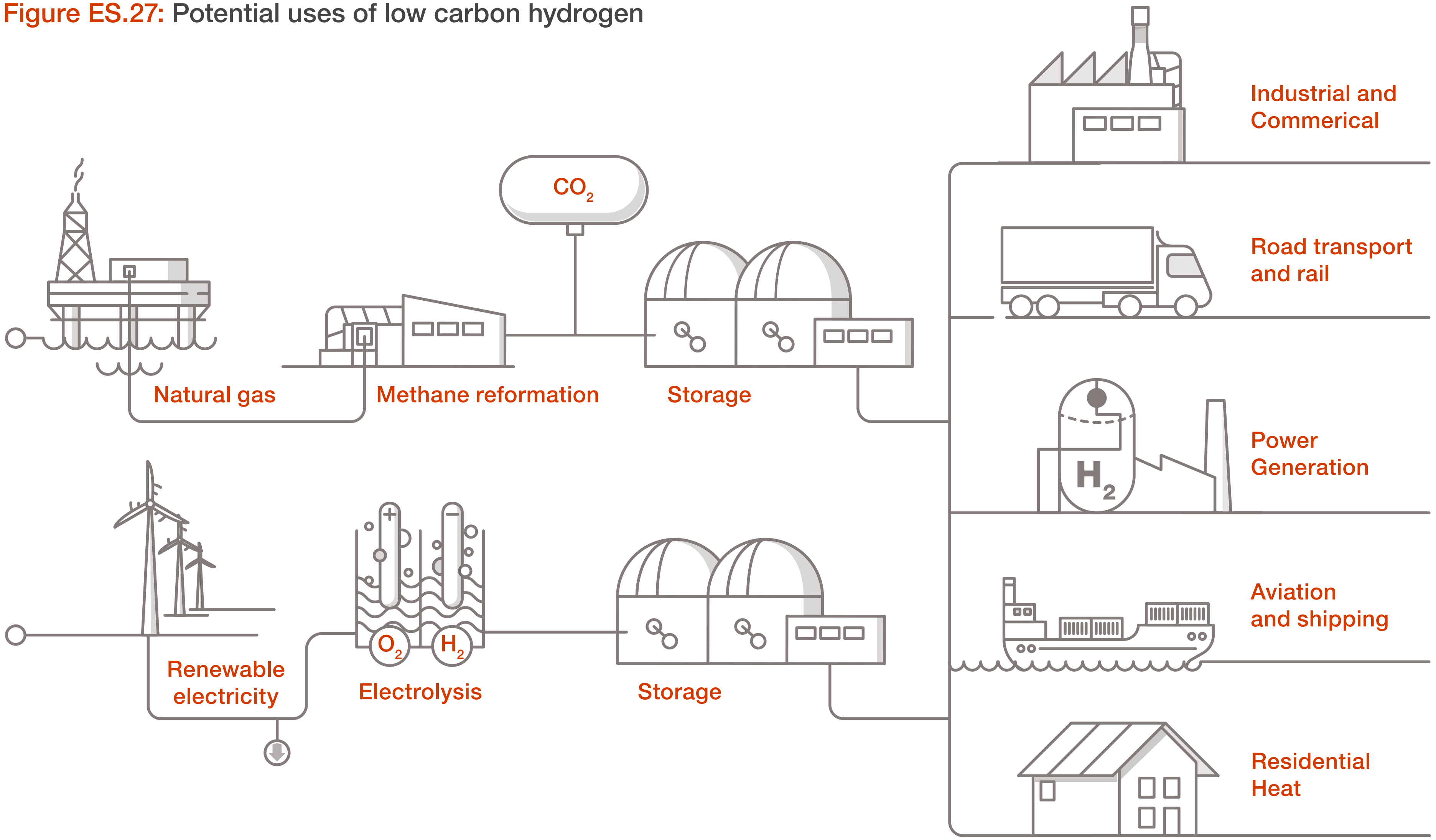
Low carbon hydrogen supply

Low carbon hydrogen will play a key role in the move towards net zero. The UK Government has set ambitious production capacity targets for hydrogen, recognising the role it can play in the fuel mix as both a low carbon energy carrier and source of demand flexibility.

Hydrogen has been used by industry for decades for refining, glass, steel, and fertiliser production. It is quickly emerging as a key solution for net zero and the move towards low carbon hydrogen production is necessary to varying degrees in all our net zero scenarios.

Low carbon hydrogen can replace many current natural gas uses, become a key component of synthetic fuels for aviation and replace existing carbon intensive hydrogen used in petrochemicals and in the production of ammonia for agriculture. At the same time, hydrogen produced by electrolysis has the potential to lower whole energy system costs associated with the management of constraints on the electricity network at periods of over-supply.

Figure ES.27: Potential uses of low carbon hydrogen



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Low carbon hydrogen supply

The Government has provided the UK Low Carbon Hydrogen Standard[8] which producers must meet to receive revenue support via the Contract for Difference. The hydrogen produced must have a carbon intensity below 20 gCO_2e/MJ to meet the standard for funding. The standard is to ensure that low carbon hydrogen production makes a direct contribution to GHG emission reduction targets.

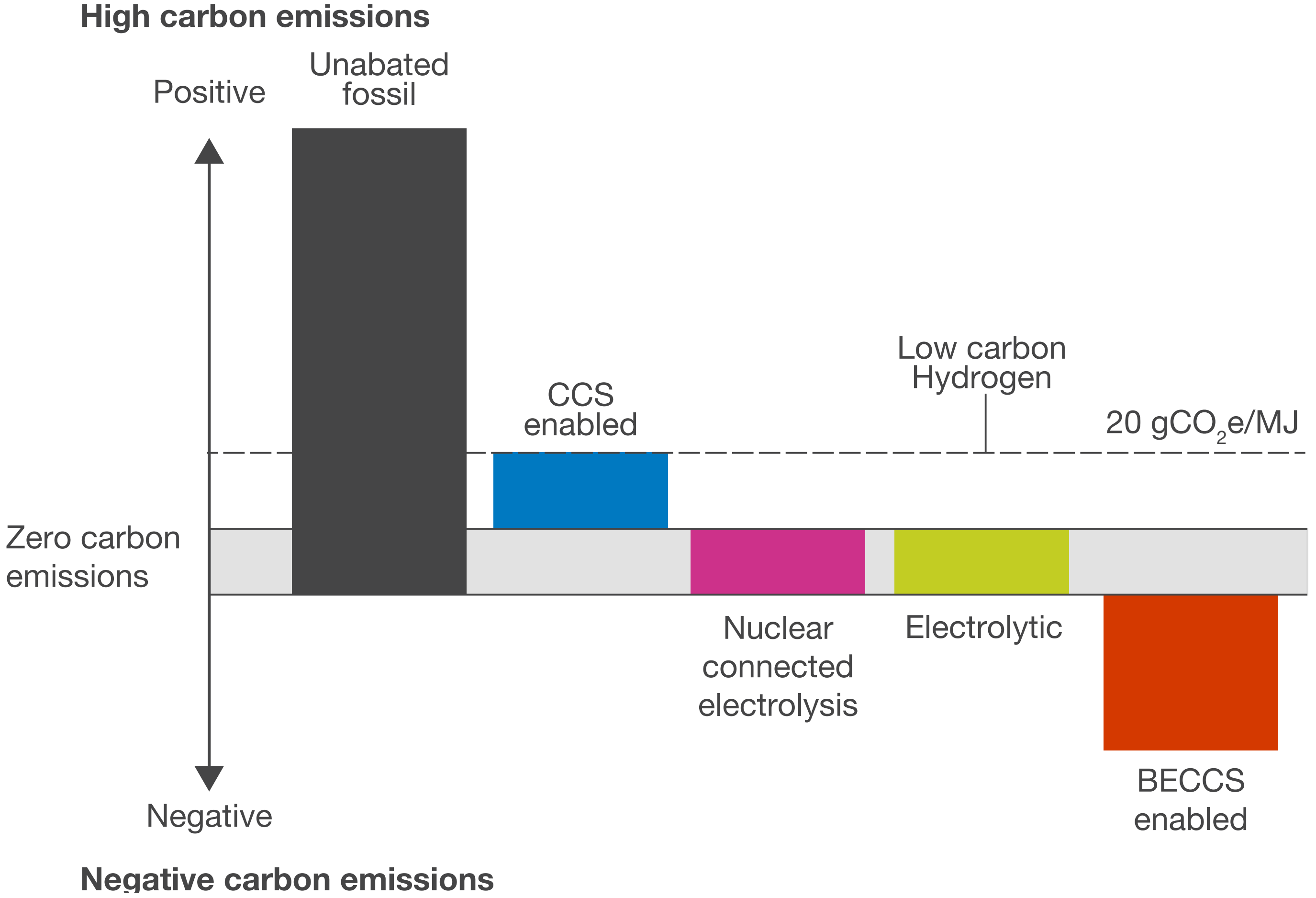
The Government's "twin-track" approach supports hydrogen production from both electrolysis and the reformation of natural gas with CCUS (CCS enabled hydrogen), providing that the hydrogen meets the strict carbon intensity requirements of the Low Carbon Hydrogen Standard.[9]

As part of the Hydrogen Roadmap, the UK Government has set an ambition of 10 GW of new production capacity to be built or in construction by 2030,[10] with an interim aim of 2 GW by 2025.[11] The Hydrogen Production Business Model and net zero Hydrogen Fund are key to reducing investor uncertainty and bringing the first projects through to operation.

All hydrogen projects rely on funding mechanisms which form part of the Energy Security Bill. To continue reducing investor uncertainty and ensure delivery of the volumes of low carbon hydrogen required, the enabling business models (Contract for Difference) and commitment to future funding must be in place.

A clear plan is needed for the funding and development of hydrogen and CCUS projects beyond delivery of the first industrial clusters. This is alongside a determination of how the required funds will be raised beyond initial government funding.

Figure ES.28: Different types of hydrogen and their carbon emissions



8 UK Low Carbon Hydrogen Standard version 2, April 2023: guidance (publishing.service.gov.uk)
9 GHG emissions intensity of 20 gCO_2e/MJLHV of produced hydrogen or less UK Low Carbon Hydrogen Standard version 2, April 2023: guidance (publishing.service.gov.uk)
10 Hydrogen strategy update to the market, July 2022 (publishing.service.gov.uk)
11 Hydrogen Net zero Investment Roadmap (publishing.service.gov.uk)

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Low carbon hydrogen supply

Unabated fossil hydrogen

Hydrogen made by methane reformation without any means to capture emissions or through gasification of coal. Sometimes referred to as grey hydrogen.

CCS enabled hydrogen

This is the same as unabated fossil fuel hydrogen except when it is produced, up to 97% of carbon emissions are captured and either stored or used. It still involves the extraction of fossil fuels, and the associated emissions this brings, and its status as low carbon technology is dependent on the effectiveness of carbon capture. Sometimes referred to as blue hydrogen.

Electrolytic hydrogen

The process of using electricity to split water into hydrogen and oxygen. Sometimes referred to as green hydrogen if the electricity used to power the process is renewable.

BECCS enabled hydrogen

Through gasification, biomass can be used to produce hydrogen. When this is combined with carbon capture, the CO_2 produced as a by-product is stored, making the overall process negative in terms of carbon emissions. This is also sometimes referred to as blue hydrogen.

Nuclear connected electrolysis

As electrolytic hydrogen but where electricity generated by nuclear is used to power the process. For this year's FES we have focused on low temperature electrolysis which can be combined with large or small nuclear reactors because it has the greatest commercial and technical readiness levels of all the options. Other potential ways of pairing nuclear technologies with hydrogen production include high temperature electrolysis such as solid oxide electrolysis (using heat as well as electricity from a nuclear power plant) or thermochemical production (using high temperature chemical reactions and heat from the nuclear plant). Sometimes referred to as pink hydrogen.

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Low carbon hydrogen supply

In the absence of a hydrogen transportation network, consumers will only be able access low carbon hydrogen if there is a funded project nearby. Without this network, and in the early years of funding, low carbon hydrogen demand is led by supply.

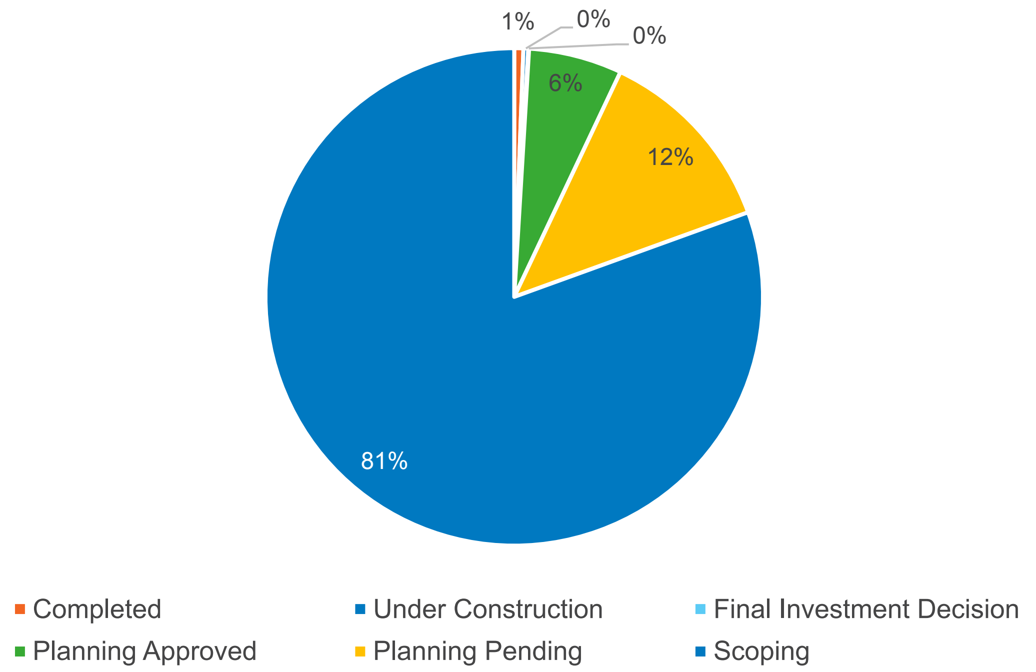
Demand for low carbon hydrogen will initially be focused around industrial clusters through projects awarded Net Zero Hydrogen Funding (NZHF) or support to develop CCUS schemes in Merseyside and Teesside. The hydrogen will primarily be used for industrial processes, with companies switching from higher carbon fuels, encouraged by government schemes such as the Industrial Hydrogen Accelerator.

There is over 15 GW of capacity in publicly announced projects, but most are in very early development and not expected to reach production before 2029. Projects are considered in early development if they are yet to receive planning permission and/or project funding. This would also include those who are carrying out Front End Engineering Design work but have not yet taken a financial decision to commence construction. This has an impact on the FES projections of delivery timescales for hydrogen and there is significant variation amongst projects.

The Hydrogen Allocation Round (HAR) process is expected to encourage the fast tracking of the planned 1 GW of new capacity over the next two rounds.[12] For HAR1, projects could apply for Hydrogen Production Business Model (HPBM) revenue support only, or for joint HPBM revenue support and NZHF capex support.

Funding announcements in March 2023 total 6 GW capacity by 2030. Additional net zero Hydrogen Fund rounds were also announced so we expect this capacity to rise. Further clarity is needed on the funding availability for future rounds, plans for delivery of track 2 clusters and expansion of track 1 clusters.

Figure ES.29: Projects in various development stages



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12 First Special Report - The role of hydrogen in achieving Net zero: Government Response to the Committee's Fourth Report - Science and Technology Committee (parliament.uk)

Low carbon hydrogen supply

In Leading the Way, our fastest decarbonising scenario, the Government's ambition of 10 GW of hydrogen production capacity by 2030 is met with the majority of this capacity being electrolysis.

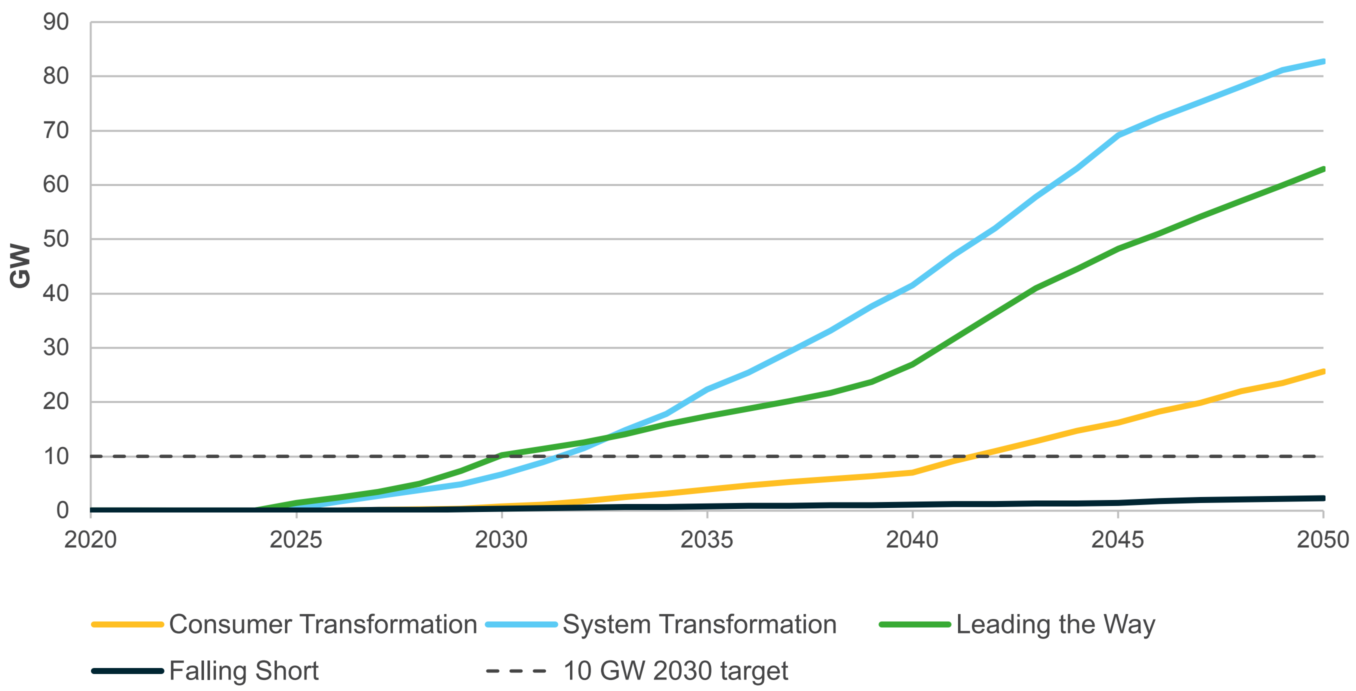
System Transformation is our high hydrogen scenario and reaches 10 GW name-plate capacity in 2032. Compared to the other scenarios, a greater proportion of production is from methane reformation, which operates at higher load factors and aligns with the greater demand for hydrogen across different sectors and the largescale transition of the current natural gas network to a hydrogen network in this scenario.

Load factors vary based on the feed stock for the hydrogen production. Electrolytic production, using wind, solar or other similar renewable generation, has a load factor which reflects the weather dependent nature of the energy production (assumed at an average 36% in FES). Meanwhile, methane reforming, with natural gas as an input, has a more predictable and regulated production, allowing for a potentially higher load factor (assumed at an average 90% in FES). Electrolytic production which is network connected can mitigate the impact of any directly connected weather dependent generation, but this increases the costs of production.

Consumer Transformation sees a higher role for electrification and, as such, 10 GW of production name-plate capacity is only achieved in 2042. Our Falling Short scenario has negligible demand for hydrogen and therefore hydrogen production does not reach 10 GW by 2050.

There is only enough capacity in the project development pipeline to meet the government target of 10 GW. Due to the remaining investor uncertainty and delays experienced to date, it is possible that not all the projects will come online in time and therefore this is only seen in Leading the Way. More projects would give greater confidence in meeting this target. In order for this to happen a clear plan is needed for the delivery of projects beyond 2030 and consistency in policy is required.

Figure ES.30: Low carbon hydrogen capacity



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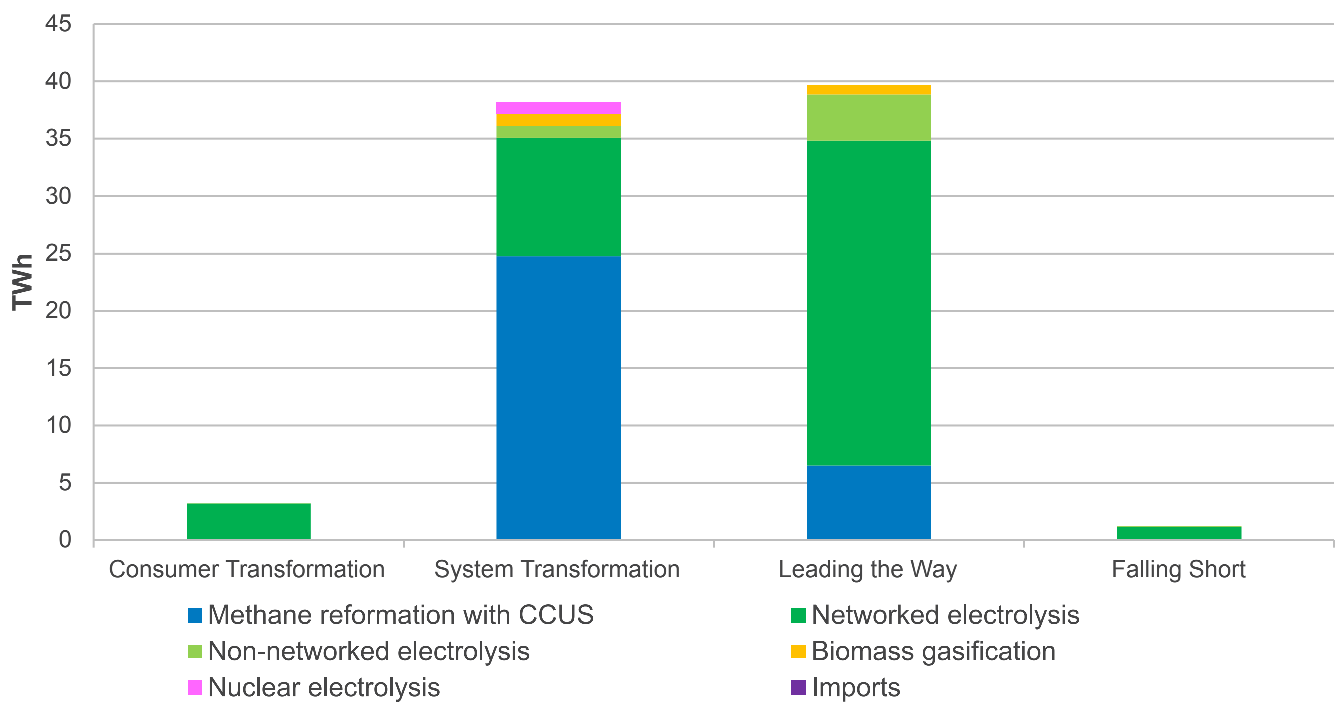
Low carbon hydrogen supply

Hydrogen for heating has only a marginal presence in short-term, and very little of the demand is domestic. The Government is expected to provide a decision in 2026 on allowing hydrogen in domestic heating, and domestic heating trials are expected to be operational from 2025,[13] but the growth on a national basis is expected to be small, with heat pumps becoming more dominant for decarbonising UK heating.

The Government is expected to announce a decision on allowing the blending of hydrogen into the UK National Transmission System (NTS) later this year. This is not expected to lead to a significant increase in production capacity in the short-term, as early projects have higher capacity than contracted offtake volumes. Blending has the potential to reduce investment uncertainty but only if this comes alongside suitable market frameworks to ensure there is an investable business case for blending. Grid blending will also be a key enabler for the use of electrolysers in grid balancing, thus reducing the costs associated with electricity network investment.

Figure ES.31: Low carbon hydrogen source by scenario in 2030



13 gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-factsheet-enabling-the-hydrogen-village-trial

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Low carbon hydrogen supply

System Transformation sees widespread hydrogen use across almost all sectors in 2050, facilitated by fully converted gas transmission and distribution networks. This enables it to supply widespread residential heating demand, as most homes with gas boilers switch to using hydrogen for heat. Leading the Way also sees uptake of hydrogen for heat, met by conversion of some gas distribution networks to transport hydrogen, reaching over 40 TWh by 2050.

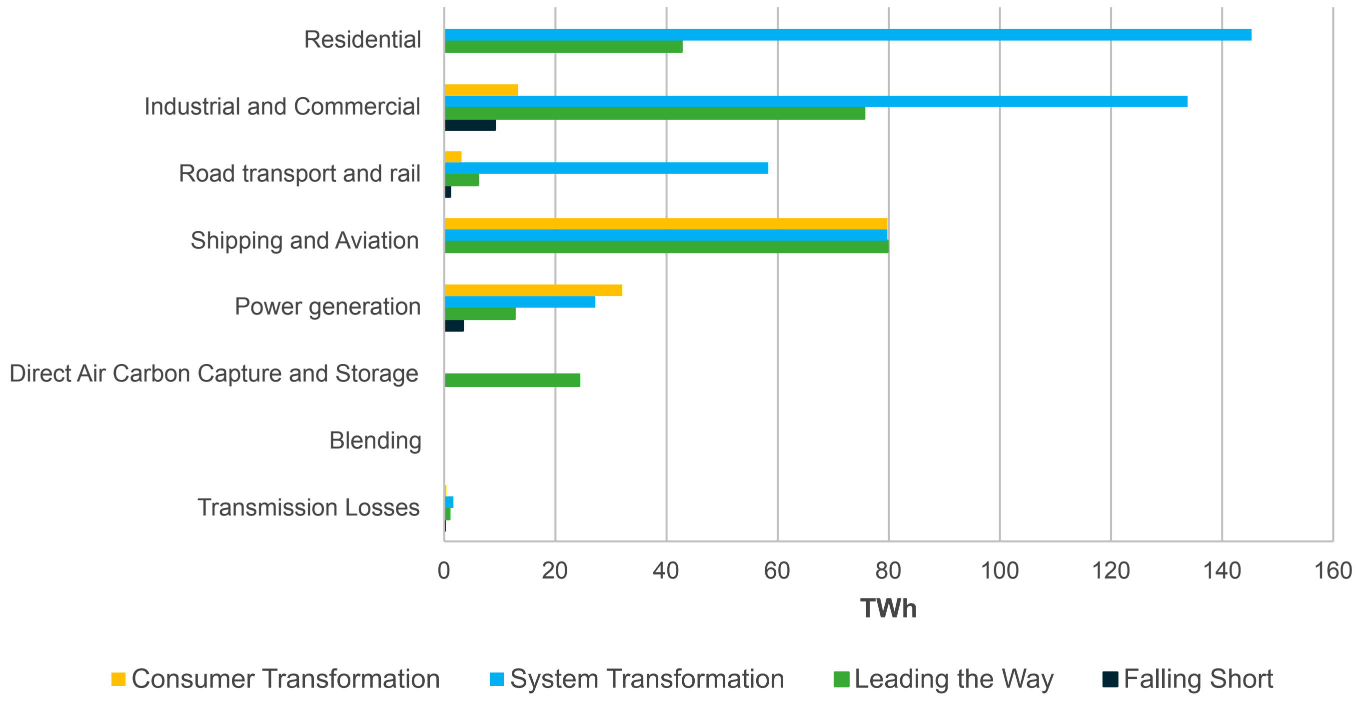
All scenarios see some hydrogen use to decarbonise heavy industry. In Consumer Transformation and Falling Short this is typically produced and used on site within industrial clusters. Leading the Way and System Transformation see higher fuel switching to hydrogen to decarbonise industry, rather than electrification, and also see use of hydrogen for heat in the commercial sector. Falling Short continues to use fossil fuels within industry, with only limited uptake of hydrogen.

For transport, the net zero scenarios see significant hydrogen use for aviation and shipping, while System Transformation also sees significant uptake in hydrogen to power HGVs.

Volumes of hydrogen used for power generation are fairly low, across the scenarios, but this plays a key role in supporting security of supply, particularly in Consumer Transformation, supplying electricity at times of peak demand or during lulls in renewable generation output. Leading the Way also sees some hydrogen use to power Direct Air Carbon Capture and Storage.

There is no demand for blending into the gas network in 2050 as this is seen only as an interim use for hydrogen. In the net zero scenarios, by 2050 the gas network or parts of it have either been converted to deliver 100% hydrogen or decommissioned. In Falling Short hydrogen supply is limited and direct use is prioritised over blending.

Figure ES.32: Low carbon hydrogen demand



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Regional spotlight - hydrogen

Without a national hydrogen network, or specific drivers to locate hydrogen production for the management of network constraints, projects will be developed close to high volume consumers.

The largest individual projects currently in the known development pipeline are located around industrial clusters, where developers are seeking to reduce early commercial risk by engaging with multiple customers. This proximity to an industrial hub is starkest around the East-Coast Cluster regions of Teesside and Humberside.

Following the first Hydrogen Allocation Round, 20 low carbon hydrogen production projects have been earmarked for funding to progress development. Over 300 MW of the name-plate capacity being considered for funding is within the two track 1 industrial clusters (Hynet and East-Coast Cluster, both in England). This represents over half of the capacity in the HAR1 process.

The Scottish Government have set an independent target of 5 GW of low carbon hydrogen by 2030. Around 100 MW of capacity in the HAR1 process is located in Scotland. Based on planned name-plate capacity of announced projects, this target is achievable with additional support and new projects needed to ensure it reaches fruition.

Figure ES.33 shows the electrolyser capacity and total wind capacity per Distribution Network Operator (DNO) region for each net zero scenario in 2050. Areas with high deployment of wind capacity also have the potential to lead to network constraints; the B6 and B7 constrained network areas in Scotland and the Northeast of England are current examples. These constraints may become harder to manage as additional wind capacity is deployed. Deployment of electrolysers in both these regions can help mitigate these constraints.

For System Transformation and Leading the Way, the regions with the greatest wind capacities also have the greatest electrolyser capacities. This is most noticeable in Scotland. For Consumer Transformation, the link between electrolyser and wind capacity is less clear, with Scotland still having high levels of wind but deployment of very small electrolyser capacity. Due to the low hydrogen demands in Consumer Transformation, the hydrogen network is very limited, meaning electrolysers remain focussed in the high demand areas.

Siting electrolysers in areas of high wind capacity will provide whole energy system benefits but this requires a strategy which considers the right market arrangements to incentivise producers, development of new hydrogen demand and transport and storage of hydrogen.

Hydrogen transport and storage is a necessary enabler to moving production away from demand. This is covered in detail in the Flexibility chapter.

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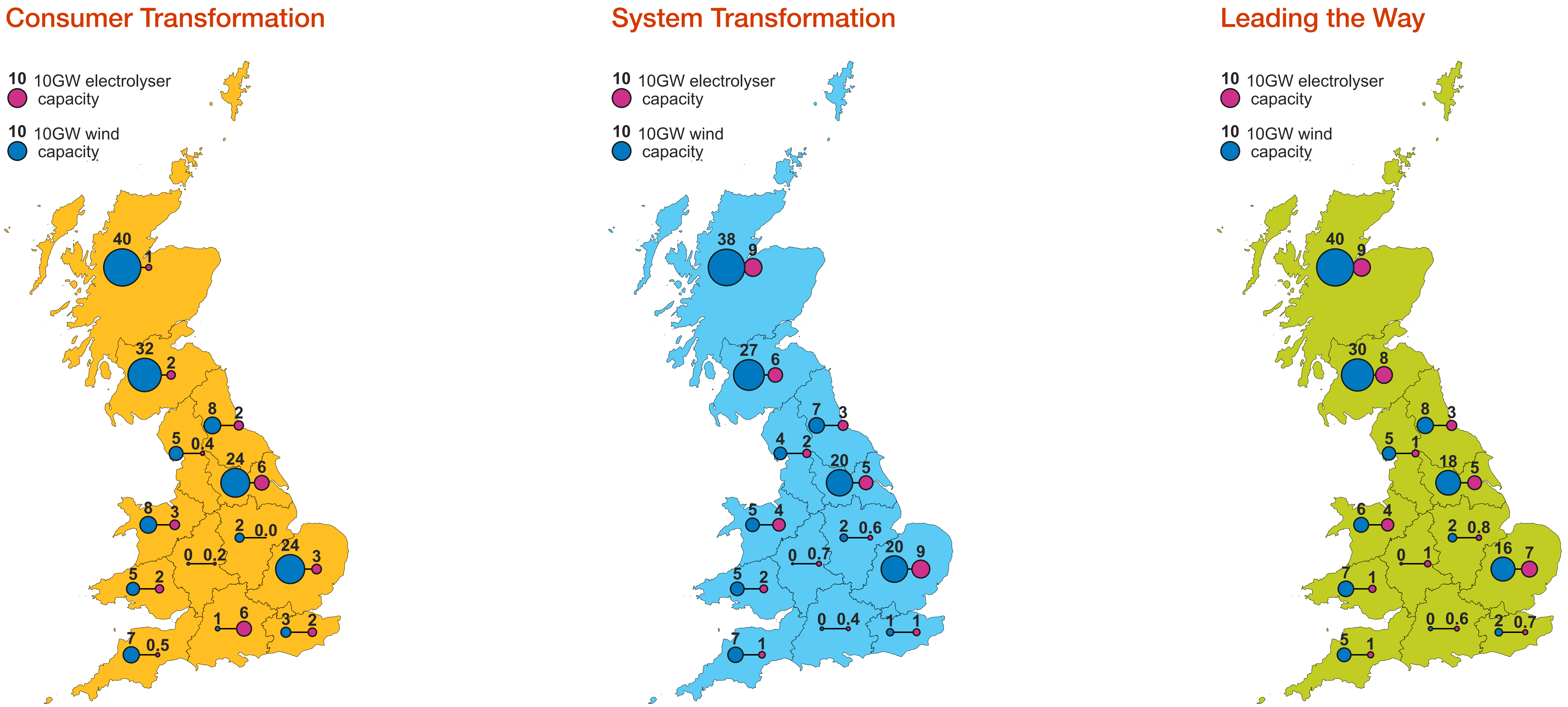
Regional spotlight - hydrogen

Figure ES.33: Electrolyser and wind capacity by DNO region in 2050



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Regional spotlight - hydrogen

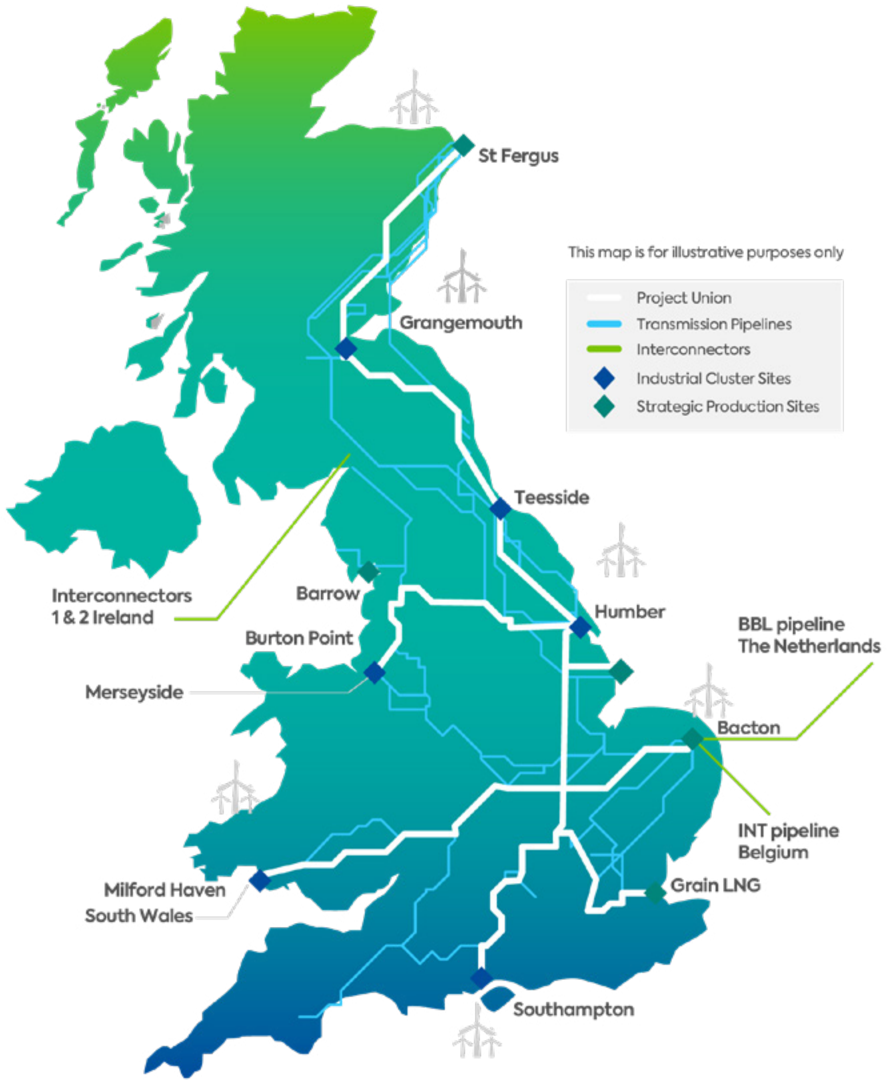
While initial hydrogen production, at least in England and Wales, is expected to be focused on industrial clusters, further expansion will require some form of supply network.

At present, there is no pipeline network for the transportation of hydrogen. Current production is either shipped by road or rail to the area of demand, or has a direct, dedicated link to it. Many gas distribution companies are investigating the options for developing a pipeline network to increase the options for connecting production and supply. The options include the building of new pipelines, as well as potentially reusing the existing gas supply network. The characteristics of hydrogen mean that only a proportion of the current natural gas pipelines can be used for this process. Blending is an option to mitigate the effects of hydrogen on existing infrastructure but has its own technical difficulties. The technical feasibility and cost of developing the network will define the scale and breadth of any hydrogen network.

Among the widest reaching network projects being developed is Project Union. Headed by National Gas Transmission, Project Union aims to develop a transmission 'hydrogen backbone' for the UK,[14] as shown in Figure ES.34. The main aim is to connect the industrial hubs which will be the focus of initial large-scale hydrogen production. The connection will allow greater supply security and reduced investment risk across the hubs. It will also allow more options for both demand creation and supply along the routes of any transmission links.

For FES, the development of a hydrogen network is one of the defining characteristics of the scenarios, as it is also tied to the development of hydrogen supply for domestic heating. Residential heating decarbonisation in System Transformation lags behind Leading the Way and Consumer Transformation as the hydrogen boiler roll-out in this scenario must wait for the development of a hydrogen network. Meanwhile, Leading the Way has regional hubs where smaller distribution scale hydrogen networks develop.

Figure ES.34: Project Union hydrogen backbone



14 nationalgas.com/document/139641/download

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The UK energy system still relies heavily on natural gas for power generation, industrial processes and heating.

Today, gas still meets around 40% of total UK energy demand, and the renewable integration achieved to date has been successful in part due to the ability of the gas generation fleet to flex output in times of low wind or sun. However, transitioning towards net zero while maintaining a reliable and affordable energy system will require a continued, if different, role for natural gas.

Our analysis shows that there is sufficient gas supply between now and 2050 to ensure security of supply. This is due to the diverse sources of natural gas available to the UK and because we expect natural gas demand to decline due to increased renewable power generation, industrial fuel switching and energy efficiency improvements. However, if gas remains in demand for heat, power and industrial processes including hydrogen production, we will continue to be exposed to price fluctuations in global energy markets for both gas and electricity, without market reform.

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Natural gas

Events over the past year have had a significant impact on the UK picture for natural gas. Despite price rises, we saw a rise in gas demand due to an increase in exports to the continent as they looked to replace Russian gas.

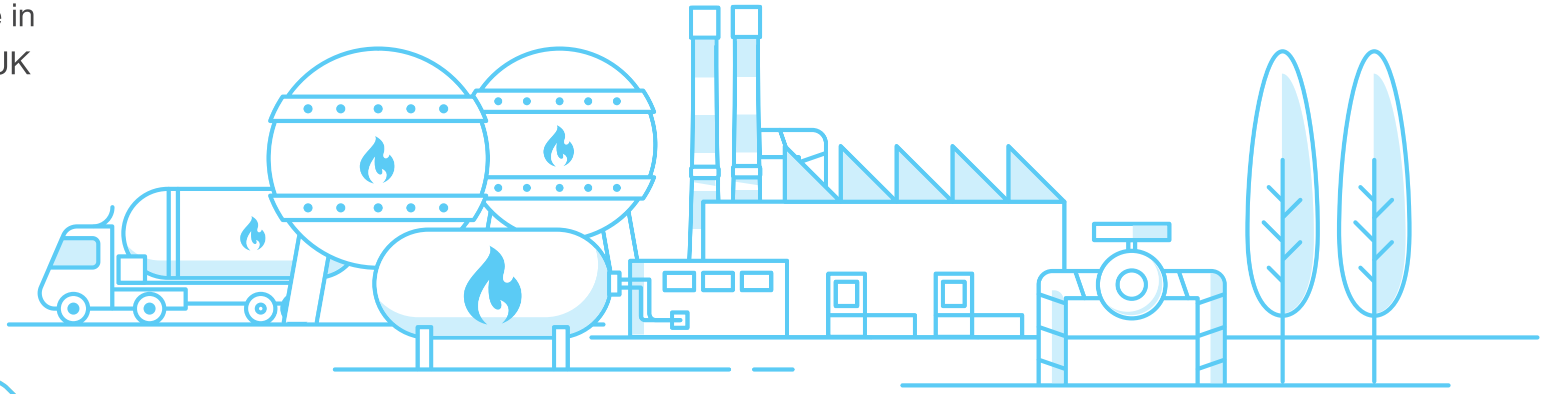
Gas prices in the UK rose by 129% in the 12 months to March 2023,[15] a driver of the high rates of inflation. Sanctions imposed on the Russian energy industry following the invasion of Ukraine saw a significant drop in Russian exports to Europe. This left Europe short of gas supply, leading to increased demand from other sources, and therefore increasing prices.

As a result of security of supply concerns for winter 2022/23, the EU set compulsory minimum gas storage levels. This led to increased gas demand as EU countries were mandated to fill gas storage sites to 80% by the beginning of winter. The perfect storm of reduced supply and increased demand caused the dramatic increase in gas price.

In 2022, a total of 89 billion cubic meters was supplied to the UK via UKCS, pipeline from Norway, shipped LNG, and green gas from UK sources, e.g. anaerobic digestors. This is an increase in supply of 10 bcm against 2021. This was primarily due to increased export demand as the UK was used as a transit market to get gas to Europe via the gas interconnectors to Belgium and the Netherlands. Gas comes to the UK as LNG due to the relatively large import capacity and good connectivity to Europe.

This increase in LNG import for regassification and export to Europe is expected to fall by 2025 in all scenarios due to development of additional LNG import infrastructure in continental Europe.

In addition to the increase in LNG imports, 2022 also saw an increase in UKCS supplies while pipeline imports dropped in response to additional demands in Europe.



15 ons.gov.uk/economy/inflationandpriceindices/articles/costoflivinginsights/energy

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Natural gas

Figure ES.35: Natural gas supply 2022

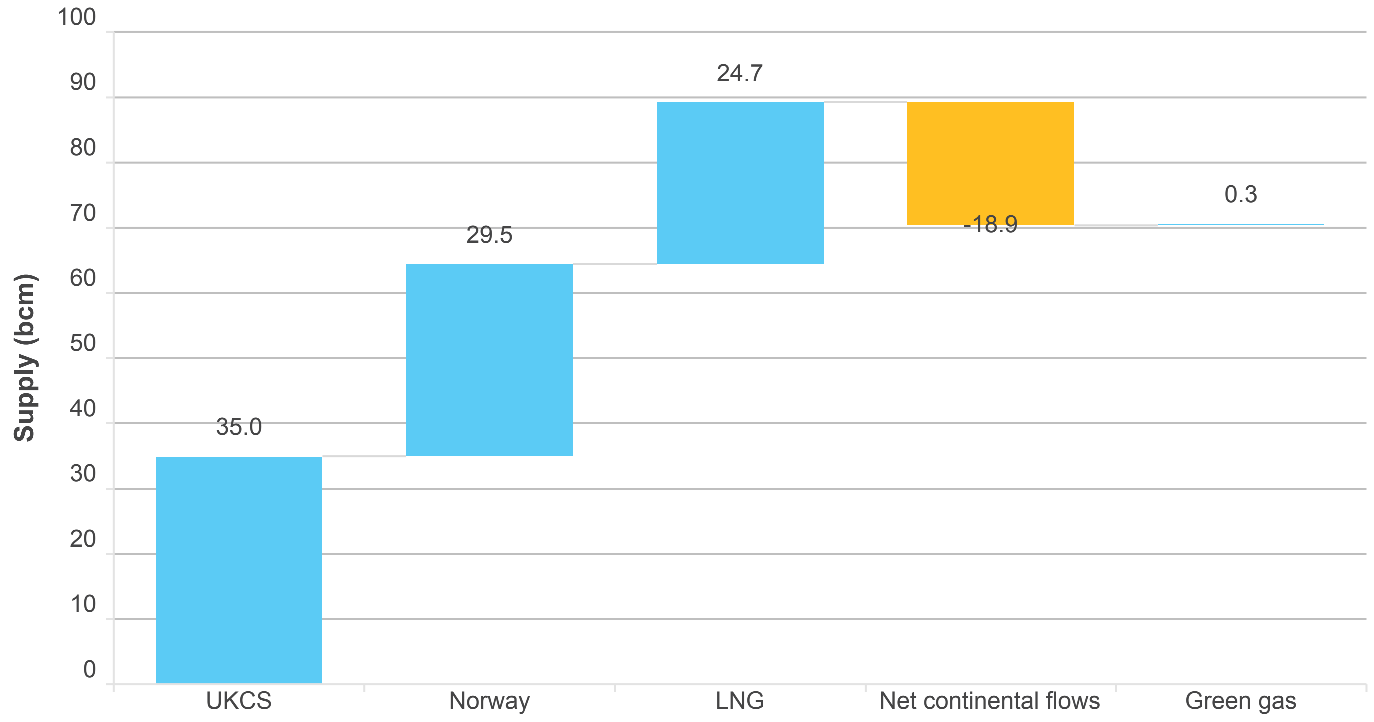
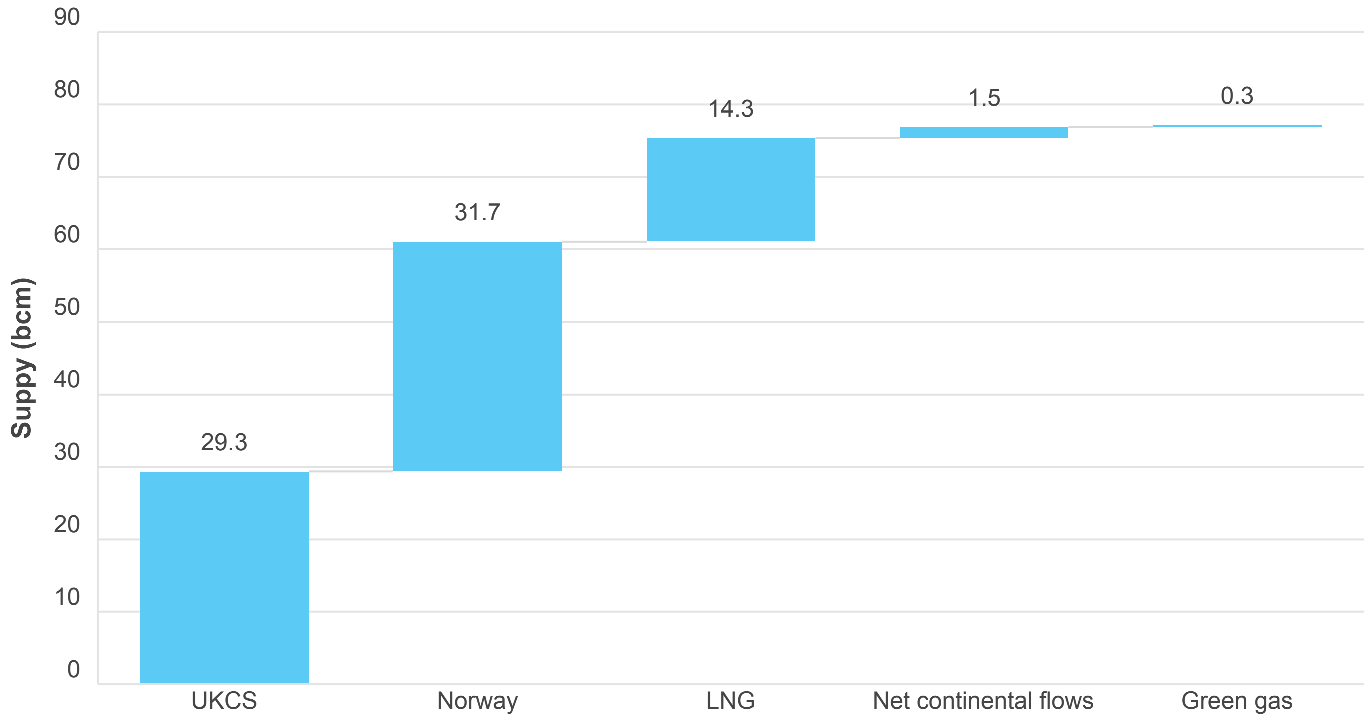


Figure ES.36: Natural gas supply 2021



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Natural gas

Figure ES.37: Annual gas supply and import dependency in Consumer Transformation

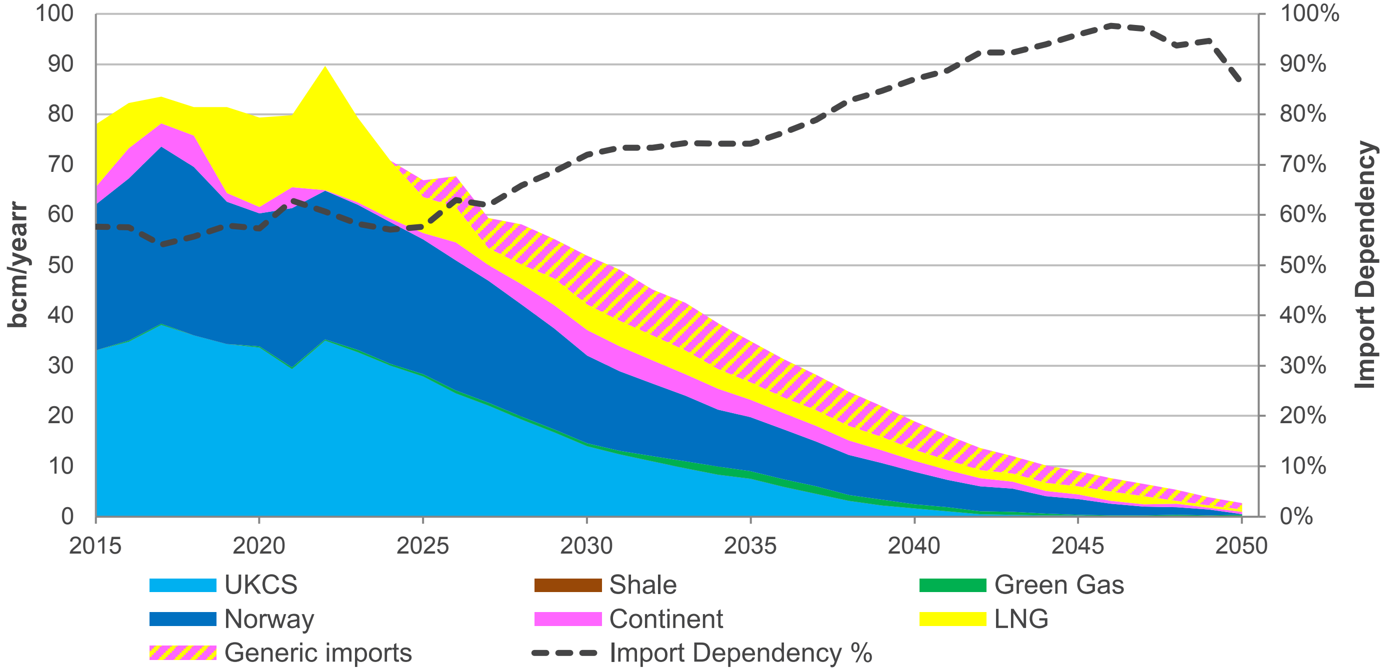
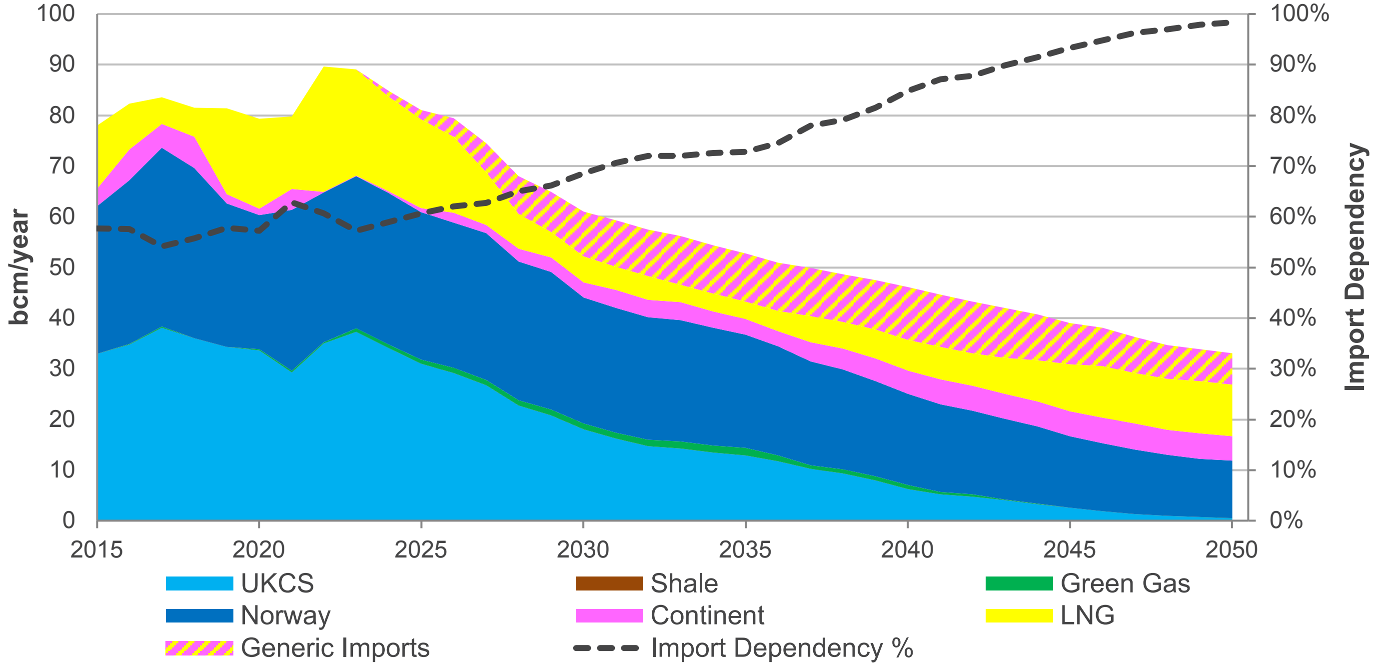


Figure ES.38: Annual gas supply in System Transformation



Consumer Transformation sees our lowest natural gas demands by 2050. Natural gas is replaced in most cases by electricity for heating homes and buildings.

There is still a small amount of natural gas demand in 2050, used to produce low carbon hydrogen and where natural gas is still required in some industrial applications.

Consumer Transformation sees the quickest drop in UKCS volumes with no output beyond the early 2040s.

System Transformation sees the highest natural gas demand remaining in 2050 of all our net zero scenarios. This remaining demand will be used for low carbon hydrogen production for industry and heat applications. This supply is met primarily through imports but UKCS output falls more slowly than in Consumer Transformation and Leading the Way.

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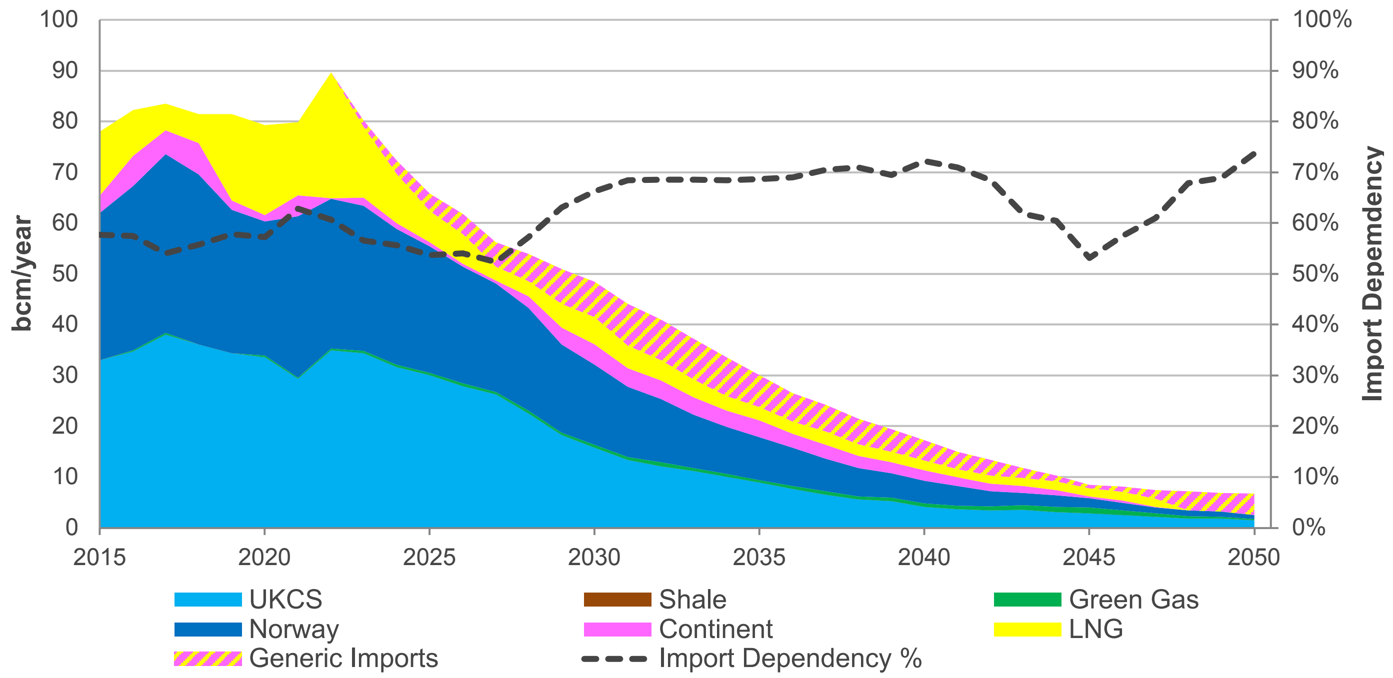
Natural gas

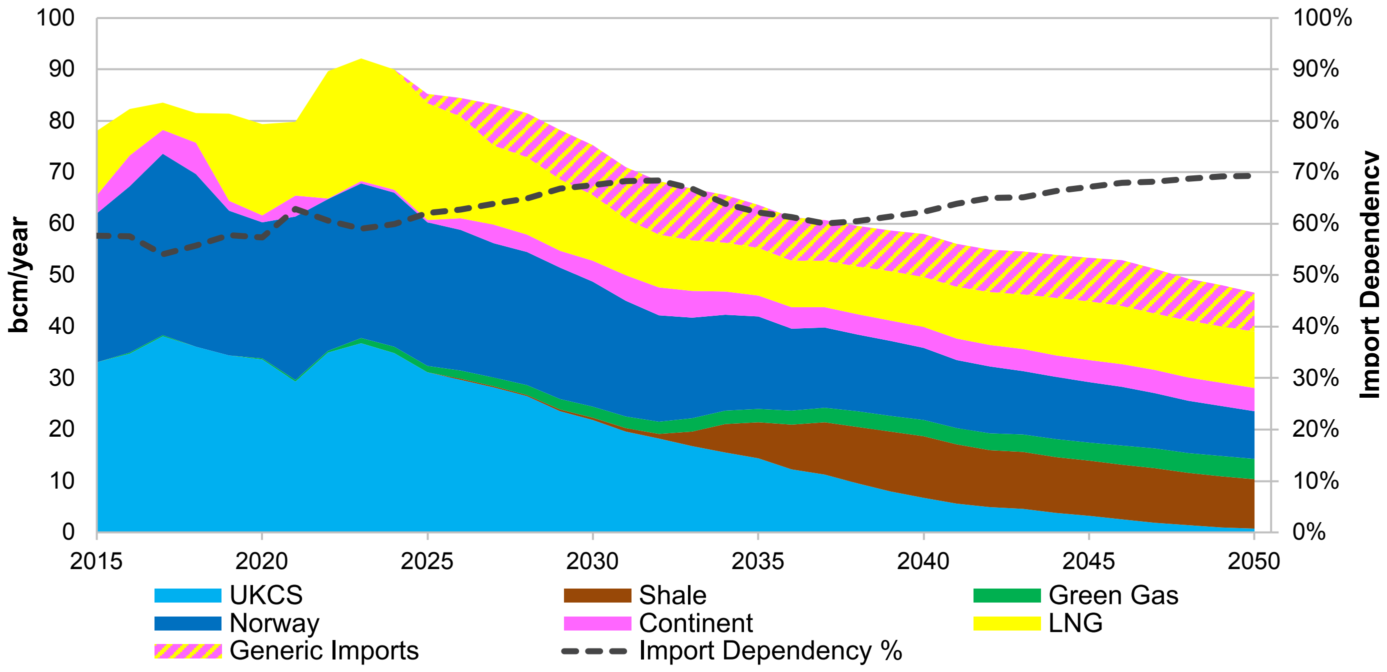
Figure ES.39: Annual gas supply in Leading the Way



Leading the Way sees the fastest reduction in natural gas demand with most of the demand between 2020 and 2050 being met by gas from the UKCS and Norway.

The drop in demand is due to the fuel switch from natural gas to electricity and electrolytic hydrogen. The remaining demand is for some industrial applications such as low carbon hydrogen production and combustion combined with CCUS.

Figure ES.40: Annual gas supply in Falling Short



Natural gas demand reduces steadily to about 65% of 2021 levels. Though natural gas is still widely used in the UK to heat homes and buildings and for industrial applications, we also see increased energy efficiency in homes and buildings, as well as increased electrification for heating.

Falling Short includes growth in domestic shale gas production from the 2030s onwards. Removal of shale gas would lead to an increase in the volume of imported gas.

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Gas import dependency

The events of the past year have brought gas import dependency into sharp focus. While the UK imported only a small amount of gas from Russia, the need to import gas leaves the market susceptible to global prices.

In Leading the Way, the UKCS is still providing a small amount of the residual annual demand in 2050, meaning that the UK can meet almost 30% of annual demand from domestic sources in 2050. Leading the Way shows the quickest decline in reliance on imported gas.

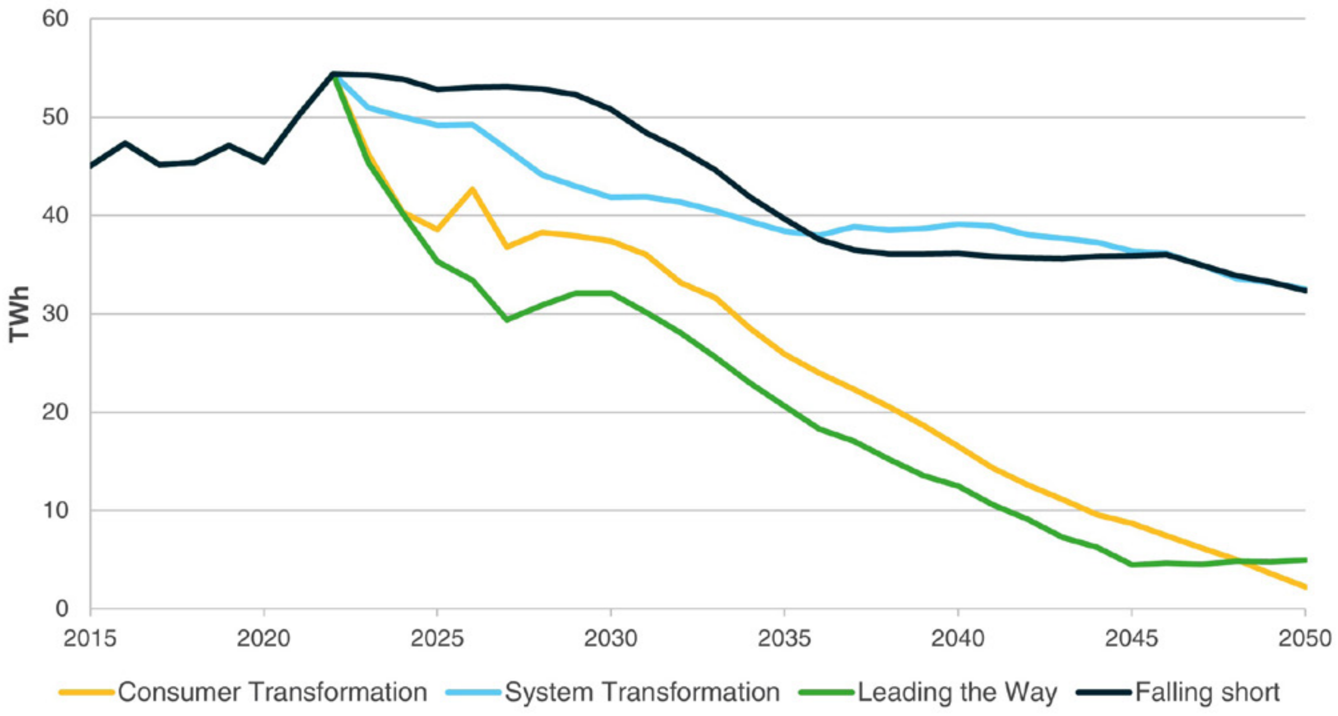
While Consumer Transformation sees our lowest import dependency by volume in 2050, due to the electrification of demand, the import dependency in 2050 is around 90% of total gas demand due to the flexibility required of the remaining demand profiles. There is a spike in gas generation in 2026 due to a gap in decommissioning of existing nuclear and commissioning of new nuclear.

System Transformation requires higher volumes of gas in 2050 which is mostly imported from Norway and the continent by pipeline and shipped as LNG in 2050.

Falling Short sees the slowest decline in import dependency to 2032. System Transformation and Falling Short have higher gas demands and hence rely most heavily on imports.

The UK government announced a series of measures to maximise supply of UK gas as part of Powering up Britain. Measures include launching the 33rd oil and gas exploration round, accelerating production through regulatory accelerators and a review of the long-term fiscal regime for oil and gas to reduce investor uncertainty. However, the most effective way to ensure climate and energy security is with a swift transition to clean energy generation and increased energy efficiency which will reduce the country's dependence on imported fossil fuels.

Figure ES.41: Imported gas volumes



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International spotlight - LNG imports

Gas storage

While the UK benefits from a diverse range of gas supply sources, it can also call on storage as an additional source of flexibility and security.

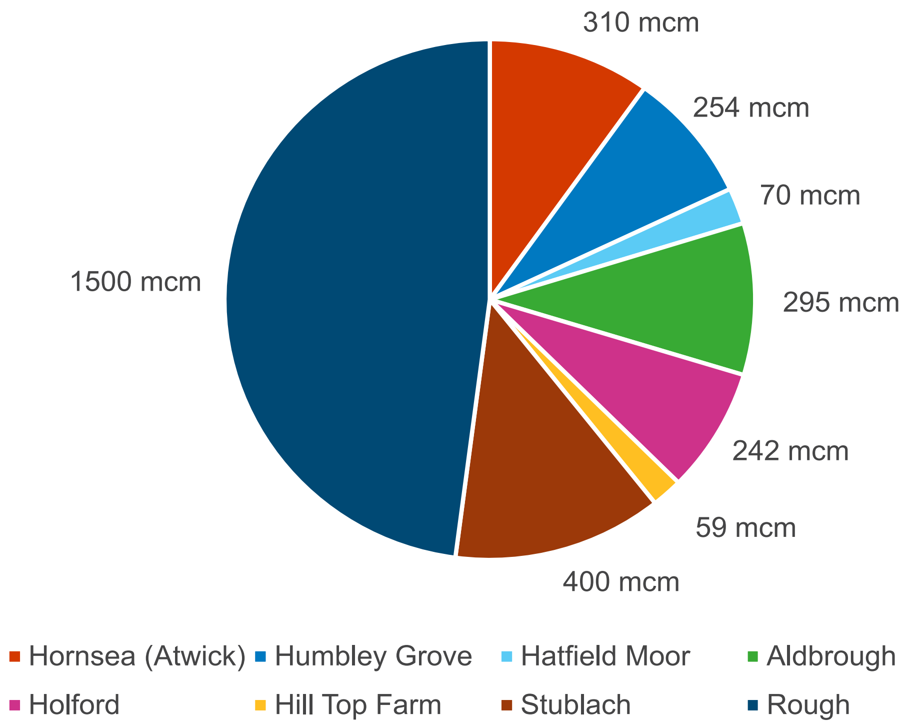
The UK's gas supply gains flexibility through two main types of storage, categorised based on the period the assets tend to be used:

- Real-time: The flexibility provided by linepack means demand on the gas network can be met even if gas supply doesn't match gas demand in real time
- Seasonal: Gas supply can be increased during winter to meet the seasonal peak demand, largely for heat. It can then be reduced during summer when demand is lower.

Throughout 2022, the UK had approximately 15,000 GWh of storage capacity,[16] with a rough 80/20% split between salt caverns and depleted gas fields. This is in addition to the 1,000 GWh of linepack available. In October 2022, Rough gas storage facility was reopened after 5 years of inactivity. While initially offering only 20% of its original capacity, this still represented around 8,750 GWh of storage, increasing the UK's overall capacity by over 50%. There are plans to double this capacity by Winter 2023/24 as highlighted in Figure ES.42. Under all FES scenarios the gas system uses this storage capacity, which is vital to system security.

Many gas storage sites are considering the future conversion to hydrogen storage but due to a lack of clarity around hydrogen transport and storage business models, investor uncertainty remains high.

Figure ES.42: Estimated working gas volume



16 ofgem.gov.uk/publications/gb-gas-storage-facilities-2021

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International spotlight - LNG imports

The UK plays a major role in the European LNG market. In 2022, the UK imported around 25 bcm of LNG.[17] The UK has significant regasification infrastructure, which allows it to re-export imported LNG to other countries in Europe.

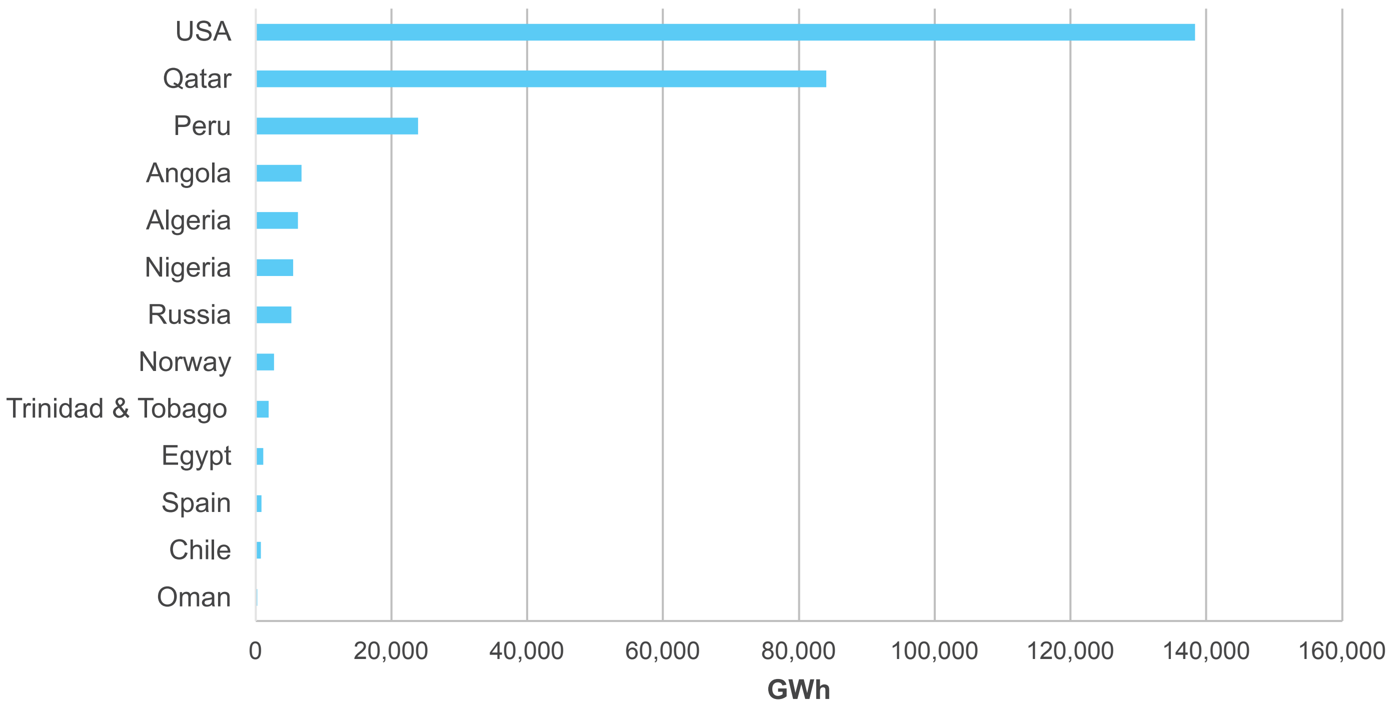
The Russian invasion of Ukraine has destabilized existing European gas supply chains and prompted European economies to seek alternatives to Russian gas imports.

Great Britain has a well-developed LNG infrastructure and diversified LNG supply portfolio, sourced from 13 different countries[18] in 2022. The United States was the largest source,[19] followed by Qatar, Peru and Angola. This diversity of supply helps to mitigate the risk of disruptions to any one source of LNG.

The UK's LNG supply portfolio is expected to continue to diversify in the coming years. This is due to factors including the development of new LNG production projects around the world, the growth of LNG trade, and the UK's commitment to reducing its reliance on Russian gas.

The diversification of the UK's LNG supply portfolio will help ensure that the UK has access to reliable and affordable gas supplies in the future. This is important for the UK's economy and its energy security.

Figure ES.43: 2022 LNG import sources



17 ofgem.gov.uk/publications/gb-gas-storage-facilities-2021
18 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1158697/ET_4.4_MAY_23.xlsx
19 Energy Trends: UK gas - GOV.UK (www.gov.uk)

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Bioenergy

Bioenergy can play a role in the decarbonisation of all sectors of the economy, but resources are limited so it is critical to ensure it is being used for the most optimal applications.

Bioenergy is already an alternative to fossil fuels but its future in the energy mix largely relies on its value as an enabler of decarbonisation via negative emissions. Bioenergy plays a key role from a whole energy perspective as it is used for BECCS in the power sector, biomethane in the natural gas system, and to produce hydrogen via biomass gasification. This is in addition to direct use in heating, transport and aviation.

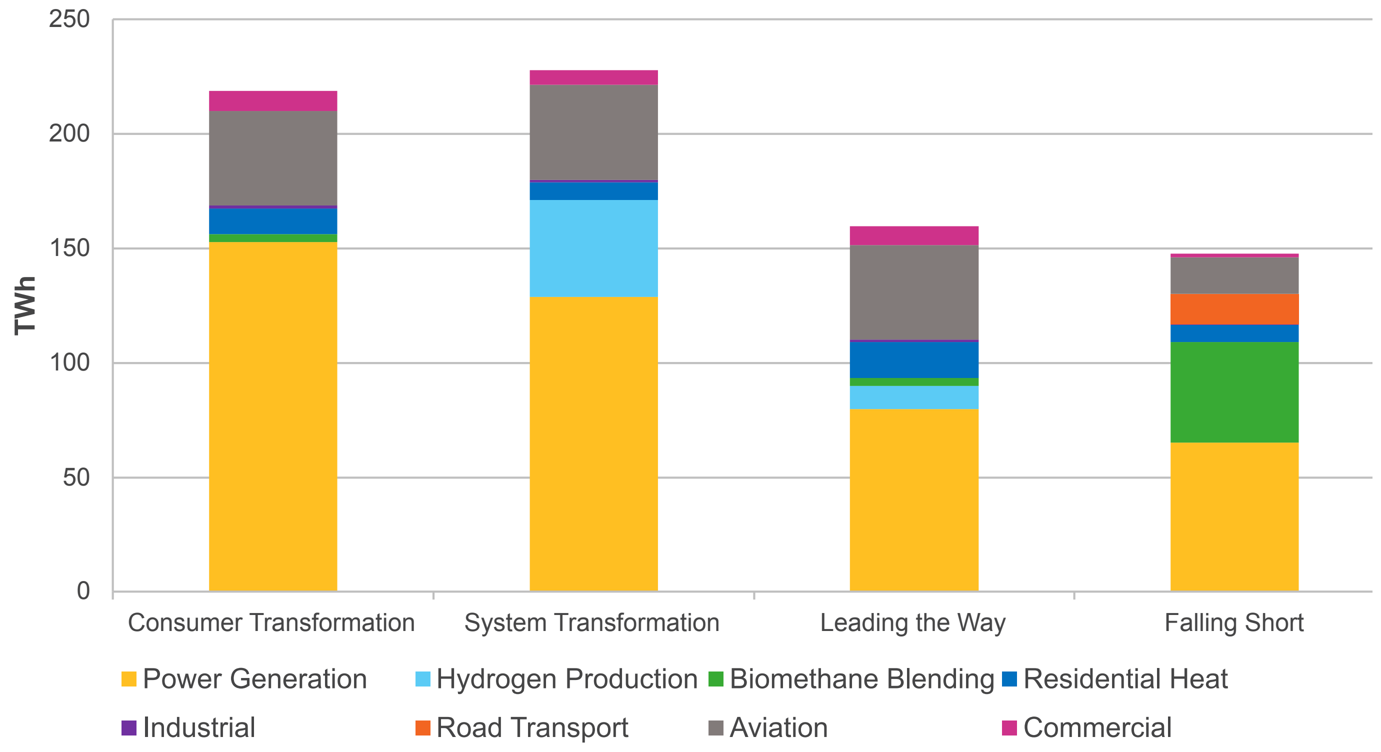
Figure ES.44 shows the proportion of demand for each application in 2050 across the scenarios. System Transformation and Consumer Transformation have similar total bioenergy demands but bioresources are being used very differently. A bioenergy strategy is critical to ensuring the limited resources are used where they bring the most value.

Due to the increased volumes of CCUS enabled hydrogen in System Transformation, 42 TWh of bioenergy is used in low carbon hydrogen production by 2050. Bioenergy use in power generation makes up the biggest proportion of demand in 2050 across all scenarios.

When used in power generation and low carbon hydrogen production, it is combined with CCUS technology and delivers negative emissions. Negative Emissions Technologies (NETs) required to enable a net zero energy system. The Net Zero chapter presents sensitivity analysis around the importance of BECCS in offsetting emissions from sectors that are difficult to abate. Removal of BECCS and DACCS from our net zero scenarios leaves residual emissions of 18-49 $MtCO_2e$ annually in 2050.

Reducing investor uncertainty by progressing business models for BECCS is critical to delivering the levels of BECCS for power and hydrogen production across our scenarios. This must be delivered alongside robust emissions accounting standards and sustainability criteria.

Figure ES.44: Total bioenergy demand in 2050



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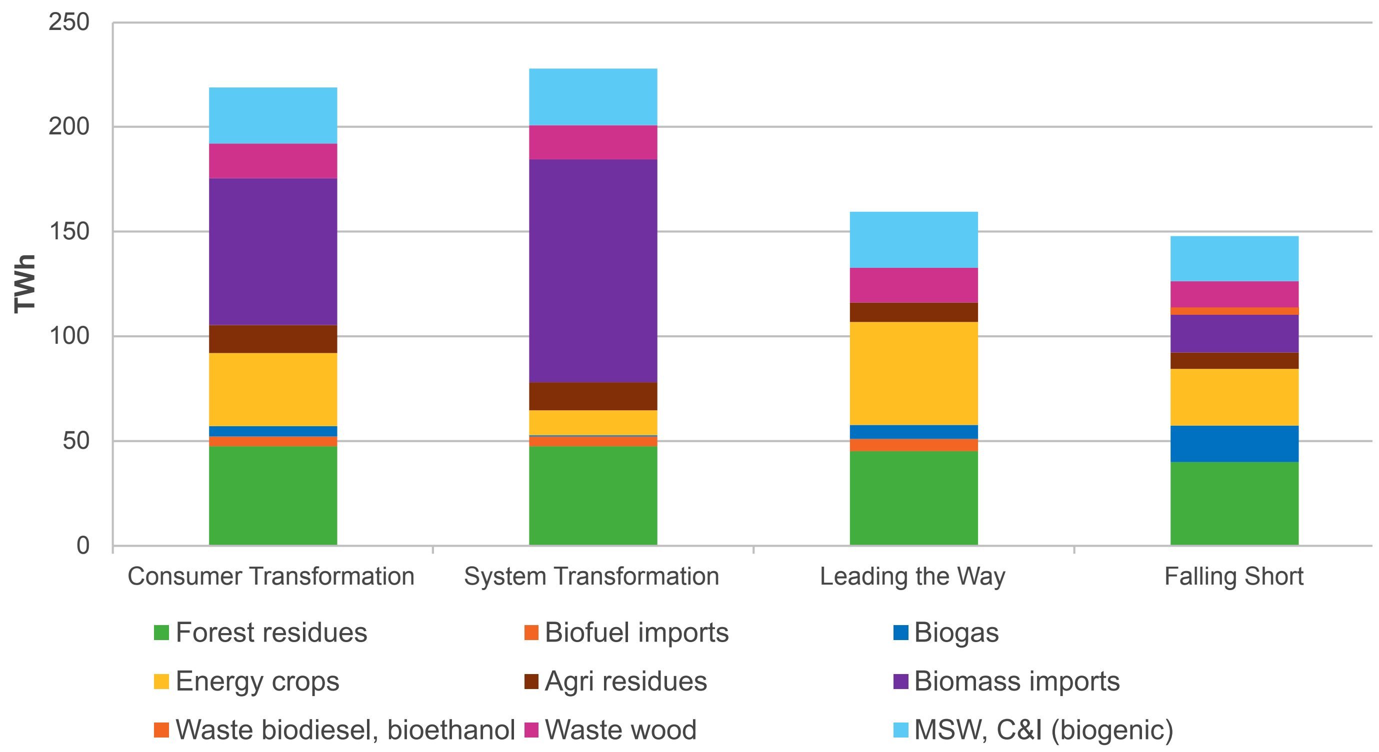
Bioenergy

In System Transformation 49% of bioenergy demand in 2050 is met with imported biomass and biofuel. Imports are lower in Consumer Transformation which sees higher supply from domestic energy crops. Only 4% of bioenergy demand in Leading the Way in 2050 is met with imports, which is limited to biofuel only, with no imported biomass. This is driven by reduced demand across all sectors, excluding aviation, compared with Consumer Transformation and System Transformation. Bioenergy demand for aviation increases consistently across all net zero scenarios. Although demand for bioenergy is lowest in Falling Short due to lower levels of decarbonisation overall, 12% of bioenergy supply comes from imported sources.

Robust sustainability criteria are essential in ensuring maximum contribution to net zero from bioenergy, which is easier to assess for domestic supply chains. Reduced reliance on imports also reduces upstream emissions and strengthens security of supply.

In the UK, the Government laid out its priorities for biomass in its 2021 Bioenergy Policy Statement.[20] A further Bioenergy Strategy has been expected since 2022. The wider outcomes of policies and incentives relating to bioenergy must be considered to avoid cross-sector conflict (e.g. land use for domestic bioresources impacting on other important areas such as food production).

Figure ES.45: Total bioenergy supply in 2050



20 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031057/biomass-policy-statement.pdf

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Consumer Transformation

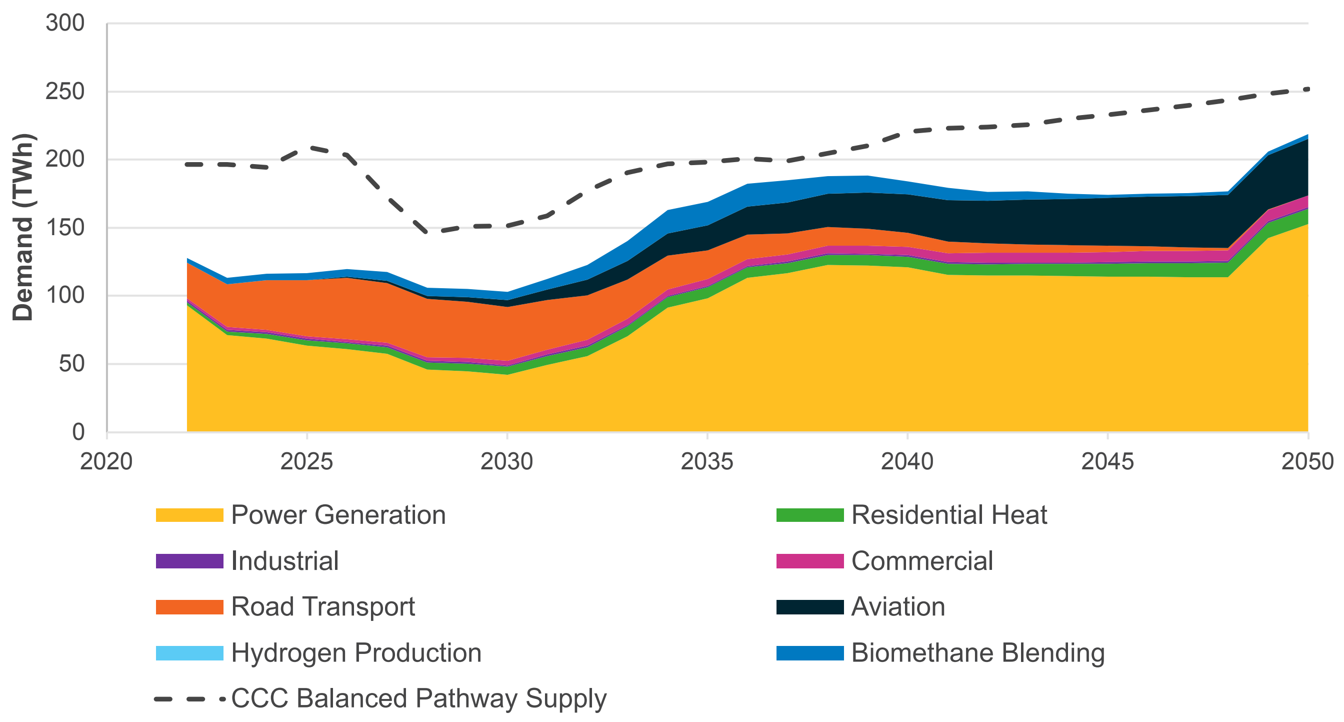
Bioenergy is not used for hydrogen production in Consumer Transformation due to the overall lower hydrogen demand being met primarily through electrolysis.

Bioenergy holds potential in aviation as it can be used as a sustainable alternative to conventional jet fuels. Demand for aviation progresses steadily and consistently across all net zero scenarios reaching 41 TWh by 2050.

Unabated power generation from bioenergy falls between now and the late 2030s in all scenarios. All revenue support for bioenergy power generation through CfD and Renewables Obligation is set to end in 2027 with significant uncertainty remaining for investors over future business models. The growth from 2030 follows delivery of BECCS for power projects with the expansion of industrial clusters which relies on the development and implementation of business models for negative emissions. Urgent action is needed to reduce investor uncertainty to avoid delays to the growth in BECCS for power in the later 2030s. Consumer Transformation sees the highest levels of power generation from bioenergy due to overall higher electricity demands and higher installed capacities of BECCS which sit at just under 9 GW beyond 2037. Higher levels of generation are seen from 2048 to meet negative emissions requirements.

Consumer Transformation sees lower demand for bioenergy for heat than Leading the Way due to higher heat pump uptake.

Figure ES.46: Bioenergy demand by sector in Consumer Transformation



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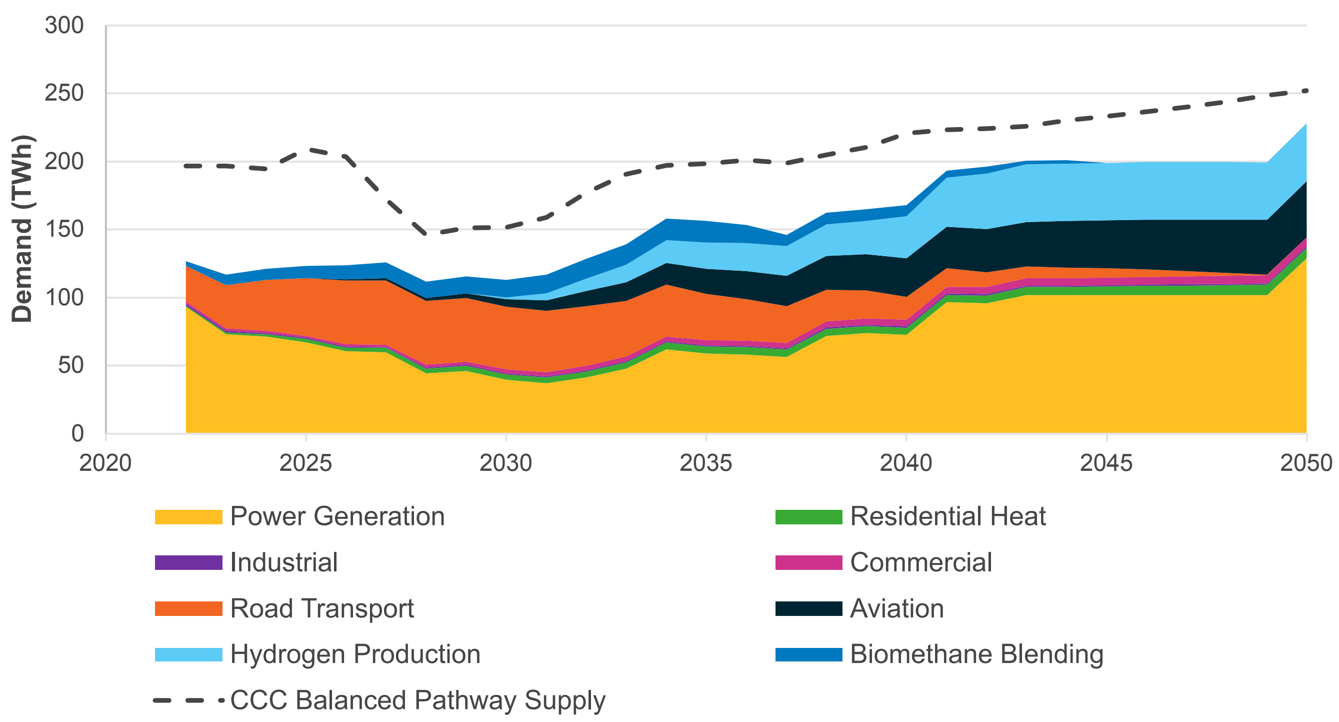
System Transformation

Bioenergy demand is highest in System Transformation due to the high demand for low carbon molecules to replace natural gas. While natural gas is predominantly replaced with hydrogen, bioenergy has a key role to play in both the production of low carbon hydrogen and replacement of natural gas in other applications.

System Transformation sees the highest bioenergy demand for hydrogen production with the first biomass gasification projects coming online in 2030. Annual BECCS enabled hydrogen supply grows from 1 TWh in 2030 to 40 TWh in 2050.

The Green Gas Support Scheme runs until 2040/42 but new entrants won't be accepted after 2025. System Transformation sees the highest bioenergy demand for biomethane production up to 2032 before falling from 2035 onwards as hydrogen replaces the use of methane in many applications. Bioenergy demand for biomethane blending falls to zero in System Transformation in 2050 for the same reason.

Figure ES.47: Bioenergy demand by sector in System Transformation



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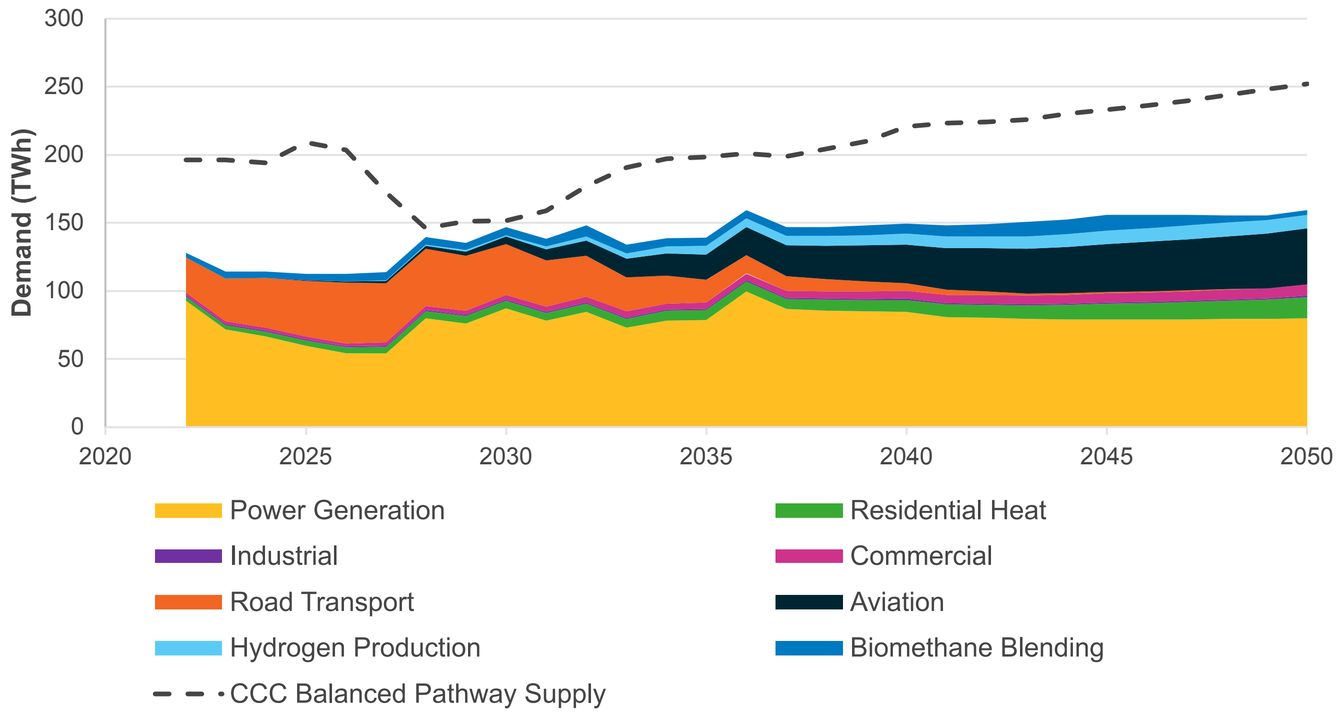
Leading the Way

Leading the Way sees the lowest levels of demand for bioenergy for hydrogen production and power generation of all our net zero scenarios. This is due to lower overall demand caused by increased levels of electrolytic hydrogen production and a greater emphasis on reducing net demand through societal change, alongside the greater role of DACCS and LULUCF in delivering negative emissions.

Bioenergy has the potential to play a larger role in domestic heating than today, but this must be balanced against the availability of alternative low carbon technologies, sustainability considerations and regional circumstances. While the role of bioenergy for domestic heat is low across all our net zero scenarios, Leading the Way sees the highest bioenergy demand for heat, with 16 TWh of demand by 2050 for district heating. This is compared to 11 TWh in Consumer Transformation and 8 TWh in System Transformation.

Bioenergy use in road transport reduces in all scenarios out to 2050 but the reduction is quickest in Leading the Way due to a faster move away from Internal Combustion Engines (ICEs).

Figure ES.48: Bioenergy demand by sector in Leading the Way



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Falling Short

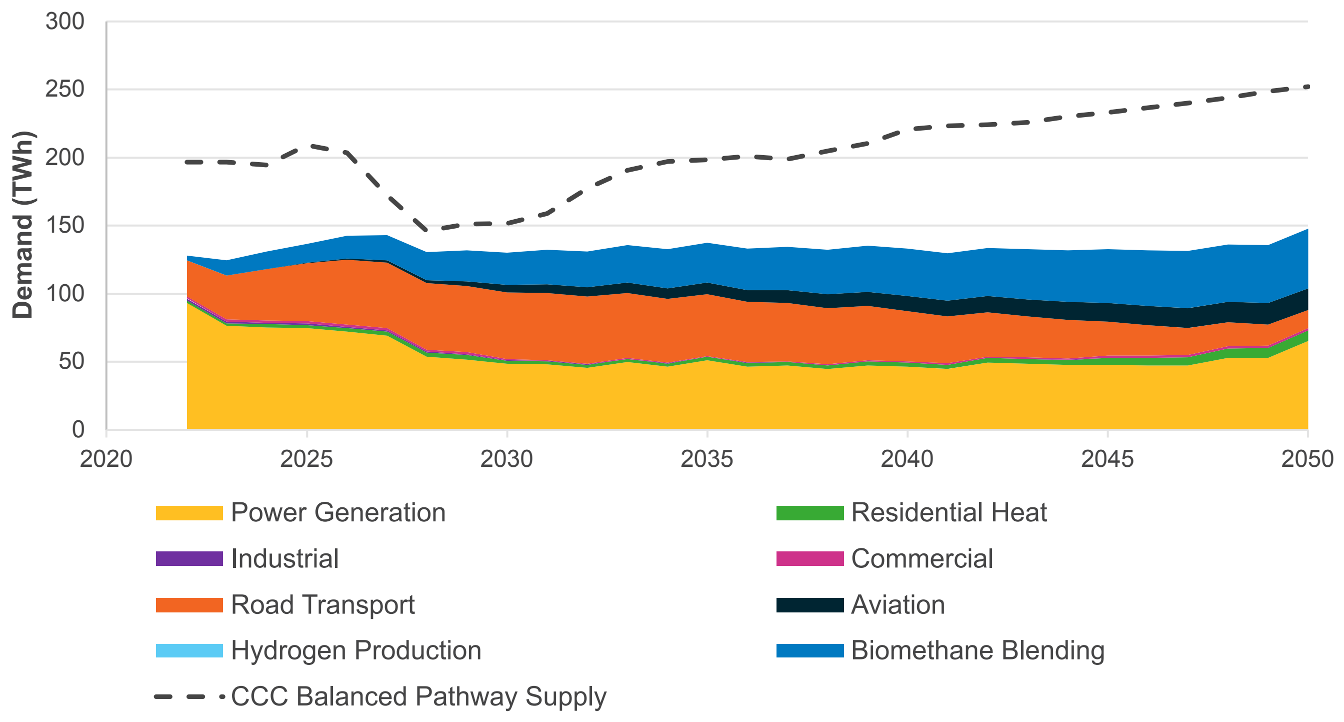
Bioenergy is not used for hydrogen production in Falling Short due to very low demand for hydrogen.

Falling Short sees the lowest demand for bioenergy for heat due to the continued use of gas boilers.

This scenario also sees the highest bioenergy demand for biomethane production which is blended into the National Transmission System. Demand rises steadily to become just under 30% of total bioenergy demand in 2050.

Falling Short sees the lowest bioenergy demand for power generation which falls in the short-term as seen in our net zero scenarios but remains relatively flat out to 2047 without the development of negative emissions business models and widespread CCS infrastructure.

Figure ES.49: Bioenergy demand by sector in Falling Short



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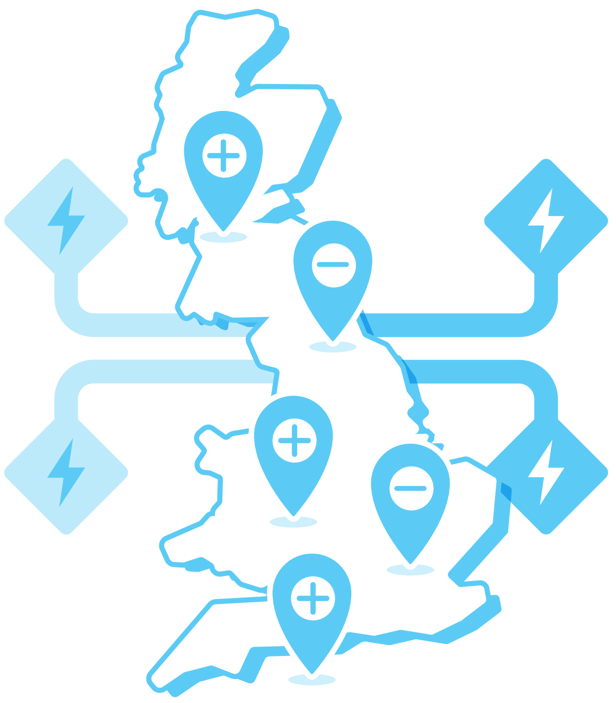
Strategic network investment

The future network will need to be developed strategically, to cater for the different characteristics of technologies, such as greater weather dependency of renewable generators, generation being located further from the current centres of demand and the opportunity to locate large demand closer to generation.

Future changes in generation and demand create new challenges in moving power across the country and between regions. Our scenarios this year continue to show growth in renewable generation out to 2050 with offshore wind accounting for a significant proportion of this growth. Growth in large demand technologies such as electrolysers will require us to take a whole energy system approach across gas and electricity to optimise the future level of network investment and minimise network constraints.

We are transitioning to a more centralised and strategic approach to network planning.

Our network planning process is undergoing major transformation as we transition to the Centralised Strategic Network Plan. This is being developed as part of our Network Planning Review in collaboration with Ofgem's Electricity Transmission Network Planning Review (ENTPR). The CSNP will proactively identify, design and progress investments in the network and will ensure that the transmission network is planned holistically, onshore, offshore, and across vectors. The options assessment will be adapted as part of the CSNP to create a level playing field whereby network options are assessed against third party and innovative solutions. In addition to economic assessment, the CSNP will also consider environmental and community factors earlier in the planning cycle.



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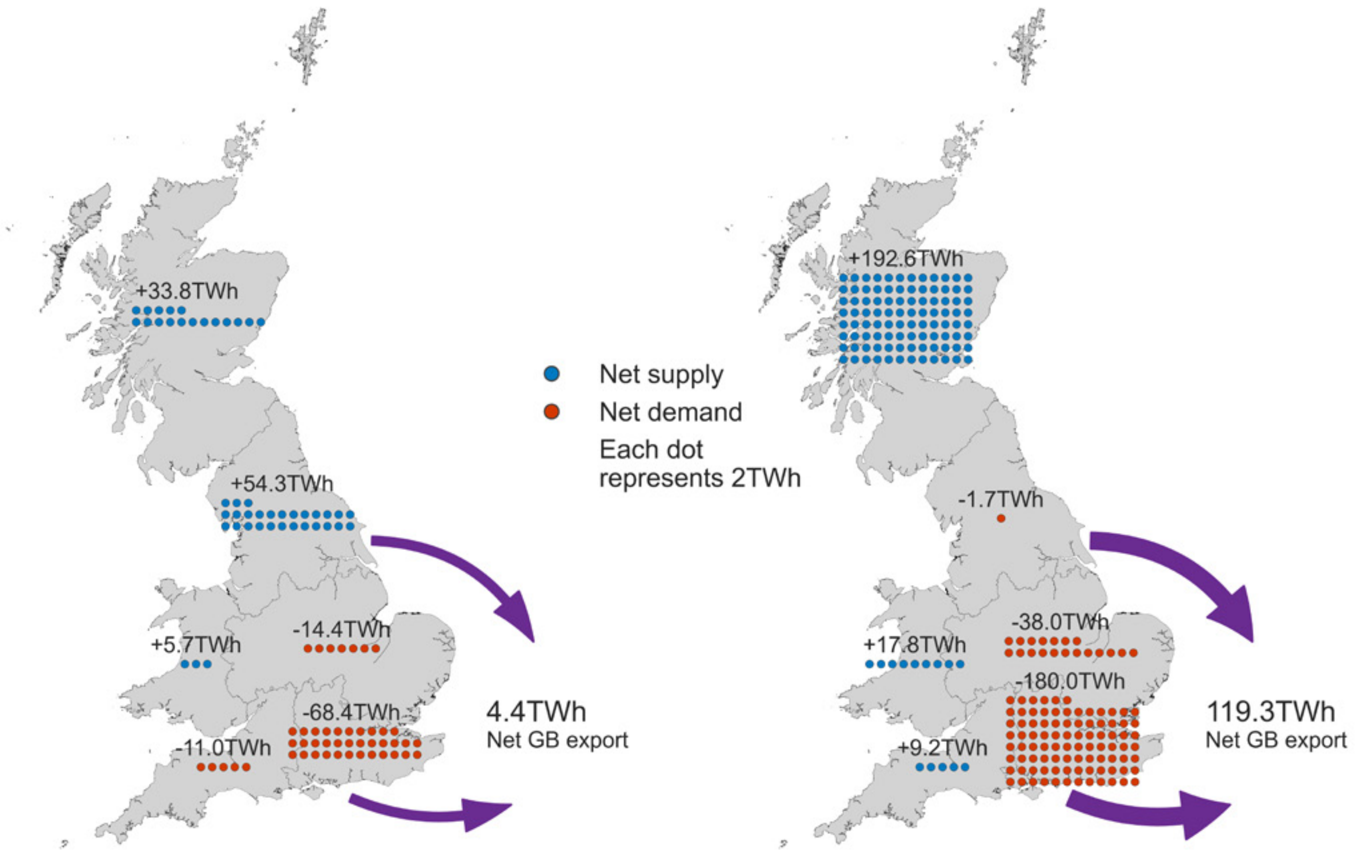
Strategic network investment

As part of the CSNP, we will develop capabilities to facilitate the co-optimisation of electricity, gas and hydrogen to find efficient whole energy system solutions. We summarise below the progress to date in our transition to a new Centralised Strategic Network Plan.

- The first transitional Centralised Strategic Network Plan (tCSNP1) was published in July 2022. This included the Holistic Network Design (HND) and the Network Options Assessment (NOA) 2021/22 Refresh. The HND proposed a coordinated approach for connecting 24 GW of in-scope offshore wind and together with the NOA refresh, we provided an offshore network design and a set of onshore network investment recommendations required to deliver the UK Government's ambition for 50 GW of offshore wind by 2030.
- The second transitional Centralised Strategic Network Plan (tCSNP2) is planned for December 2023. This will include the recommendations of the HND follow-up exercise that looks to design a connection for an additional 20.7 GW in Scotland.
- Following the publication of Ofgem's 'Decision on the initial findings of our Electricity Transmission Network Planning Review' in November 2022, we expect Ofgem to undertake further consultation on the next level of detail of the CSNP and continue to support the process to establish the Future System Operator responsible for delivering the CSNP.

To find out more about the CSNP or the Network Planning Review contact us at: box.NPR@nationalgrid.com.

Figure ES.50: Locations of electricity generation output and demand in Leading the Way in 2022 and 2035



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Connections

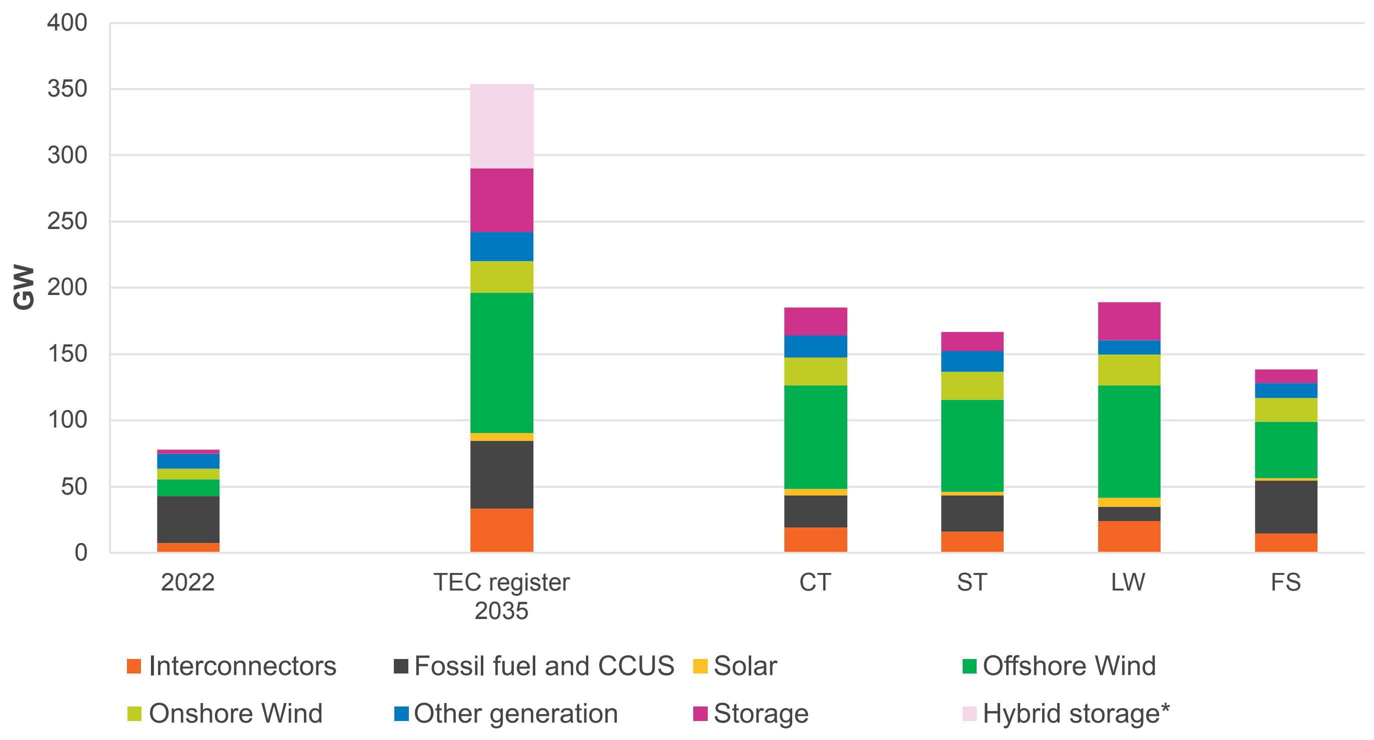
Connections reform is required to facilitate quicker, more coordinated, and efficient connection to the GB electricity system to support the delivery of net zero. Continued collaboration between Government, Ofgem and industry is critical. The process must be future proofed to facilitate potential prioritisation of connections for delivery of whole energy system benefits and net zero in line with strategic network planning.

Delivering net zero will require connecting new capacity and new types of customers more quickly than at any time since the current process was established. Incorporating this new generation and demand will give rise to an increasing volume of connections, as well as significant shifts in the nature of connecting customers and their needs.

The amount of generation capacity contracted to connect between now and 2035 significantly exceeds even the highest FES scenario estimates. Up to 189 GW of capacity would be needed by 2035 under the 'Leading the Way' scenario. The Transmission Entry Capacity (TEC) register (which excludes most generation connected to the distribution system) indicates over 350 GW of capacity is already contracted, of which 80 GW has already connected.

Levels of fossil generation in the TEC register in 2035 outstrip levels in Falling Short but these would also include existing plant with plans to retrofit CCUS. Storage capacity in the TEC register for 2035 far exceeds the levels required in Leading the Way but duration of storage is not clear.

Figure ES.51: Installed transmission generation capacity and scenario projections compared to TEC register pipeline



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Connections

Based on previous experience, not all of the capacity within the TEC register would be expected to connect, for instance with customers submitting modification applications to push back contract dates, or simply terminating contracts. Uncertainty regarding if and when contracted capacity will come forward is therefore making it harder to plan the system and deliver net zero.

A one-size-fits-all and first come first served connections process means all applications are treated the same, regardless of their likelihood of progressing to connect. This takes up space in the queue and ultimately leads to customers making more speculative applications to secure their place.

In December 2022, at the conclusion of Phase 1 of our connections reform programme, we published our Case for Change[21] to set out the concerns that customers and stakeholders have with the connections process.

Some of these concerns are in the process of being addressed by other industry initiatives, including our 5-Point Plan. However, further change is required and as part of Phase 2 of the connections reform programme a consultation has been published to set out how those concerns can be further addressed by a reformed connections process. We would welcome your views on our proposed recommendations through our live consultation.

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21 nationalgrideso.com/document/273021/download

5-Point Plan

We are working hard to make as many improvements as possible to our connections process under the current frameworks. Our 5-Point Plan[18] includes a range of initiatives to seek to reduce the size of the current queue to connect to the transmission system and the overall timescales for connection. We anticipate 70% of the pipeline of connecting projects, which currently have a connection date after 2026, will be able to connect between 2 and 10 years earlier because of these changes. This plan is:

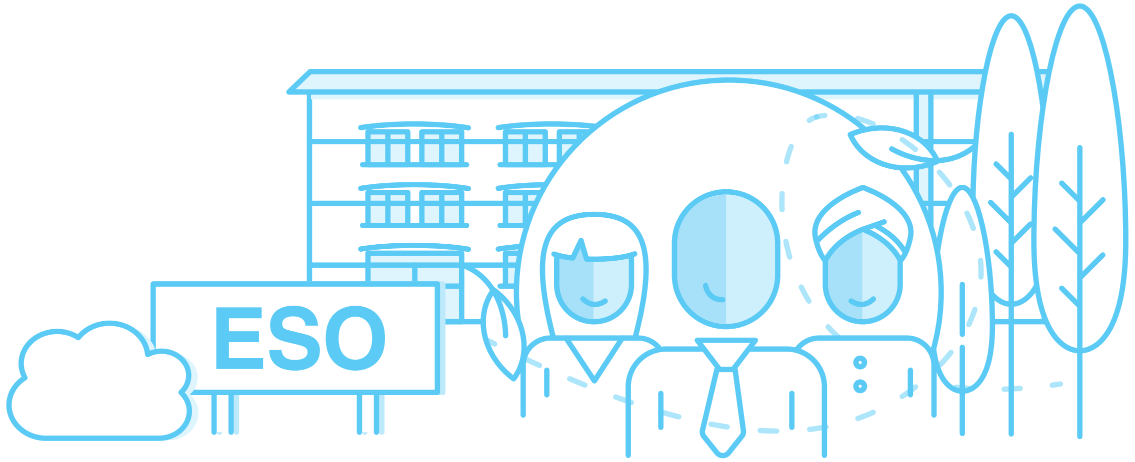
Allowing customers to leave our queue without incurring penalties for doing so. This amnesty closed in April 2023 and received over 8 GW of interest – alleviating pressures within the pipeline of projects. This action has now been completed and Ofgem are working to approve these contract terminations.

We are updating how we calculate project connection dates. This action has been completed and we are working with GB's Transmission Owners (TOs) to review and update existing contracts with these new Construction Planning Assumptions (CPAs).

Batteries and other energy storage technologies soak up energy generation when connected to the grid as well as releasing it back onto the grid. As this technology has a dual purpose, we have changed how we calculate its impact on the system.

We are developing new contractual terms for connection contracts to manage the queue more efficiently, so those projects that are progressing can connect and those that are not can leave the queue. The proposals have now been consulted on; we are preparing the final paper to go to Ofgem soon.

And finally, we are enabling energy storage projects to connect to the grid more quickly. This will speed up connections for up to 95 GW of energy storage projects in the pipeline. To ensure system security, they may be instructed to reduce their output, however, only on very rare occasions.



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18 nationalgrideso.com/industry-information/connections/connections-challenges-what-are-we-doing-now

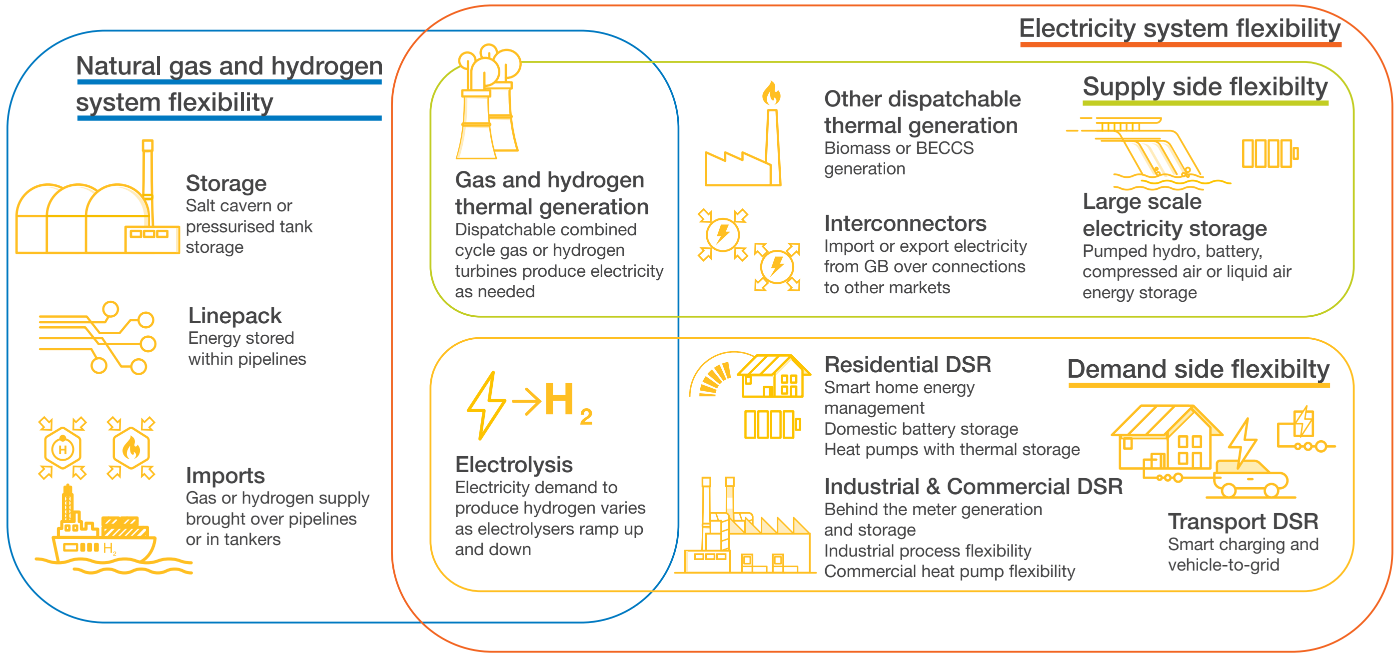
Flexibility

Introduction

Over the last few years, the government has set interim targets to ensure the country is on track to reach net zero by 2050. One of these targets is that Great Britain must generate all its electricity from clean energy sources by 2035. The associated increase in weather dependent generation, coupled with variations in demand and increased electrification, introduces the need for higher levels of flexibility.

Flexibility is defined in FES as the ability to shift the consumption or generation of energy in time or by location.

Flexibility is crucial to operating the energy system where the supply and demand of energy needs to be balanced over different timescales, from seconds to hours, days and seasonally to ensure efficient operation of the system.[1] Bridging the Gap 2022 highlighted the need for flexibility and for broad and large-scale investment to start now to facilitate its further deployment and the role in managing supply and demand.[2]



The UK's electricity networks are currently demand-led which means supply is increased or decreased to meet demand. In the future, with greater volumes of weather dependent generation on the electricity system, demand will need to shift to follow supply, with storage also helping to smooth out variation in available generation. Demand will need to be increased or decreased to meet supply which will require higher levels of consumer engagement. Many consumers are already willing to make changes that will help Great Britain reach net zero faster, whether through purchasing domestic solar PV (Photovoltaic) systems or buying an electric car and responding to price signals to alter their energy use. However, consumers must be supported to develop greater awareness of how they can further engage in the energy transition.

1 Operability Strategy Report, ESO: nationalgrideso.com/document/273801/download
2 nationalgrideso.com/future-energy/future-energy-scenarios-fes/bridging-gap-net-zero/bridging-gap-net-zero-flexibility

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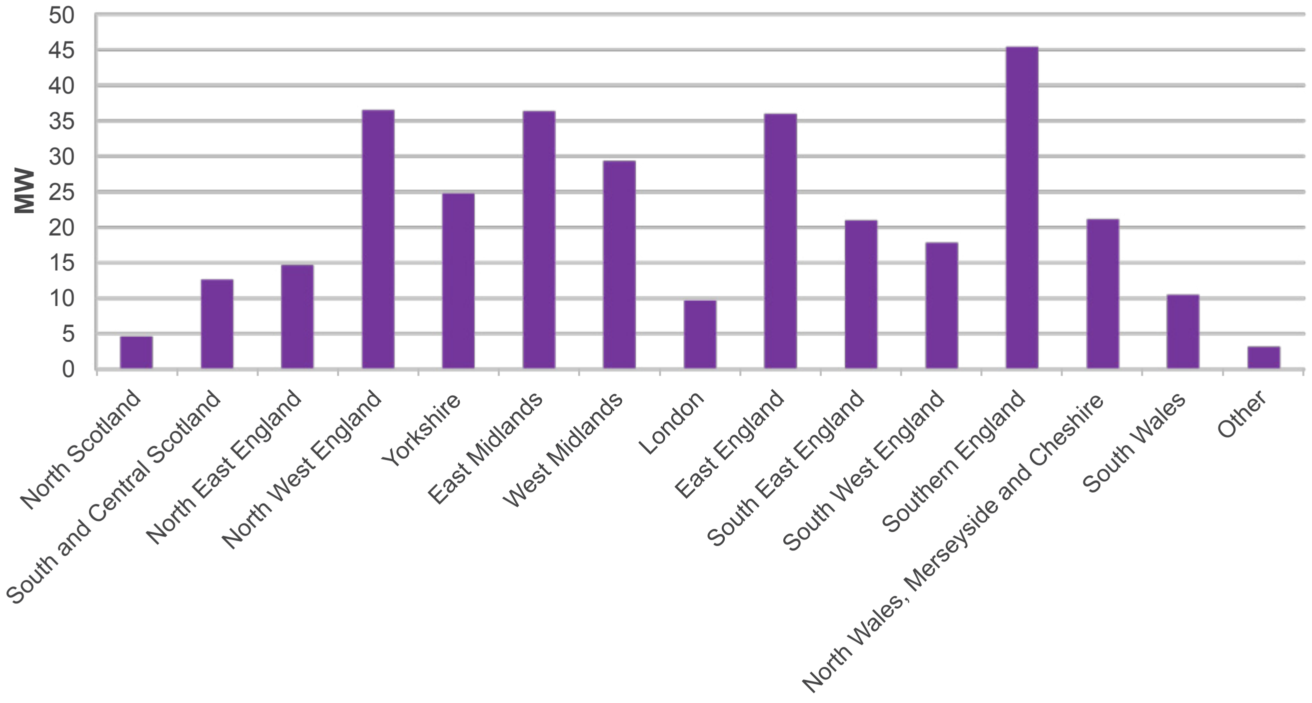
Introduction

For the first time, we saw over a million consumers participate in the Demand Flexibility Service (DFS), launched during November 2022 by the ESO and adopted by energy suppliers, aggregators, and technology organisations. DFS has been used to manage national demand when it is at its highest during peak winter days. DFS provided significant levels of Demand Side Response (DSR) and contributed to energy balancing[3] (example given for 23rd of January 2023). As low carbon technologies, such as smart meters, heat pumps, Electric Vehicles (EVs), and batteries, become more widely available and affordable, they will continue to increase the importance of consumer participation, with the necessary automation, and to transform the way energy is being used today.

Alongside DSR from various sectors and large-scale energy storage, other technologies that support a transition to net zero (such as interconnectors), can provide flexibility from the supply side. In all scenarios apart from Falling Short, hydrogen is used for flexibility. This is achieved by using weather-dependent supply (i.e. renewable generation) to store energy in the form of hydrogen, which can then be used to meet additional demand needs. The correct siting of flexible assets, mostly of long-duration, across all sectors has the potential to reduce the investment required for the management of network constraints and bring down the cost of energy for consumers. More information regarding the definition and the different types of flexibility are given in the Energy Background Document (EBD).

Higher levels of flexibility will be needed to efficiently manage supply and demand, as we move towards net zero. Currently, not all forms of flexibility have the right route-to-market and market signals required for their delivery. For some flexible technologies, such as Long Duration Energy Storage (LDES) and DSR from various sectors, investment and market reform are needed in the short-term to ensure delivery in the 2030s and 2040s.

Figure FL.01: Example of the DFS scheme, launched by ESO during November 2022



Our FES 2023 analysis and stakeholder feedback show that we remain within the credible scenario of long-term ranges of FES 2022. We took a deeper look at the short-term trajectory and present new analysis of key issues we face on the path to net zero in this chapter.

3 nationalgrideso.com/industry-information/balancing-services/demand-flexibility-service-dfs

Key insights

Improved market signals and new distributed flexibility solutions are key to managing a secure, net zero energy system at the lowest cost to the consumer.

Changes to the scale of flexibility are needed:

- Operating a future energy system with high levels of renewables and no unabated natural gas generation will require significantly more flexible, zero carbon capacity than we have today. New technologies will need to deliver the services historically provided by natural gas.

- Increasingly, peak demand will not be the only driver of system stress. It will be driven as much by peaks and troughs in electricity supply and flows. As a result, the imbalance between supply and demand, which does not correlate with these peaks and troughs will also be important. All of these will play a key role when planning and operating the system as we transition to net zero.

- Large amounts of short-duration flexibility will be needed to match supply and demand within the same day. During periods of high or low renewable generation, greater amounts of within-day flexibility will be needed. During extreme weather events, flexibility will be needed for weeks, and a diverse set of flexible solutions is needed to ensure adequacy in these extreme periods.

Distributed flexibility and Demand Side Response:

- The growth of distributed flexibility (flexible energy demand resources, such as storage, EVs, heat pumps and thermal storage connected at distribution level) is a key enabler to achieving net zero.

- Demand side flexibility will be increasingly important. The Demand Flexibility Service showed consumer willingness to participate in DSR, but this was only the starting point. Appropriate market signals and technology advancement are needed to ensure effective DSR levels in the future. DSR potential of 6-12 GW is predicted by 2040 from residential, commercial, and industrial sectors in our net zero scenarios.

- Across all net zero scenarios, cars are primarily electrified, increasing electricity demands and requiring strategies to manage how they are charged, and how system costs are distributed. Increasing implementation of smart EV charging is an essential action to help reduce the impact on peak demand and reduce curtailment of renewables.

- Commercial trials of Vehicle-to-Grid (V2G) business models are required to explore their viability and contribution system services. It also requires current challenges to be addressed, such as the slow rollout of charging infrastructure.

- Management of peak electrical demand for heat, and its level of flexibility, will be an important factor in the extent to which heat can be electrified. The amount of heat flexibility is limited in the short-term, especially after 2025, due to a decrease in electric storage heaters after that date. The uptake of heat pumps and thermal storage is not sufficient to outpace this, meaning an increased roll out of heat pumps will be required. In the later years, between 10-12 GW of heat demand could be flexibly managed in 2050 from the residential sector alone. It is crucial to provide a greater understanding of the interactions between housing heat flexibility solutions and the performance of heat pumps for different housing stocks and weather conditions to better estimate the consumer heat flexibility potential.

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Key insights

The importance of energy storage:

- Electricity storage at both transmission and distribution level is an efficient way to manage supply and demand by reducing the amount of generation and network investment needed to decarbonise. The amount of electricity storage in the network in the short-term is largely driven by new battery storage projects winning contracts in the Capacity Market (CM).
- Longer-term needs are driven by prolonged periods of low wind and met by longer duration assets, as battery storage alone will not be sufficient to ensure adequacy during stress periods. We see a minimum of 30 GW of storage by 2050 in our net zero scenarios, comprised of different storage technologies to fit different applications. Such applications include fast-acting response for inertia/frequency stabilisation purposes, within-day balancing (moving energy between days as the weather changes) and ensuring adequacy needs are met across the seasons.
- Prolonged low renewable-output periods will cause stress in the system. Interconnectors and Long Duration Energy Storage could make a significant contribution to managing supply and demand and ensuring security of supply in the 2030s. Considerable uncertainty remains, around the policy, market structure and financial support mechanisms needed in the short-term to facilitate LDES deployment later in the 2030s and 2040s.

Markets and whole energy system investment:

- Market reform is needed to provide the locational signals required to optimise dispatch and incentivise new investment in the best locations to support a flexible, whole energy system.
- With suitable market reform, market wide half-hourly metered settlements and automation, consumers will be able to reduce their energy costs at the same time as reducing the costs of operating the energy system.
- Investment in locational flexibility is needed in the near-term as energy storage, interconnectors, DSR and electrolysis can deliver more value in some locations than others and help reduce curtailment.
- Large electrical demands, such as electrolysis, Direct Air Carbon Capture and Storage (DACCS) and data centres can also be used to absorb excess electricity at times of oversupply. A coherent strategy is required to ensure large electricity demands are located where they provide the biggest benefit to consumers and the whole energy system.
- Large-scale energy storage supports security of supply and is essential to meeting net zero, but the amount needed is dependent on the rollout of hydrogen, hydrogen storage, and other sources of flexibility available in each modelled scenario.

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Flexible solutions between now and 2050

As the UK moves towards net zero, greater volumes of renewable generation and further electrification will increase the net requirement for flexibility. Flexibility will become more important in ensuring a reliable and low carbon energy system.

Flexibility will play a range of roles in the future, including storing energy through seasons, covering extended periods of extremes in high demand or low supply, and charging and discharging over minutes or less to maintain operability of the electricity network.

This increased need for flexibility over a range of durations and scales presents both a challenge and an opportunity for the future whole energy system. As the UK approaches net zero, natural gas will no longer be able to provide the flexibility it has in the past. However, innovation is leading to a range of new technologies which can help provide this flexibility, often over a range of scales and durations.

The graphic on the following page highlights some of these technologies, the issues they can help manage, the duration over which they must operate, and the scale of requirement. The role of these technologies will be investigated further in the following sections.

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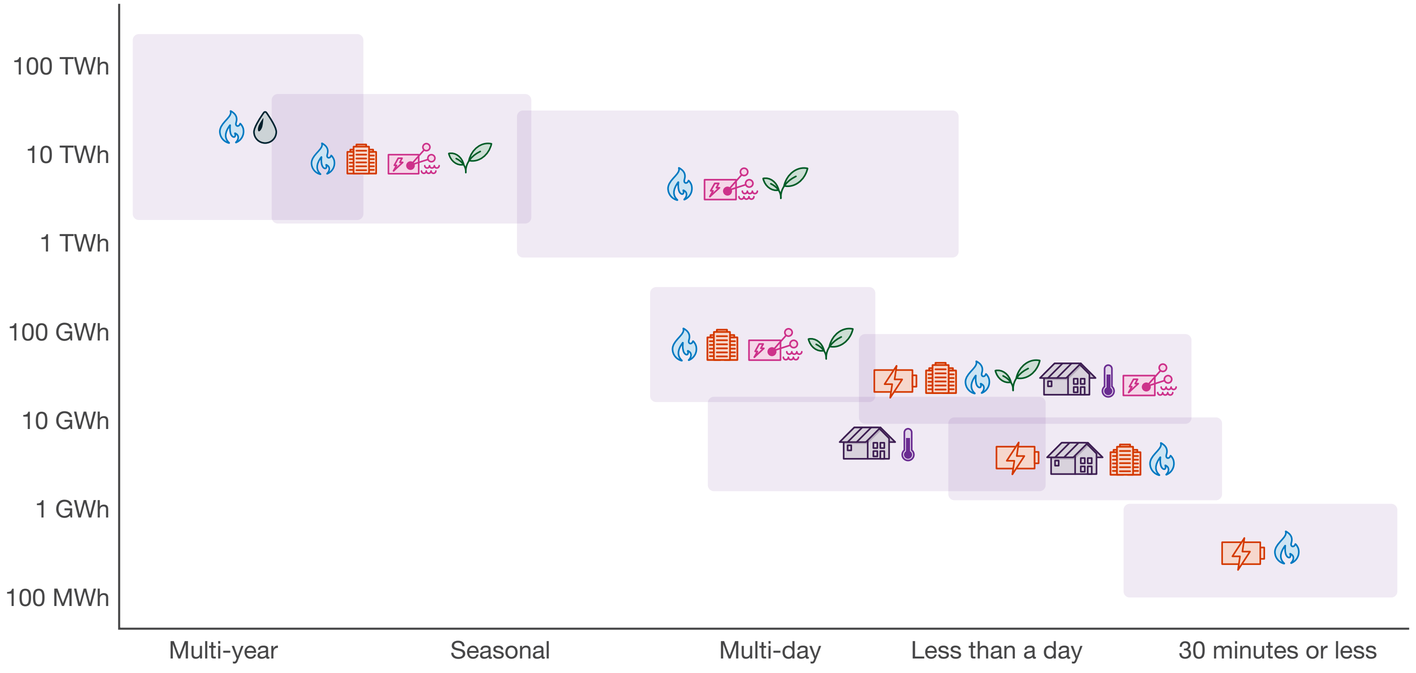
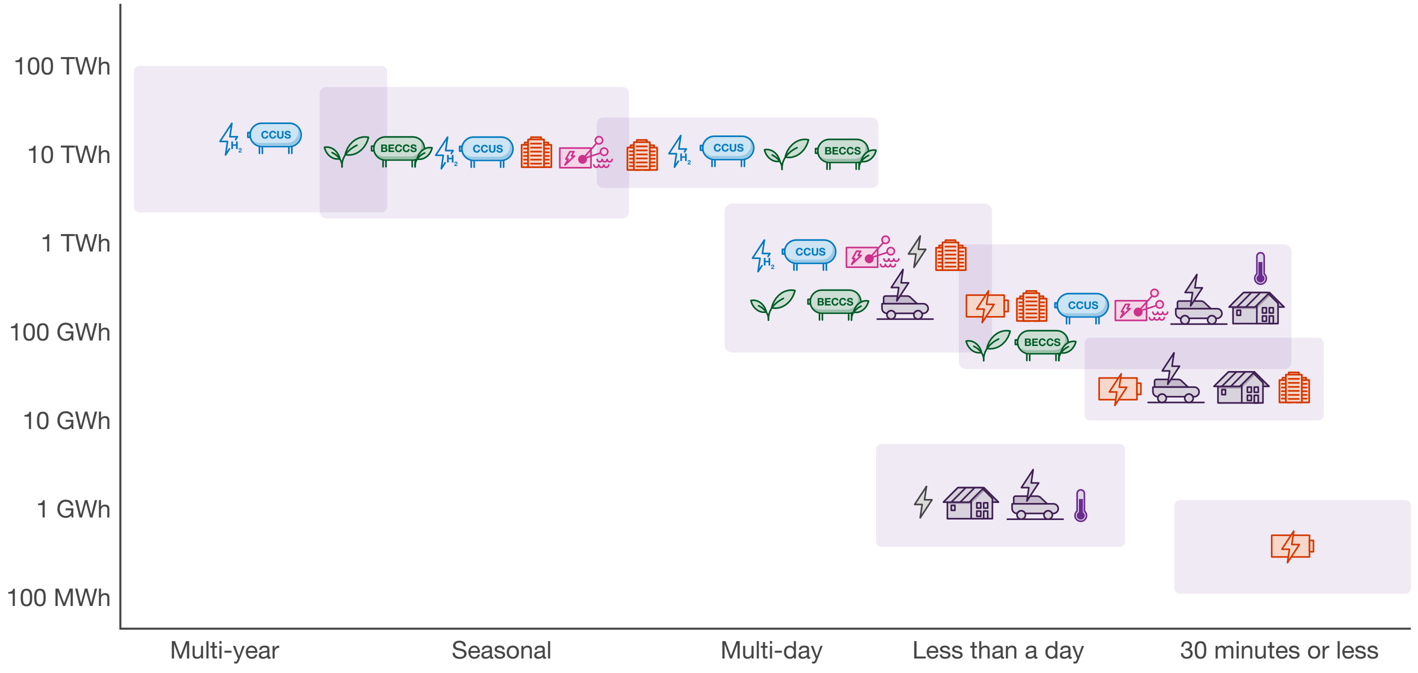
Flexible solutions between now and 2050

Flexibility requirements in 2023



Flexibility requirements in 2050



Key:

Electricity storage: Batteries Long Duration Energy Storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**

Electrolysis: **Thermal energy storage:** **Oil:** **Demand Side Response:** Domestic or industrial EV flexibility

Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

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Consumer Demand Side Response

The residential, commercial and industrial sectors are expected to offer increased levels of demand flexibility in the future. We define that as consumer Demand Side Response which has a key role to play in Great Britain's transition to net zero.

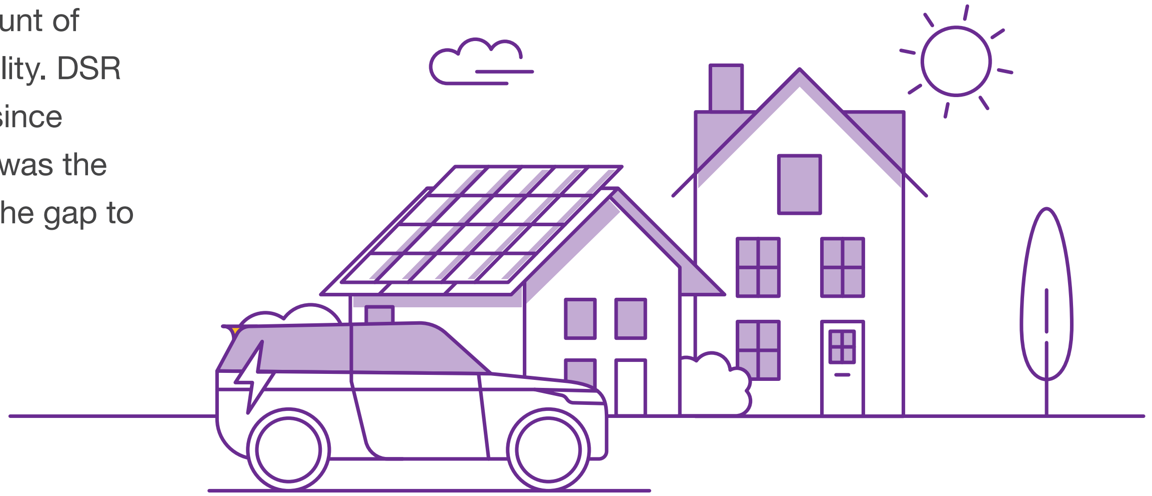
Consumer engagement plays a crucial role in the transition towards a sustainable and secure energy system, while reducing energy costs. Leading the Way and Consumer Transformation see high levels of societal change with consumers being a driving force in reaching net zero, through their increasing awareness of how to engage in the energy transition. This includes becoming more engaged with DSR services, driving electric cars and installing low carbon heating systems. We experienced the latter with the DFS service that was launched by ESO during November 2022.

As we approach 2050 and greater volumes of renewable generation are connected to the grid, DSR services will become increasingly important to help balance supply and demand during peak times. However, to ensure that customers can engage with DSR services in the 2030s and 2040s, the necessary automation, technological improvements and improved market signals are needed.

Figure FL.02 shows the consumer DSR contribution out to 2050. In the short-term we see industrial and commercial DSR and DFS, a part of which is residential DSR (lighting, appliances, smart charging, and heat). Leading the Way and Consumer Transformation present the highest consumer engagement and therefore, DSR levels. Falling Short is the scenario where we are expecting the least amount of decarbonisation, electrification and therefore flexibility. DSR levels ramp up in 2024 and 2025 for this scenario, since margins were deemed to be tight. Therefore, there was the expectation that DSR would be required to bridge the gap to meet Loss of Load Expectation (LOLE).

Overall, across the scenarios there is uncertainty in the range of projections in the next 5-6 years, but we observe more peak demand reduction than in the previous years because of potential participation in the DFS or a similar service.

For the next ten to fifteen years, there is a significant growth in consumer DSR flexibility. This includes potential development in the markets and systems which lead to improvements in consumer DSR, such as digitalisation, market reform and the market wide half-hourly settlement system.



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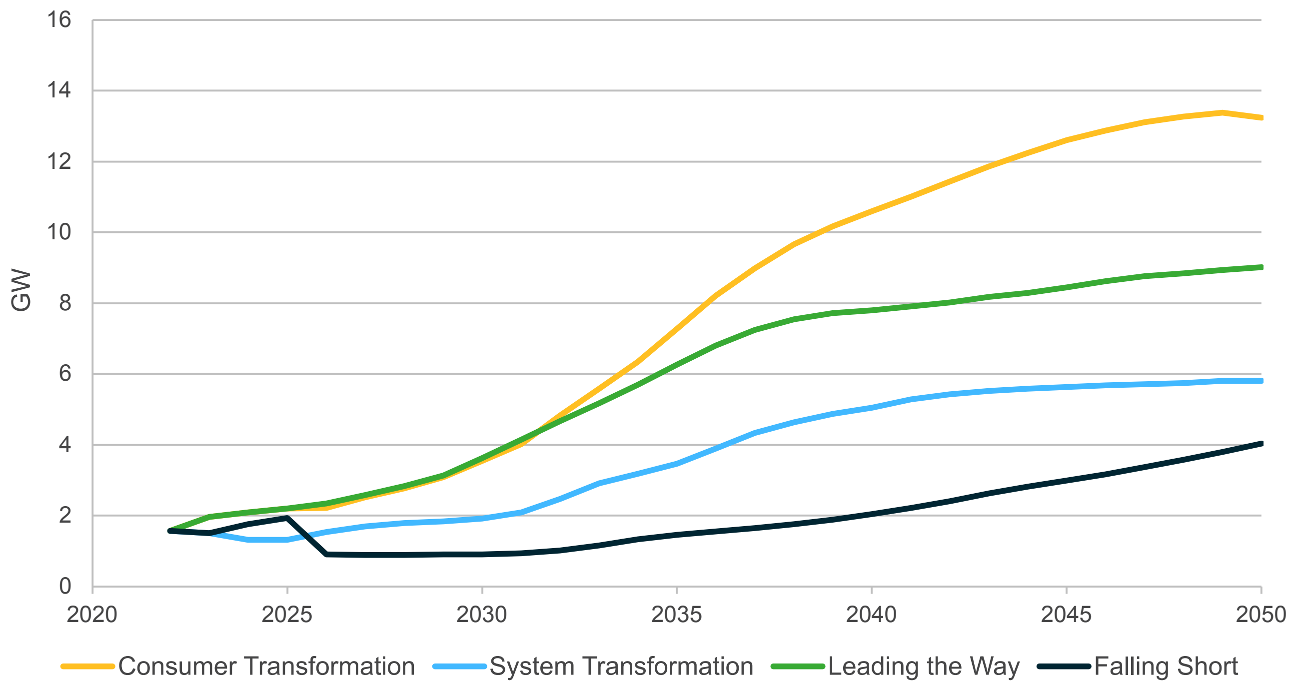
Consumer Demand Side Response

Over the next ten to fifteen years, there is growth in DSR across all scenarios. In Falling Short, the DSR market develops slowly over time. In System Transformation, a significant proportion of consumer demand, especially for the industrial and commercial sectors, moves away from electricity and onto hydrogen.[4] This results in lower electricity demand levels available for DSR flexibility relative to the other net zero scenarios. Therefore, of the net zero scenarios, System Transformation has the lowest DSR levels.

In Consumer Transformation, consumer demand electrifies as much as possible, particularly in the areas of residential heating, commercial heat pumps and other secondary systems which are potentially available for DSR. This scenario has the highest consumer electricity demand of the FES 2023 scenarios and therefore the highest levels of DSR over the future years.

Although lower than Consumer Transformation, Leading the Way also has relatively high levels of DSR as this scenario reflects a rapid drive to be efficient and smart system as possible.

Figure FL.02: Demand Side Response from residential, commercial and industrial sectors in the long-term



4 For more information on the electricity and hydrogen demand levels per scenario and different sectors (residential, commercial and industrial), please see our Energy Consumer chapter here

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Transport flexibility

Transport flexibility through smart charging and Vehicle-to-Grid, will play an important role in the future energy system. Across all scenarios, cars are primarily electrified, increasing electricity demand, and requiring strategies to manage how they are charged, and how system costs are distributed. This presents an opportunity to increase system flexibility, integrate renewables and better match supply and demand. With suitable incentives and automation, drivers will be able to reduce their transportation costs at the same time as reducing the costs of operating the energy system.

Most of the flexibility value provided by EVs comes from vehicles charging at home overnight, although commercial vehicle fleets or workplace EV chargers can play a greater role at other times of day. During the daytime we expect some commuters to plug in their cars at work. Smart optimisation of EV chargers can benefit consumers and the energy system, ensuring that vehicles maximise the use of low carbon and low cost electricity. Commercial fleet operators are also incentivised to keep running costs low and providing flexibility from smart charging and V2G can support this. Increasing demand through smart charging at times of high renewable output could be as valuable to the energy system as reducing peak demands.[5]

We remain positive about engagement in the short-term using measures such as mandating that home charge points be smart enabled and half-hourly metered settlements are in place. Further information and data availability on how to smart charge, its benefits and how to select a tariff could help consumer engagement in this direction. It is important to gain a better understanding of the current consumer engagement levels, i.e., the number of consumers who currently own an EV and/or have a smart tariff. Overall, smart chargers and automation will make the transition to smart tariffs simple for consumers, both in relation to domestic chargers and centralised charging hubs.

It is also important that we have the right market design. Market reform is required to give granular price signals by time and location, accurately reflecting system conditions close to real time. This will help to avoid unintended consequences such as many EVs (or other DSR technologies) responding to a price signal at the same time, leading to fluctuations in frequency which could cause system operation issues.

The peak demand reduction from smart charging in the short-term is shown in Figure FL.03, where we observe lower transport DSR levels until 2030. Better information on consumer engagement in smart charging would be required to draw conclusions on the DSR behaviour in the short-term.

5 For more information on the charging types, and the availability of off-street parking and home/public/hub chargers, please see the Energy Consumer chapter here

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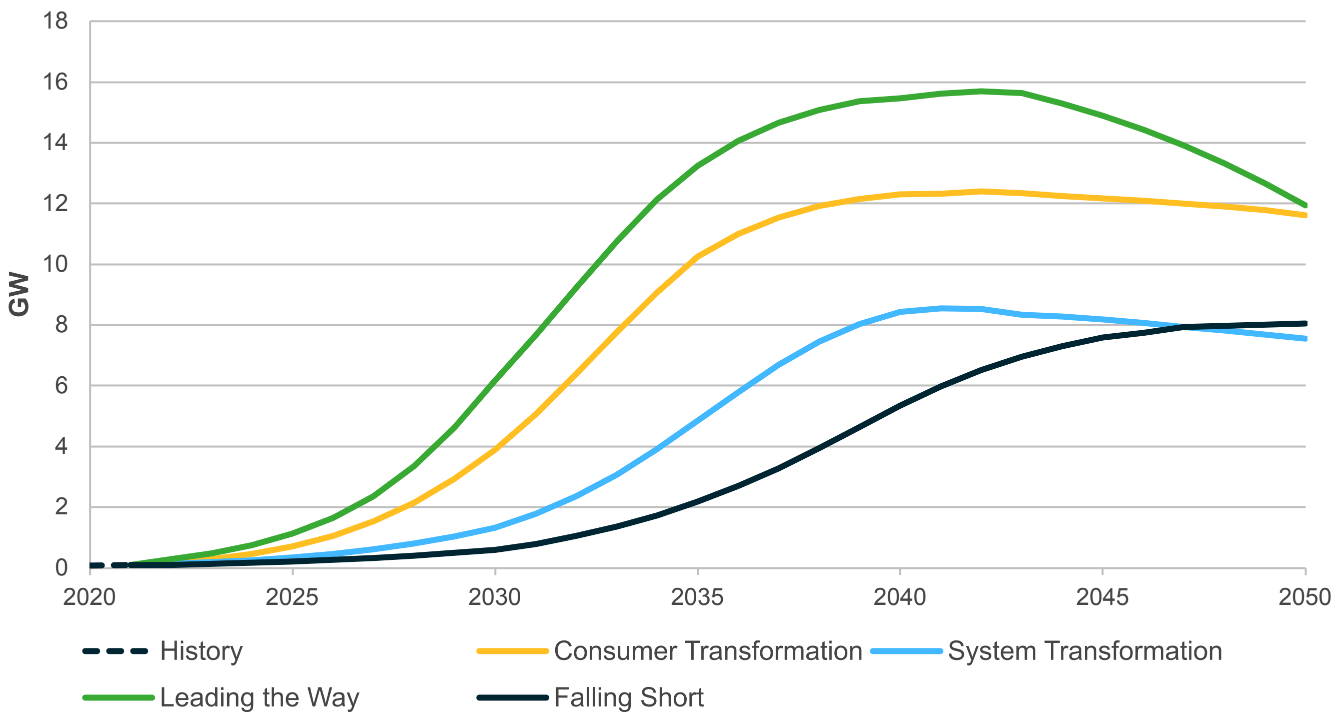
Transport flexibility

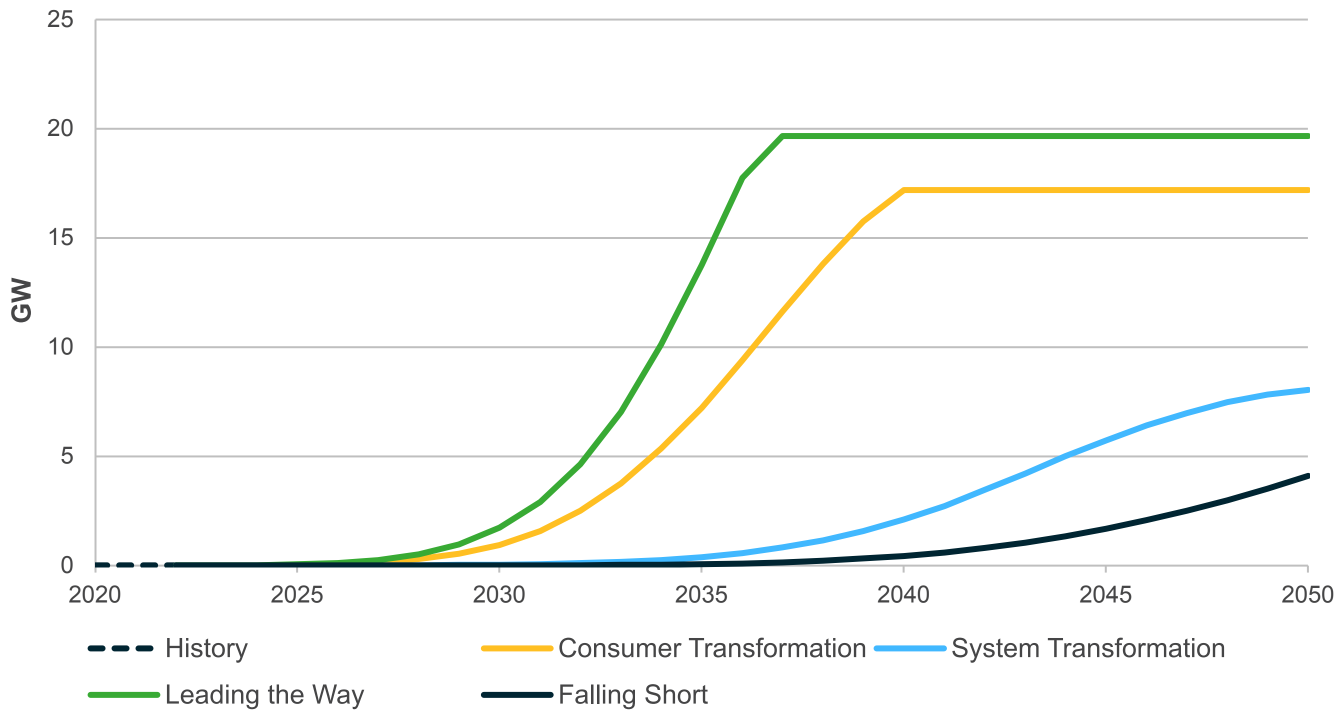
Figure FL.03: Demand Side Response from the transport sector (smart charging)



As V2G is still a new technology, there remains uncertainty in the short-term over when it will begin to provide flexibility to the electricity system. After the 2030s, it grows very rapidly to reach 17-20 GW at the end of this decade under our scenarios with the highest consumer engagement.

As shown in Figure FL.04, we assume that prior to 2025, V2G volumes are negligible as this is when we expect barriers to be overcome such as bi-directional charging and market wide half-hourly settlement. We only expect volumes in the meantime to be from small scale trials. In the short-term, forecasts of less than 0.2 GW are available from V2G capacity at peak in 2028. We believe this is possible due to on-going trials, but it will need to be accompanied by a reduction in the cost of bi-directional chargers, additional commercial trials and an increase in business models available to consumers.

Figure FL.04: Demand Side Response from the transport sector (Vehicle-to-Grid)



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Consumer heat flexibility

Thermal energy storage can be used to reduce electricity demand at times of low supply or peak demand, or to increase it at times of higher supply. For example, a heat pump warms a hot water tank or a dedicated thermal store when prices are low, which then supplies heat to the house for 3-4 hours over a system stress period. Increased electrification of heat demand occurs across all scenarios, and so thermal storage will become increasingly important.

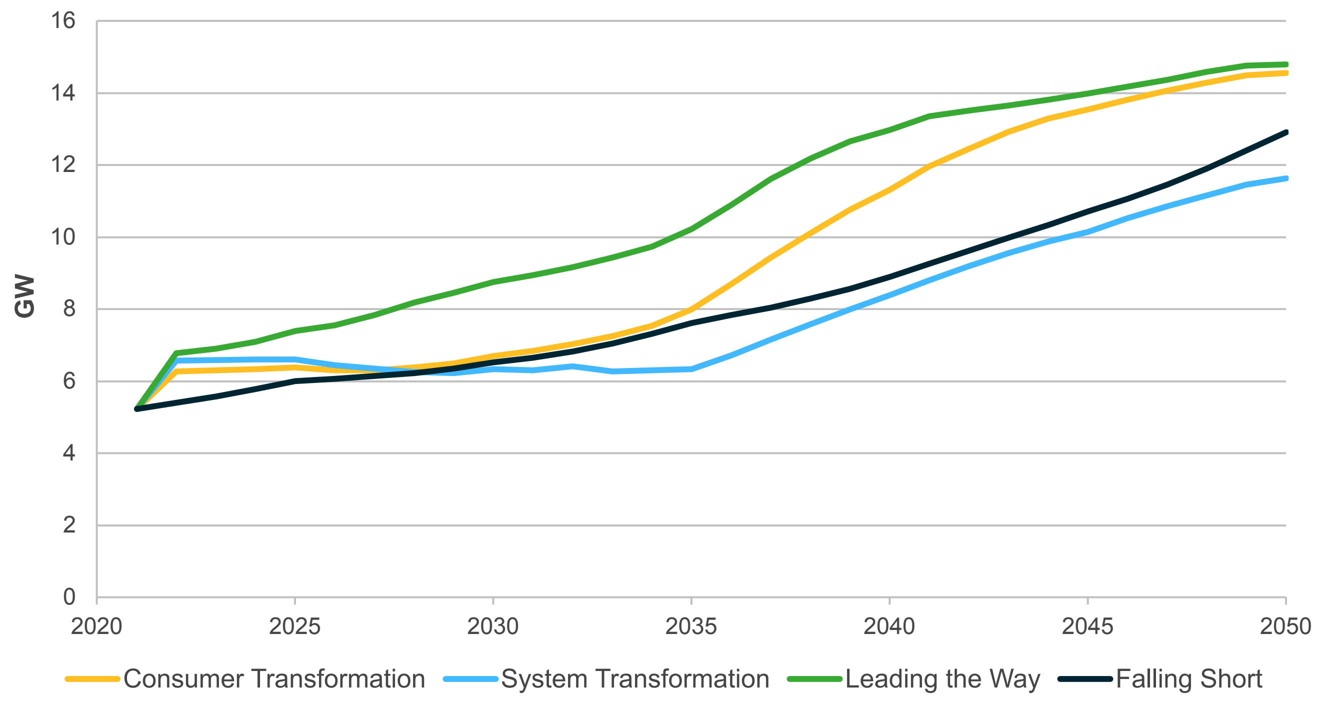
Thermal energy storage refers to a series of technologies which store heat energy and includes hot water tanks and solid storage (including storage heaters) as well as newer technologies.

The extent to which consumers (residential, industrial, and commercial) embrace dynamic tariffs and thermal storage will have a significant impact on balancing the energy system. The electrification of heat has the potential to significantly increase peak electricity demands, and so the adoption of smart controls, thermal storage and DSR for heating systems plays an important role in mitigating this increase and reducing the need for additional generation capacity and electricity network reinforcement. Thermal storage can then operate on a set schedule or based on forecast electricity prices to store heat at times when electricity prices are lower and then discharge at peak times.

We see an increase in total heat flexibility to 2025, and a decrease post-2025 in the short-term, as shown in Figure FL.05. This is occurring because the amount of electric storage heaters is decreasing after 2025. Meanwhile, the uptake of heat pumps and thermal storage is not yet sufficient to outpace this reduction, a similar trend also seen in System Transformation, which relies on the up-take of hydrogen boilers.

This highlights the need for quicker rollout of heat pumps which can help meet the net zero target by electrifying demand and contribute significantly to consumer DSR flexibility, when managed smartly and with the proper market signals. In addition, the interactions between housing heat flexibility solutions and the performance of heat pumps in Great Britain require better understanding for different housing stock, and weather conditions to better estimate the consumer heat flexibility potential. Overall, management of peak electricity heat demand and its level of flexibility will be an important factor in the extent to which heat can be electrified.

Figure FL.05: Total electric heat flexibility



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Consumer heat flexibility

Thermal storage, accompanied by heat pumps, can provide significant flexibility as we transition to net zero. We show in Figures FL.06 and FL.07 the behaviour of thermal storage used on the peak (coldest) day with Air Source Heat Pumps (ASHPs) and Ground Source Heat Pumps (GSHPs), respectively. This behaviour is illustrated in Leading the Way for the year of 2050, and it shows the GB-level aggregated profiles. For the same electricity price profile, less peak shaving is required by GSHPs for cost effective operation due to higher efficiency, even in cold weather conditions. Specifically, thermal storage typically charges up overnight, and discharges partially during the morning peak and again during the evening peak. At 6pm thermal storage discharge shaves 32% of ASHP demand and 25% of GSHP demand.

Hybrid heat pumps will also play a role in shifting electricity demand away from peak in System Transformation and Leading the Way, as the heating system switches to use hydrogen at peak times. District heating systems usually have a large thermal store to help manage supply and demand, and this will also play an important role in helping shift heat demand away from peak.

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Consumer heat flexibility

Figure FL.06: Thermal storage operation with an ASHP on a peak day in Leading the Way

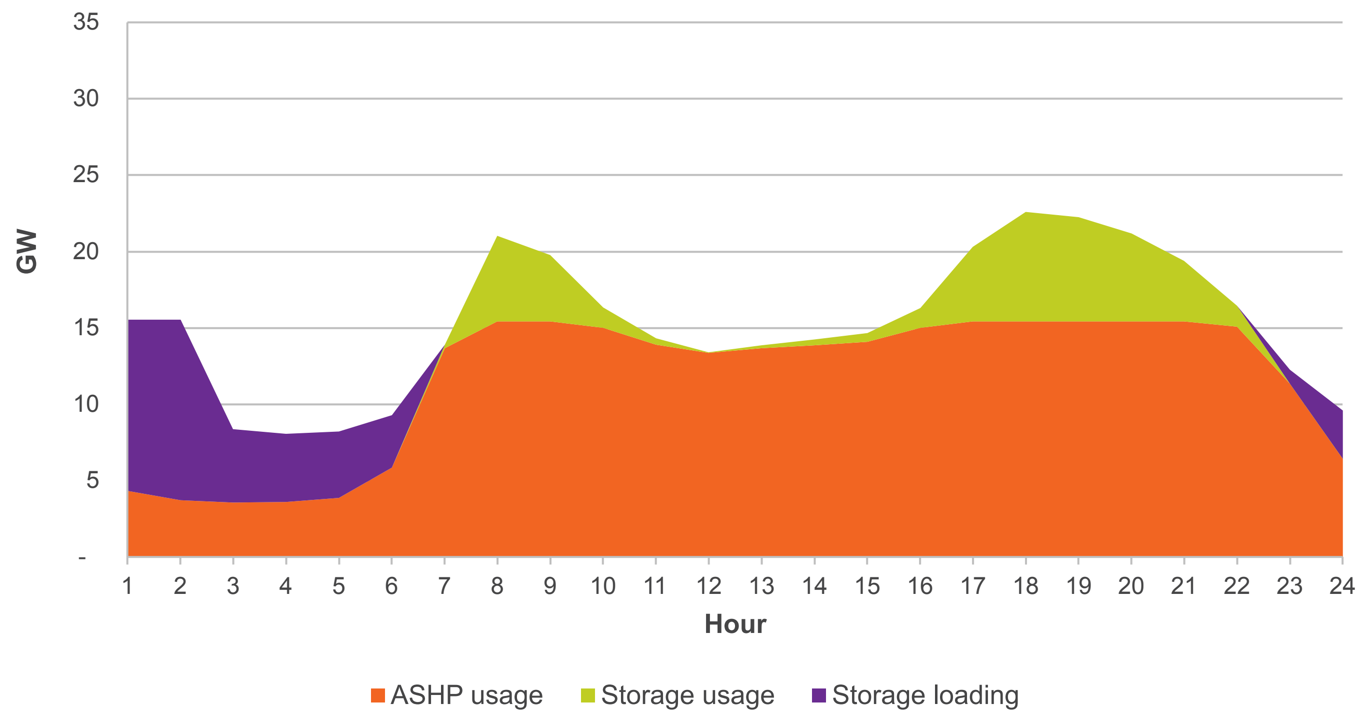
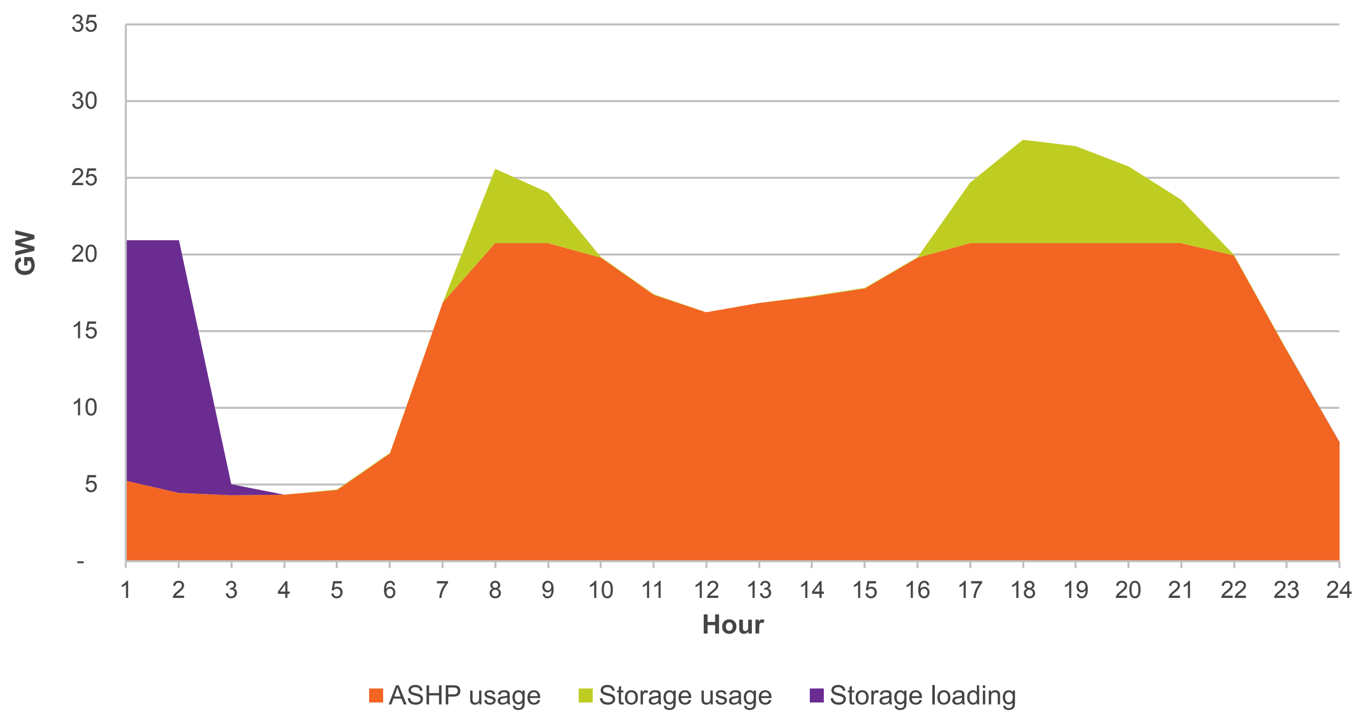


Figure FL.07: Thermal storage operation with a GSHP on a peak day in Leading the Way



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Large electrical demands

New large electricity demands are expected in all net zero scenarios, including, for example, electrolysers to convert electricity into hydrogen. This type of demand has significant potential to deliver whole energy system flexibility and reduced network constraints alongside decarbonisation.

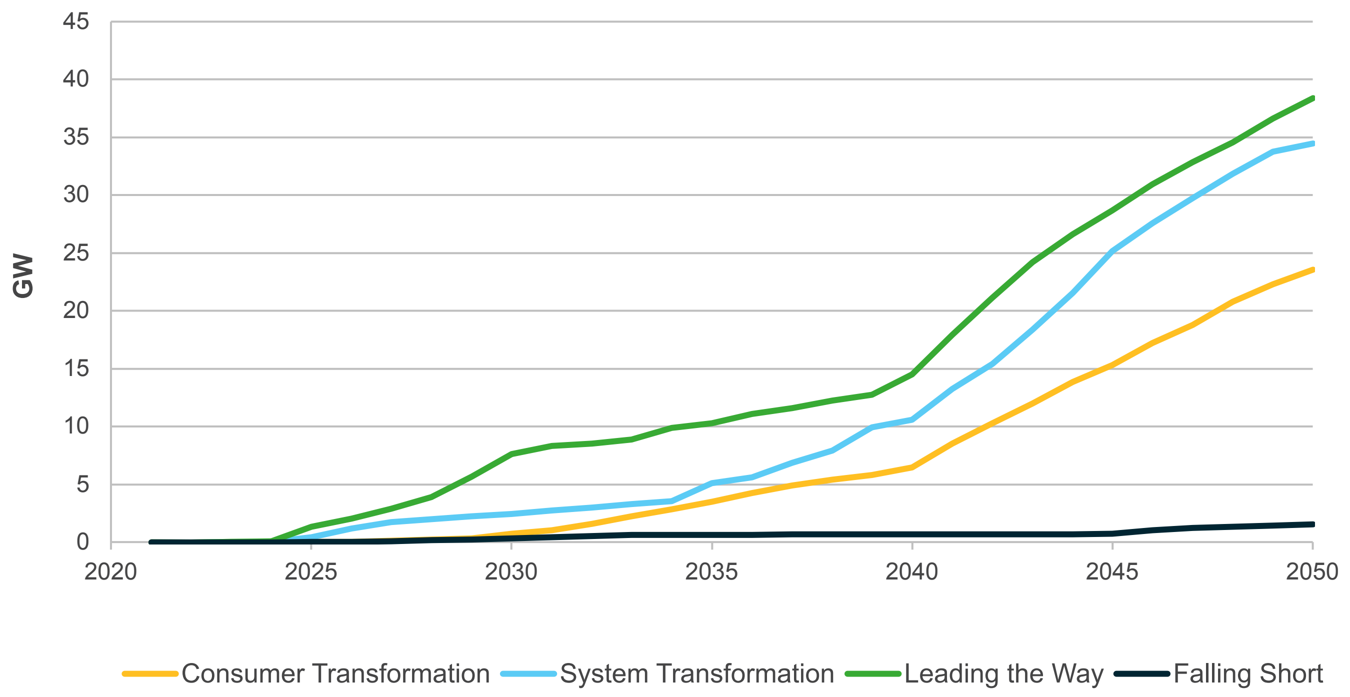
Large electricity demands such as electrolysis, direct air capture, and data centres can play an integral role in balancing the grid and reducing investment costs associated with managing constraints on the electricity network. These technologies can be switched up or down to balance demand against increasing weather-dependent power generation, helping ensure that the grid remains stable and reliable.

Within the next few years, deployment of electrolysers is essential for reaching the Government's target of at least 5 GW of electrolytic hydrogen by 2030. Subject to the passing of the Energy Bill, producers of low carbon hydrogen will be financially supported through a Contract for Difference (CfD), but without a national hydrogen network, developers must co-locate hydrogen production with the demand. Access to water is also essential for electrolysis meaning there are additional challenges to optimising the production location to where whole energy system benefits are optimised.

Transportation of hydrogen can be technically challenging and costly without a hydrogen network, although plans for future hydrogen networks exist and start on a more local basis (Hynet/East-Coast Cluster). For more details on the hydrogen network and the associated transportation, please see the Energy System chapter.

Grid blending could be one solution for the transportation issue and a decision is expected on up to 30% blend during 2023. It is critical that the right market framework is in place. Consideration should also be given to the development of new hydrogen demand around network constraints.

Figure FL.08: Network-connected electrolysis capacity: Electrolysers connected to the GB distribution and transmission systems either directly or via generation plant (excluding nuclear)



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Large electrical demands

Direct air capture uses electricity to capture carbon dioxide directly from the air, which can then be stored or used to produce synthetic fuels. The deployment of direct air capture may be more practical in areas with historically high carbon emissions such as industrial clusters, reducing the costs associated with transporting captured CO_2 to storage sites.

Data centres are also a significant consumer of electricity and can be used to help balance the grid. By adjusting the amount of processing power and storage capacity used, data centres can help to absorb excess generation during periods of high renewable output. This not only helps to balance the grid, but it also reduces energy costs for data centre operators, providing a win-win scenario for both the electricity grid and data centre industry.

These processes require significant amounts of electricity, which can be supplied by the grid during periods of excess generation. By providing an additional outlet for this excess generation, these technologies help to balance the grid and reduce investment needed to manage constraints on the electricity network.

A coherent strategy is required to ensure large electricity demands are located where they provide the biggest benefit to consumers and the whole energy system. This strategy must consider the barriers to each technology, including proximity to both the constraint and where the end product will be used or stored, and access to infrastructure and market frameworks that will incentivise development where it provides most benefit.

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Hydrogen storage

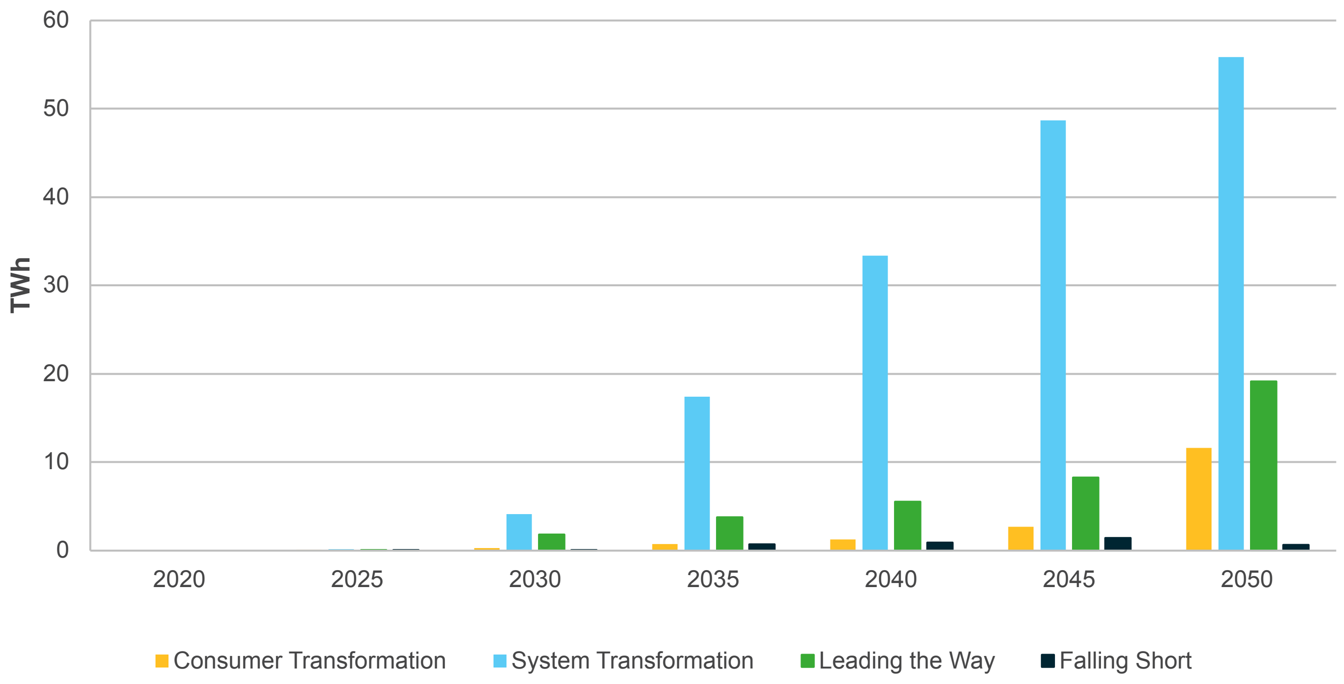
Hydrogen can provide significant flexibility benefits across the whole energy system. It is needed to replace some of the flexibility currently provided by natural gas but this relies on the development of hydrogen transportation and storage.

In the net zero scenarios in 2050, whole energy system flexibility is provided primarily using electricity or gas to produce hydrogen, storing it, then using the hydrogen in the power sector or to meet end user demand directly. Producing hydrogen through electrolysis offers demand side flexibility to the electricity system and converting it back to power offers supply side flexibility. If hydrogen is not used immediately for heat or transport, it can be transported for use elsewhere or stored for later use in potentially very large volumes. This allows energy generated in windy periods to be used in calm periods, or to be stored between summer and winter. The overall 'round-trip' efficiency of this process is low due to losses at the production, compression and combustion stages but must be weighed up against the potential value of the curtailed electricity at times of high or constrained renewable output leading to the lowest cost for consumers.

Hydrogen storage will be important to support security of supply and to accommodate electrolytic hydrogen at times of excess wind or solar. Given hydrogen's future importance to the energy system, urgent focus is needed to optimise the energy system infrastructure changes needed to support hydrogen storage and contribute to delivering zero carbon energy to consumers. For more information on this, see our Energy System chapter.

From our own FES 2023 analysis and stakeholder engagement, most of the hydrogen storage projects (via underground caverns) are currently under scoping phase and only a very small capacity is expected to be operational towards the end of 2028. Across all three net zero scenarios, hydrogen storage capacity begins to develop with between 0.6-3.5 TWh by 2030 (Figure FL.09). Levels of hydrogen storage post-2030 will also depend on the future potential revenue streams for flexibility and the support available to develop hydrogen storage sites.

Figure FL.09: Hydrogen storage capacity requirements



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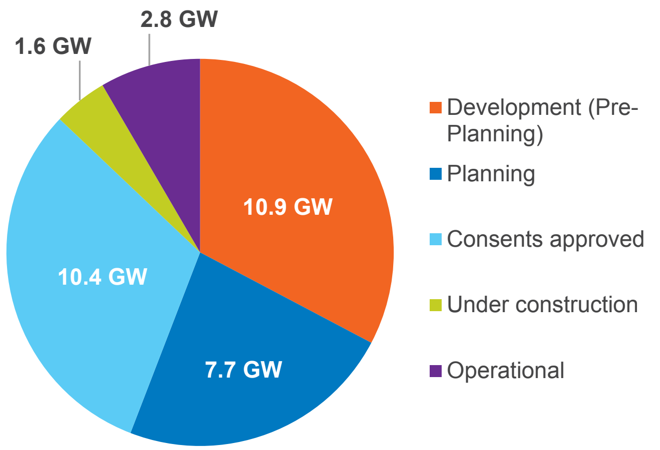
Electricity storage

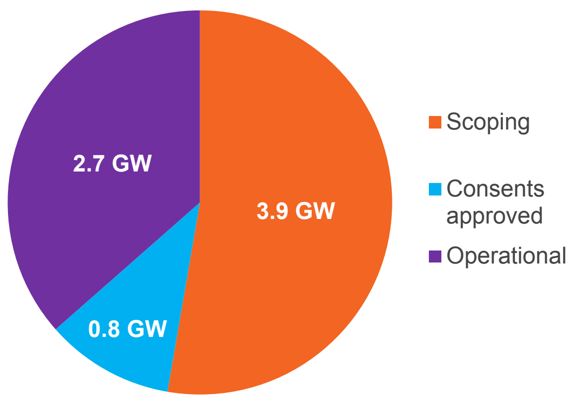
Electricity storage is needed to efficiently manage supply and demand. Installed capacity and volume need to increase significantly to support the decarbonisation of our electricity system as we transition to net zero.

In FES, we consider battery storage, Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES) and Liquid Air Energy Storage (LAES). Other emerging technologies, such as gravitational and pumped heat storage, are not yet included in our analysis as there is very limited information on future sites, additionally, the technologies are currently under further research and development. As they further develop, it is possible they may displace some of the capacity and volume we currently allocate to other storage technologies. We will continue to review our modelling assumptions and update future publications as more market information becomes available.

Currently in GB (Figure FL.10), there is 2.8 GW of operational battery storage capacity, mostly with 1-hour discharge duration. The maximum installed volume of PHS is 25.8 GWh with 2.74 GW of capacity, a much higher ratio (Figure FL.11). This year, we have seen a significant change in electricity storage capacity based on the latest Capacity Market (CM) auctions. Between 20-30 GW of electricity storage is expected to connect into the system by 2030 in Leading the Way and Consumer Transformation (Figure FL.11). This has pushed up our scenario range in the short-term across all our net zero scenarios. System Transformation sees less installed electricity storage deployment compared to Consumer Transformation and Leading the Way, which represent the upper barriers of supply chain issues, planning considerations and connection delays; with the last being underway for the short and long-term. Thus, we believe that further action could increase the amount of electricity storage entering the market.

Figure FL.10: UK portfolio by status for battery storage (left) and PHS (right) in 2023 (GW)





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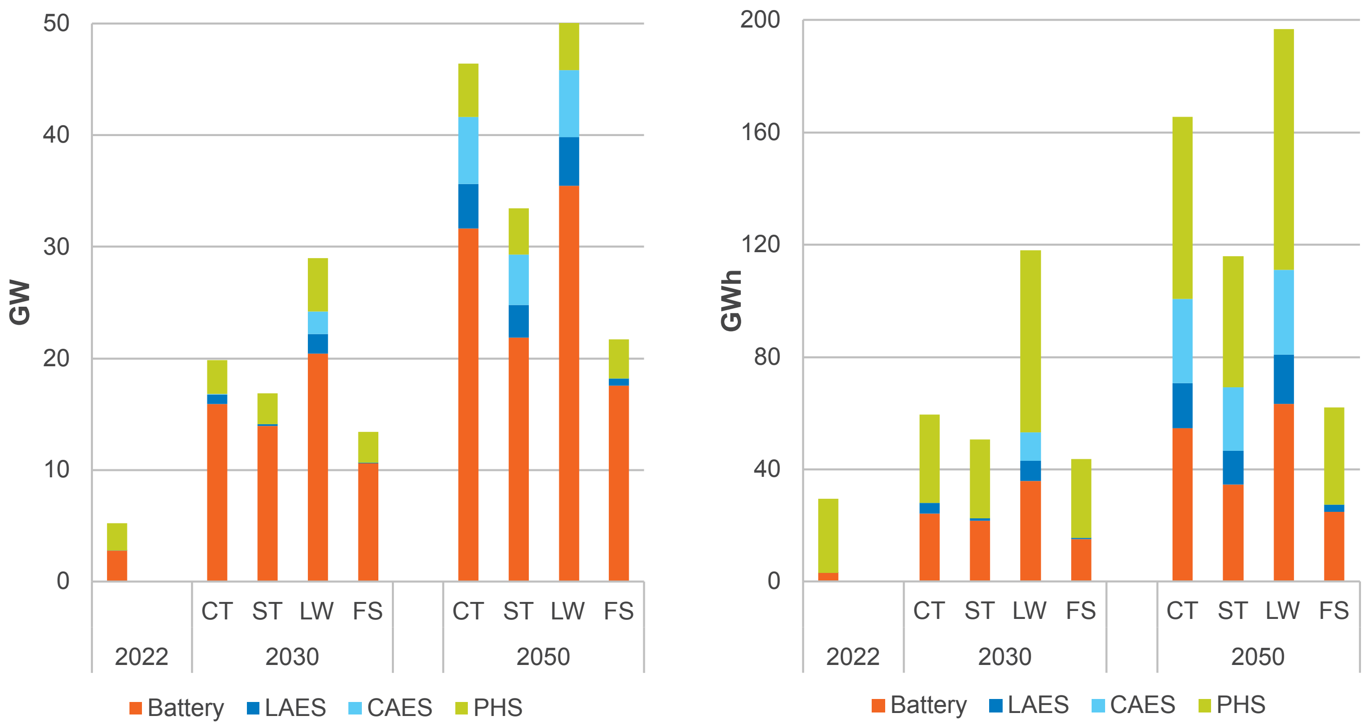
Electricity storage

Figure FL.11: **Electricity storage installed capacity and volume (excluding Vehicle-to-Grid)**



Next, we show in Figure FL.12 the capacities versus volumes of the electricity storage technologies assumed in FES for Leading the Way (the rest of the scenarios are shown in our FES 2023 data workbook), and the aggregated Vehicle-to-Grid response. The ratio between storage capacity (GW) and volume (GWh) defines the amount of time an electricity storage technology can discharge for at full power, which in turn influences the type of service the storage technology can provide. Batteries typically discharge for up to 2 hours, although stakeholder feedback suggests this is partly market driven and could increase to at least 4 hours. PHS, CAES and LAES all typically see much more energy stored compared to power output (up to 14-hour discharge FES scenarios) and can charge or discharge at maximum output for a longer period.

Different durations of energy storage provide different benefits to the energy system. Two to four-hour storage typically helps meet short within-day variations in demand and supply, provide short-term reserve or help manage the real-time operability of the network. Longer duration storage can help secure the system over longer periods of high or low renewable generation output. However, non-electrical storage in other fuels such as hydrogen or gas is better suited to very long-term or inter-seasonal storage.

For more details on electricity storage, please see our recent thought piece here.

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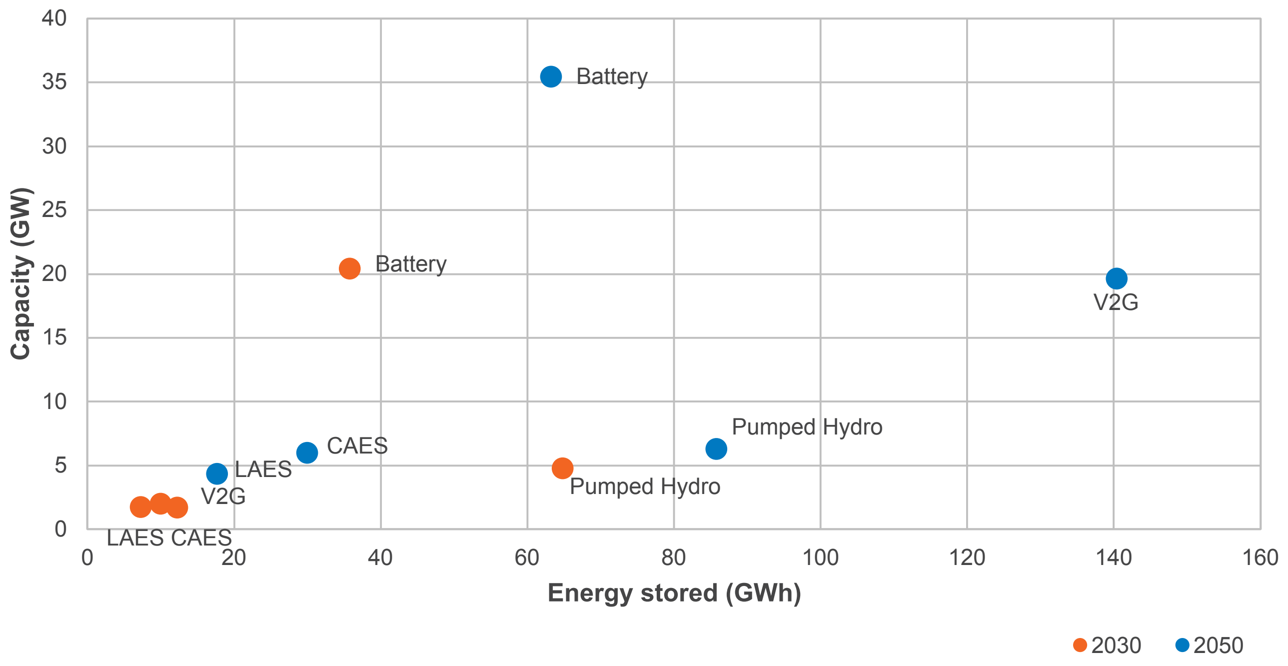
Figure FL.12: Varying energy and power outputs of electricity storage types in 2030 and 2050 for Leading the Way (including Vehicle-to-Grid)



We expect signicant deployment of transmission connected storage in Scotland towards 2050. Our stakeholder engagement, research and analysis expects that 35% of total battery storage deployment (~3.9 GW) will be sited in Scotland versus a combined capacity of 7.1 GW in England and Wales. This is a significant increase compared to FES 2022 data.

This increase in battery storage connected projects in Scotland (Figure FL.13) is driven by recent pathfinder contracts for management of the electricity network, greater land availability for new projects in Scotland, and shorter connection times. The pie chart only shows the split between Scotland compared to England & Wales because it is derived from transmission connections data from the Transmission Entry Capacity (TEC) Register. We specifically looked at which transmission network projects are connecting with Scottish Hydro Electricity Transmission (SHET) and Scottish Power Transmission (SPT) covering Scotland and which projects are connecting to National Grid Electricity Transmission (NGET) covering England & Wales.

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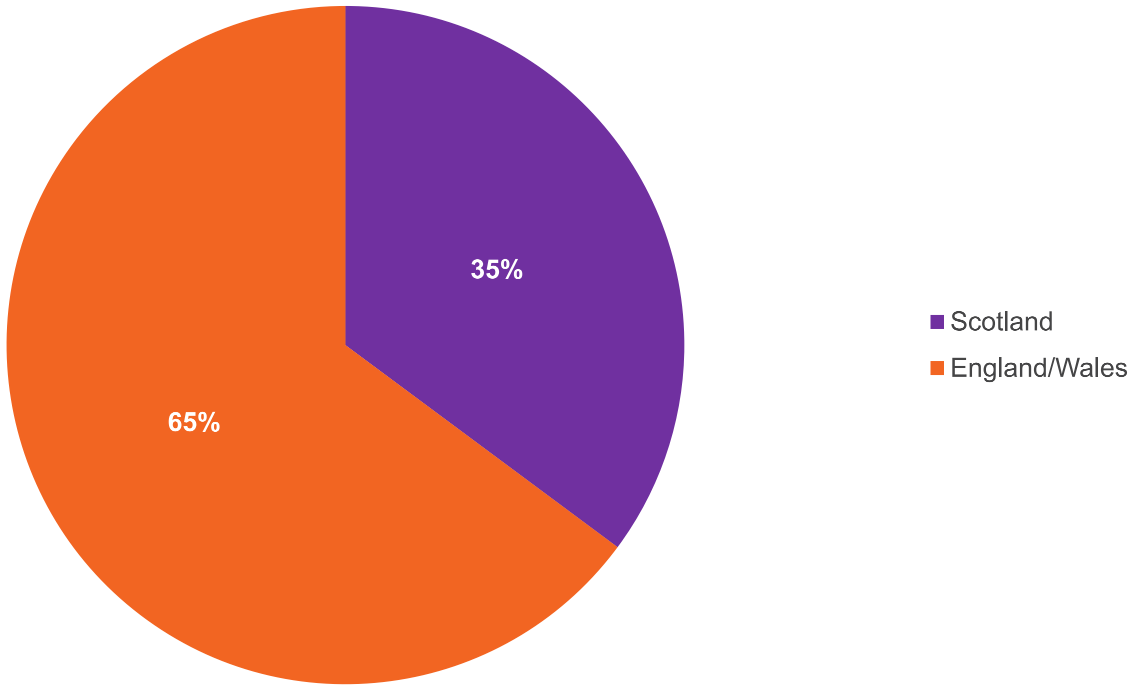
Electricity storage

Overall, the policy, regulatory and market environment for storage will need change to bring forward the levels of energy storage we expect to need on the system. This could involve changes to how storage is treated by electricity codes, removal of planning permission barriers and market change to allow greater revenue stacking of different services to improve the business case for storage projects. This is most needed for longer duration storage; The Department for Energy Security and Net Zero (DESNZ) recently announced the winners of their Longer Duration Energy Storage Demonstration Competition which aims to accelerate the commercialisation of innovative longer duration energy storage projects.

Figure FL.13: Transmission - Battery storage projections in Leading the Way for 2050



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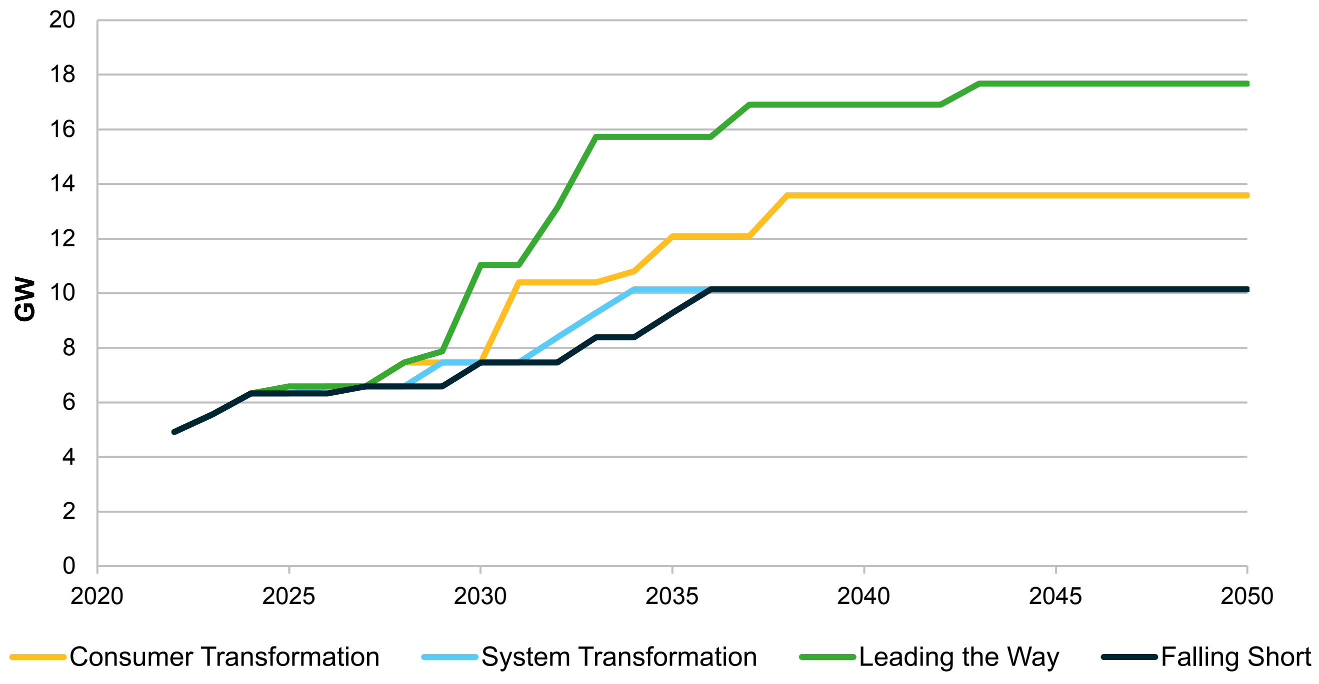
Interconnectors

Interconnector imports and exports, and their potential to facilitate the integration of weather-dependent and decentralised generation is vital as we transition towards net zero.

Our modelling considers the security of supply implications of relying on interconnectors to meet peak demand in the same way as our Capacity Market modelling, more details of which can be found in our Electricity Capacity Report (ECR). Figure FL.14 shows electricity interconnector flows at peak (the hour with the highest peak winter demand). Positive values represent interconnector imports, indicating that imports are expected at peak even out to 2050 under all net zero scenarios. In Consumer Transformation and Leading the Way, peak flows see a large increase in the early to mid 2030s as interconnector capacity continues to rise, fossil fuel capacity is phased out and peak electricity demands grow as the economy electrifies.

Aside from importing at peak, interconnectors are also used to move energy between GB and its neighbours throughout the year. In recent years there are typically net imports over our interconnectors with continental Europe throughout the year, particularly at peak times, although this is partially offset by export to Ireland and Northern Ireland. The movement of power over interconnectors will continue to be primarily driven by price differentials between electricity markets.

Figure FL.14: Interconnector Peak Flows (TWh)



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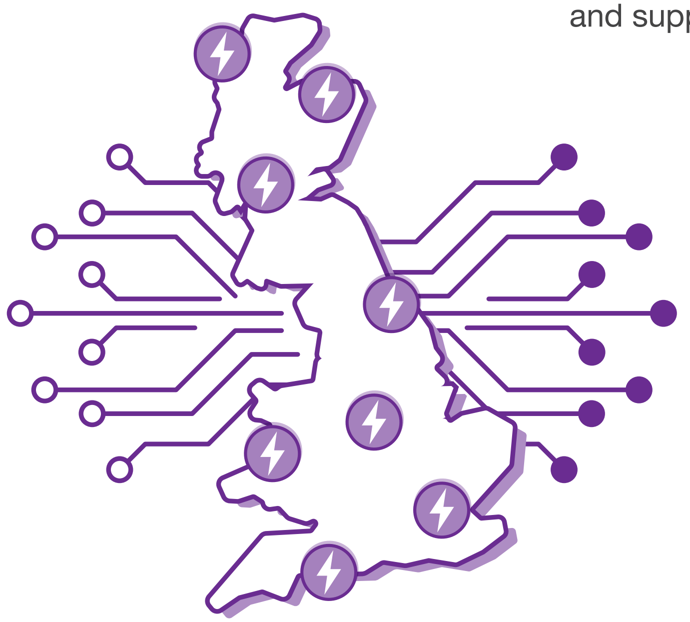
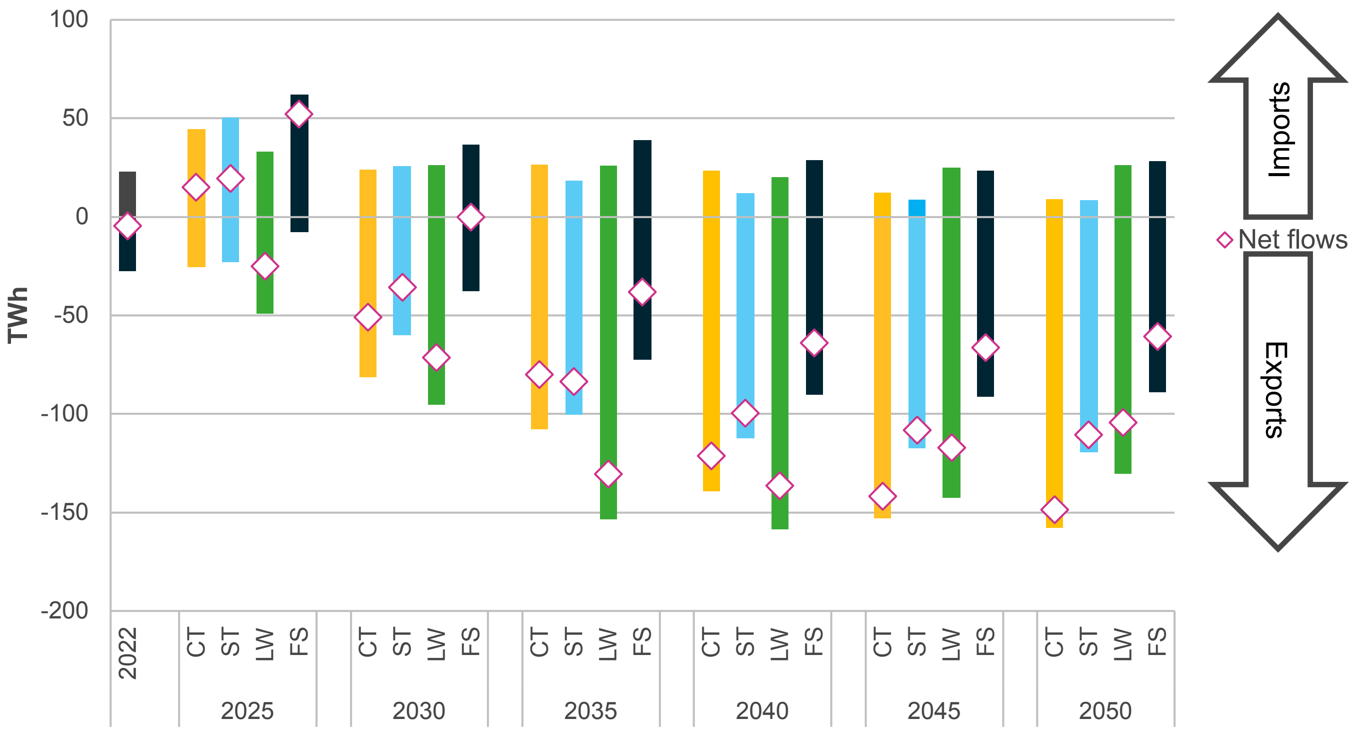
Interconnectors

While operation over the year varies, we do see changing trends in net flows (Figure FL.15). From 2030 to 2050, all scenarios see an increasing annual export of electricity with annual net exports from 2030 across the net zero scenarios. The high levels of variable renewable generation, particularly offshore wind, in these scenarios means supply often exceeds demand and so power is exported to the continent.



However, exporting over interconnectors is not a solution for all excess power. Sometimes there may not be excess demand to consume the power in Europe, or at other times there may be network constraints restricting its movement within GB. Post-2030 the growth of integrated offshore networks will help manage the flow of power between GB, offshore wind farms in the North Sea and Northern Europe, as offshore transmission infrastructure is shared, and supply is balanced across the network.

Figure FL.15: Interconnectors Imports and exports (TWh)



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Dispatchable sources of supply

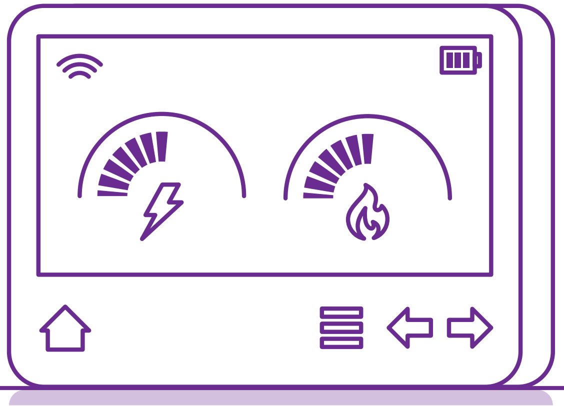
Dispatchable sources of supply increase across all scenarios as we move towards net zero, due to increased peak demands. However, the generation mix will also change from its current picture, with greater emphasis on non-fossil fuel-based sources across all our net zero scenarios.

Demand Side Response will be crucial to help manage peak demands, as shown in Figure FL.05, but some demand is inflexible and needs to be met by sources of supply under all conditions, even when renewable generation output is low. Today the bulk of dispatchable capacity comes from natural gas generation. In the future a much greater share will come from other sources, such as electricity storage and interconnection with other countries and electricity markets.

Unabated gas generation declines to zero ahead of 2050 in the net zero scenarios and load factors begin to reduce earlier still; however, some level of capacity needs to be retained to meet security of supply and provide resilience, although this is less so in Leading the Way.

In the net zero scenarios, hydrogen generation capacity increases through the 2030s, providing a new source of flexible thermal generation capacity (Figure FL.16). Beyond this, however, significant increases in other technology types are also needed. In Leading the Way, although unabated gas generation capacity is phased out by the end of 2035, there is only a small and temporary reduction in net dispatchable sources of supply as increased levels of energy storage and interconnectors are deployed (Figure FL.16). As renewable generation capacity is rising sharply over this period, reaching almost 236 GW by 2050, this dispatchable supply may be required to run for several hours at a time, potentially over several days and so it is important that the energy storage deployed includes a suitable capacity of longer duration technologies. More broadly, this highlights the importance of ensuring these alternative dispatchable technologies are supported now so they are deployed at the required scale in the future.

In System Transformation and Consumer Transformation, the slightly slower closure of unabated gas generation means there is less reliance on other technologies for resilience until post-2040, although unabated gas generation is providing almost no energy production (please see relevant charts in our data workbook). In Falling Short, gas generation, both unabated and gas Carbon Capture, Usage and Storage (CCUS), plays the biggest role in ensuring security of supply all the way to 2050 (Figure FL.17).



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Dispatchable sources of supply

Figure FL.16: Dispatchable electricity supply sources (excluding renewable sources) for Leading the Way

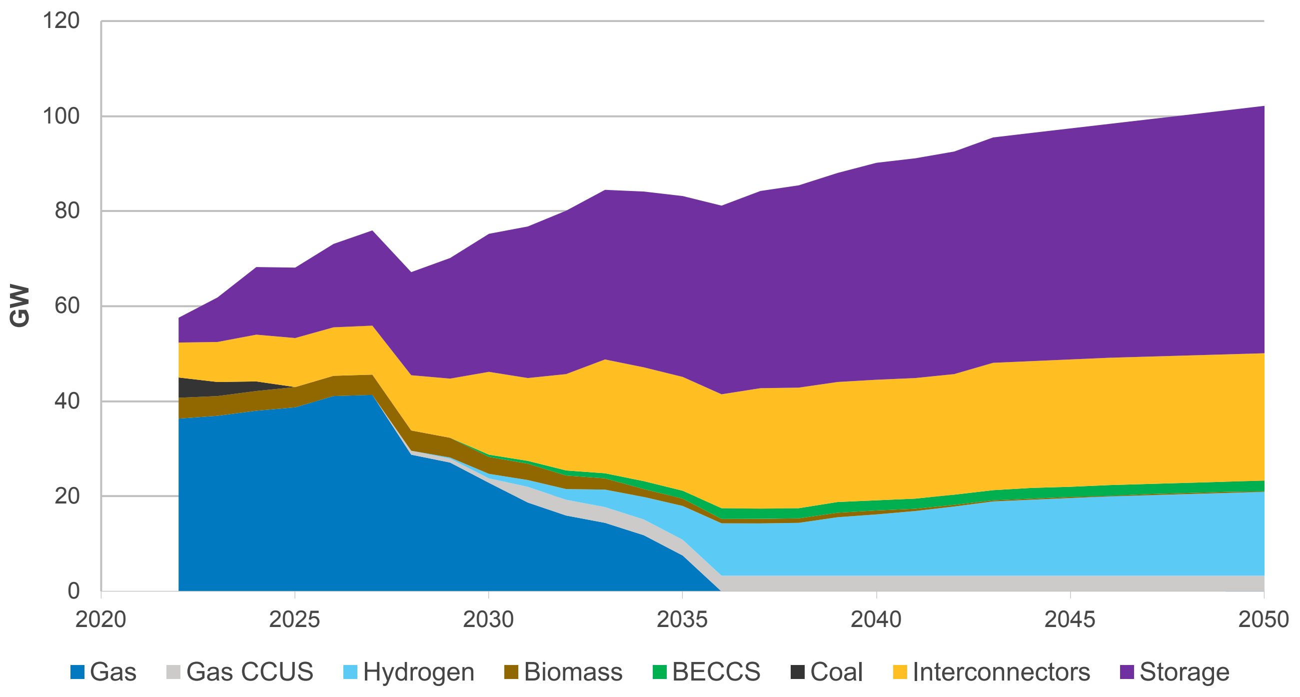
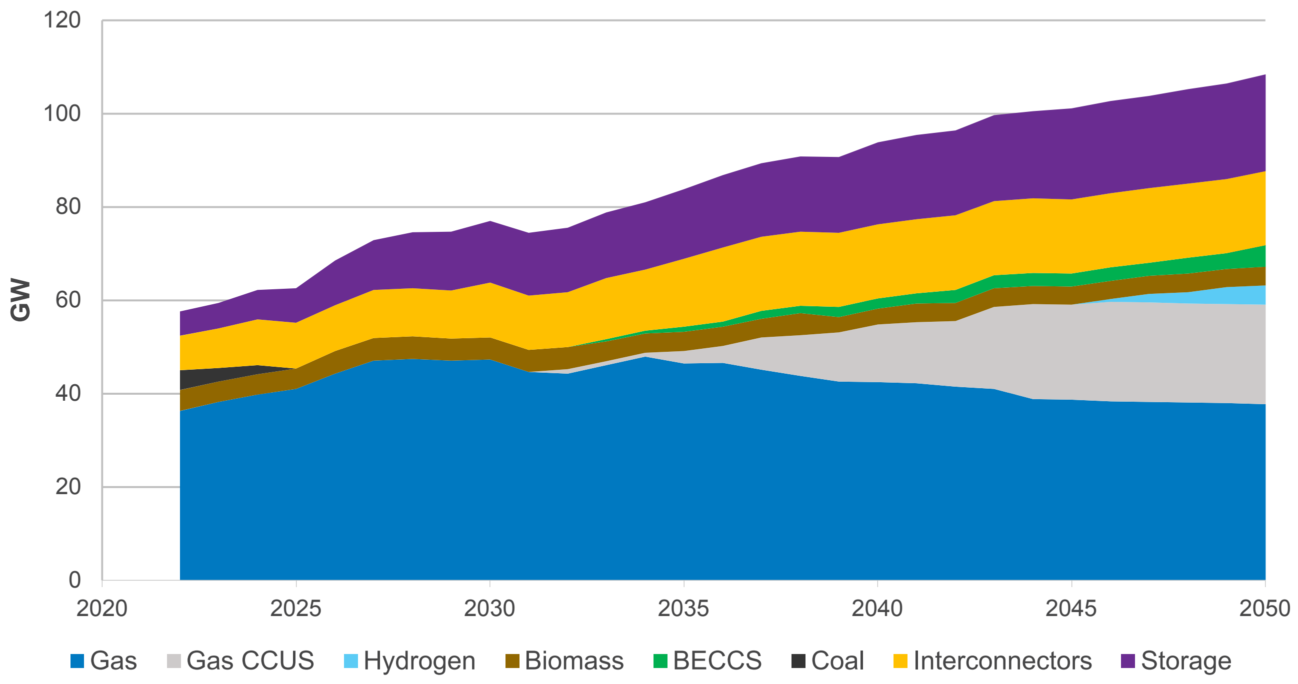


Figure FL.17: Dispatchable electricity supply sources (excluding renewable sources) for Falling Short



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Curtailment

As increasing levels of renewable generation are deployed, particularly wind, there will be times (i.e., windy days) when supply is significantly higher than demand and therefore curtailment cannot be avoided, assuming all levels of flexibility have already been utilised.

As discussed throughout this chapter, flexibility can be used to store excess renewable supply, or to shift demand to consume it. After all flexibility options have been used, if supply still exceeds demand, then some sources will be asked to stop generating (curtailment) to keep the system stable; this could be any generation type and tends to be the cheapest to turn off at the time. As renewable capacity is rapidly increasing, flexibility options such as interconnectors, energy storage, electrolysis and demand side flexibility should be developed simultaneously, rather than in later years. When supply is high compared to demand, we would expect these flexibility options to respond to low electricity prices and market conditions and begin operation. Whilst several flexible technologies (e.g., interconnectors or demand side flexibility or energy storage) can help to reduce curtailment to some extent, electrolysis is particularly useful in this respect. This is because hydrogen is much easier to store than electricity and so can hold significant volumes of curtailed energy for a long time, even potentially across seasons.

Generation can also be constrained due to network capacity limits but isn't included here as FES models energy flows on unconstrained networks. The impacts of network constraints on energy flows are analysed in other ESO and industry publications, for example our Network Options Assessment (NOA) and Electricity Ten Year Statement (ETYS) which are transitioning in to the Centralised Strategic Network Plan.

Figure FL.18 shows annual curtailment for each scenario out to 2050. System Transformation has the most curtailment, peaking at almost 65 TWh by 2040. However, this then decreases sharply through the 2040s as electrolysis capacity and the potential to export hydrogen increases. Leading the Way is generally a well-balanced system, with greater energy efficiency measures and flexibility, which lowers peak demand and therefore maximum generation capacity. It also deploys electrolysers at scale more rapidly and has the greatest capacity until 2045. These factors, alongside the highest level of interconnector capacity and a quicker build out of renewable generation, results in the smallest peak in annual curtailment, of 42 TWh, which occurs around 2037 but then rapidly reduces in the 2040s.

Although Falling Short has minimal levels of electrolysis, it also has the least renewable generation. This leads to greater curtailment in 2050 than Leading the Way and System Transformation but less than Consumer Transformation, with peak annual curtailment of 42 TWh in 2043. Consumer Transformation sees peak annual curtailment occur in the middle of 2040s at 65 TWh. This is later than the other scenarios and is due to a slower and smaller deployment of electrolysis but the greatest wind generation capacity from 2040 onwards.

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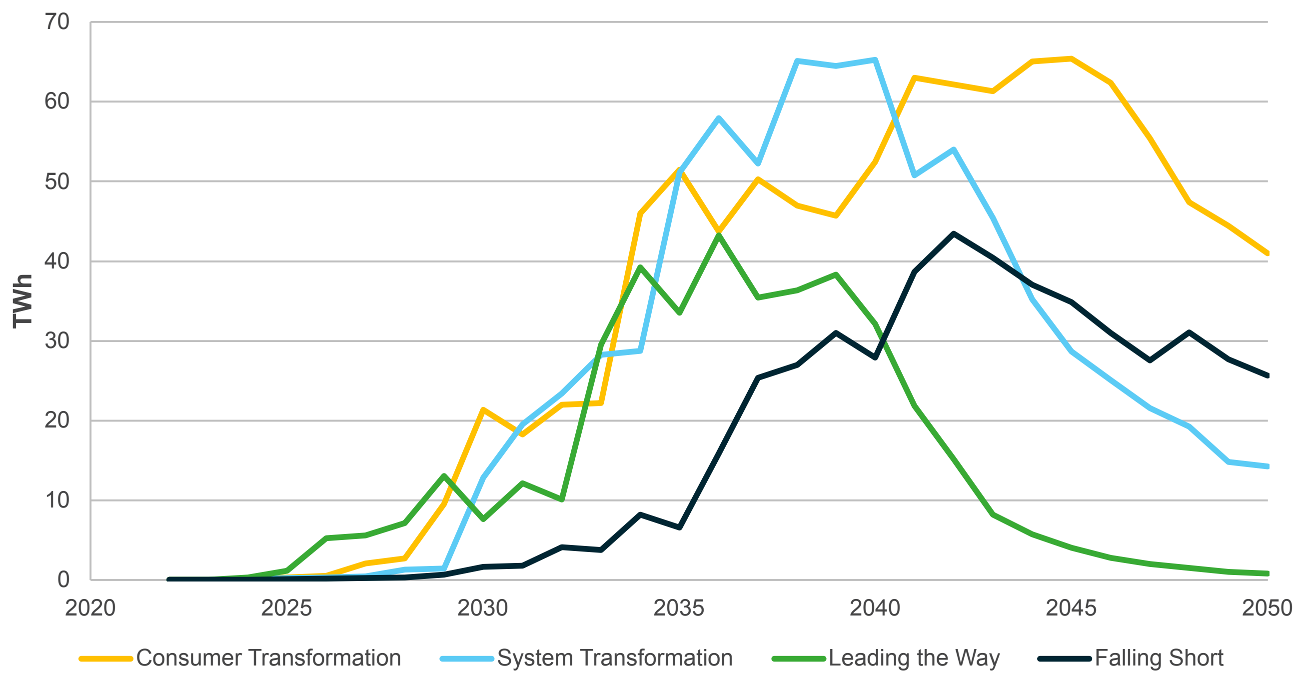
Curtailment

Figure FL.18: Annual curtailment (TWh) for all the scenarios out to 2050



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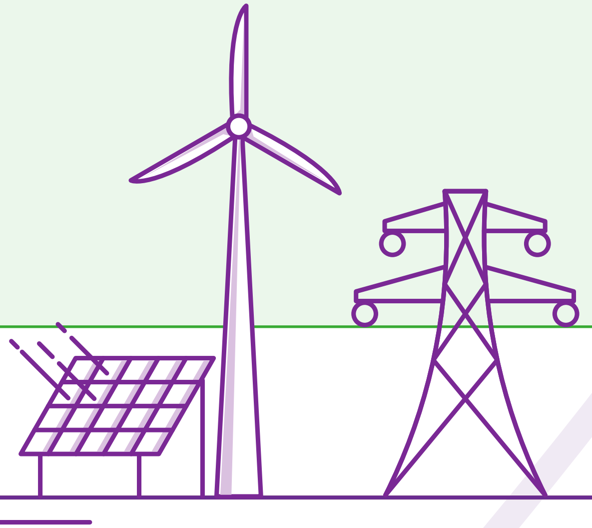
Leading the Way

The route to 2050

- Peak electricity demand increases post-2025 as the economy electrifies.
- Rapid early take-up of Demand Side Response and smart charging and V2G give the potential for demand at peak times to be reduced by almost 15 GW in 2030 and 40 GW by 2050 compared to the counterfactual demand with no Demand Side Response.
- Almost 2 TWh of hydrogen storage is needed by 2035 amidst growth in electrolysis and hydrogen generation, while natural gas demands fall sharply.
- Unabated natural gas generation capacity declines sharply from 2025 and is phased out completely by the end of 2035, in line with the Climate Change Committee (CCC) target of no unabated gas generation by 2035. This is mitigated by growth in interconnection, storage and hydrogen generation as well as additional demand reduction from Demand Side Response technologies.
- Interconnection capacity increases rapidly, reaching 10 GW by 2025 and almost 8 GW by 2030, and net exports are seen over the interconnectors from 2025.

What does 2050 look like?

Demand side flexibility provides slightly more capacity than supply side. High levels of energy efficiency and greater consumer engagement limit peak demands through Demand Side Response and V2G output. Electrolysis, hydrogen generation and hydrogen storage combine to offer high levels of whole energy system flexibility, with the high levels of electrolysis and load shifting able to maximise the use of local renewable generation. There are also high exports across the interconnectors.



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Consumer Transformation

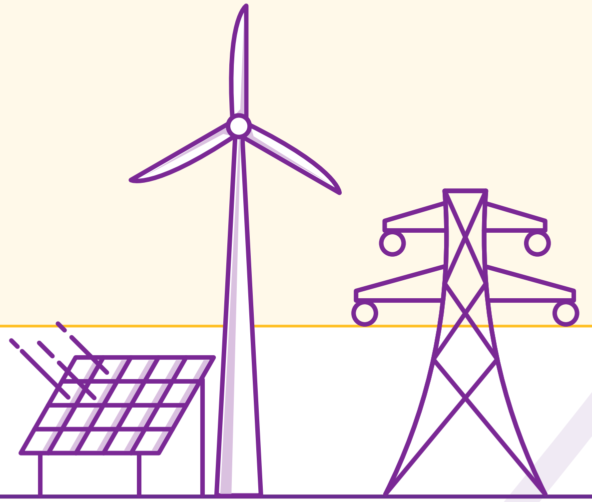
The route to 2050

- Peak electricity demand starts to increase from the mid-2020s as different sectors of the economy electrify.
- Through the 2020s, developments in flexibility are gradual; on the supply side it is made up primarily of growth in interconnection and storage and there is limited growth in Demand Side Response outside of the industrial sector.
- In the 2030s, Demand Side Response and consumer engagement rapidly increase, partly due to assumptions around high levels of societal change and lack of technical barriers in this scenario. This helps to mitigate demand growth.
- Some unabated natural gas electricity generation capacity remains well into the 2040s to provide security of supply, but generation is gradually reduced from the mid-2020s (supplying only ~2% of demand by 2035) with other forms of dispatchable generation filling the gap.
- Hydrogen storage starts to support flexibility through the early 2040s while natural gas demand falls sharply.

By the 2040s, domestic smart automation has become the norm, with demand side flexibility and Vehicle-to-Grid technology providing a maximum demand reduction capacity at peak of over 40 GW in 2050.

What does 2050 look like?

Flexibility capacity from demand side options is almost equal to that from supply side options. A combination of electrolysis, storage and hydrogen generation offer high levels of whole energy system flexibility and high net exports over interconnectors help to manage renewable generation output.



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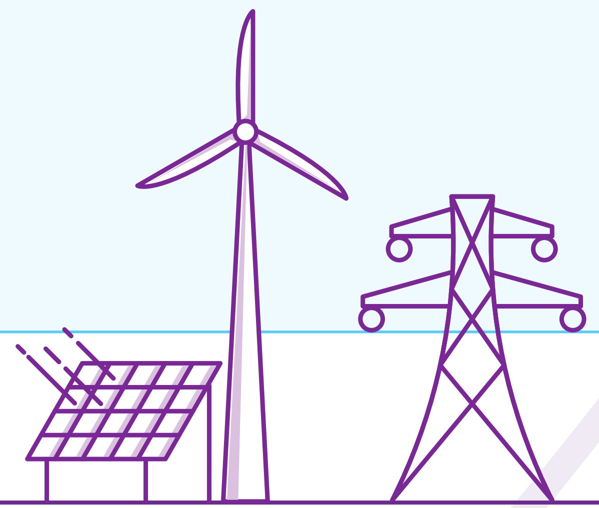
System Transformation

The route to 2050

- Peak electricity demand increases only steadily until post-2030 where electrification of transport starts to accelerate.
- Contribution from Demand Side Response to mitigate this increase is limited (compared to Leading the Way and Consumer Transformation), with contributions from smart charging from the mid-2020s onwards and V2G post-2035. Together, these provide a maximum demand reduction capacity of around 11 GW by 2040.
- Hydrogen storage is developed at scale from the early 2030s, reaching almost 33 TWh by 2040; the gas network is repurposed to transport hydrogen.
- Throughout the 2030s, hydrogen and gas Carbon Capture, Usage and Storage generation capacity is deployed reaching 22 GW in total by 2040, offsetting the decrease in unabated gas generation on the supply side.
- Interconnection capacity reaches just under 16 GW by 2040.

What does 2050 look like?

Supply side flexibility still outweighs demand side flexibility, although demand side flexibility still increases considerably from today. Widespread use of hydrogen for heat and industrial and commercial sectors keeps peak electricity demands relatively low, although lower consumer engagement limits the contribution of Demand Side Response. Dispatchable thermal generation from gas CCUS and hydrogen support security of supply. Net exports over interconnectors help manage renewable generation output. Hydrogen use across the economy is supported by high levels of hydrogen storage to move energy inter-seasonally.



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Falling Short

The route to 2050

- Peak electricity demand increases all the way to 2050 as electrification occurs (albeit more slowly than the other scenarios) but with limited energy efficiency improvements.
- Demand Side Response and Electric Vehicle smart charging take-up is low due to low consumer engagement, providing only 4 GW of demand reduction capacity at peak by 2030 and 9 GW by 2040, with very minimal engagement in V2G.
- A limited role for hydrogen across the economy sees only slow growth in electrolysis and almost no large-scale storage.
- Unabated natural gas generation continues to play a significant role backing up renewable generation and meeting security of supply. From 2035, some of this generation is displaced by gas CCUS which reaches 11 GW by 2040.
- Growth in interconnection capacity is slow but still reaches 12 GW by 2030.

What does 2050 look like?

Supply side flexibility continues to dominate over demand side flexibility. Peak electricity demands rise to be as high as those in Consumer Transformation by 2050. Relatively low levels of consumer engagement in Demand Side Response alongside some electrification but limited deployment of energy efficiency is responsible. The natural gas network and storage continue to provide energy flexibility, meeting heat demands and supplying gas generation (with and without CCUS) which helps to meet security of supply. Levels of electrolysis and hydrogen usage across the whole energy system are small.

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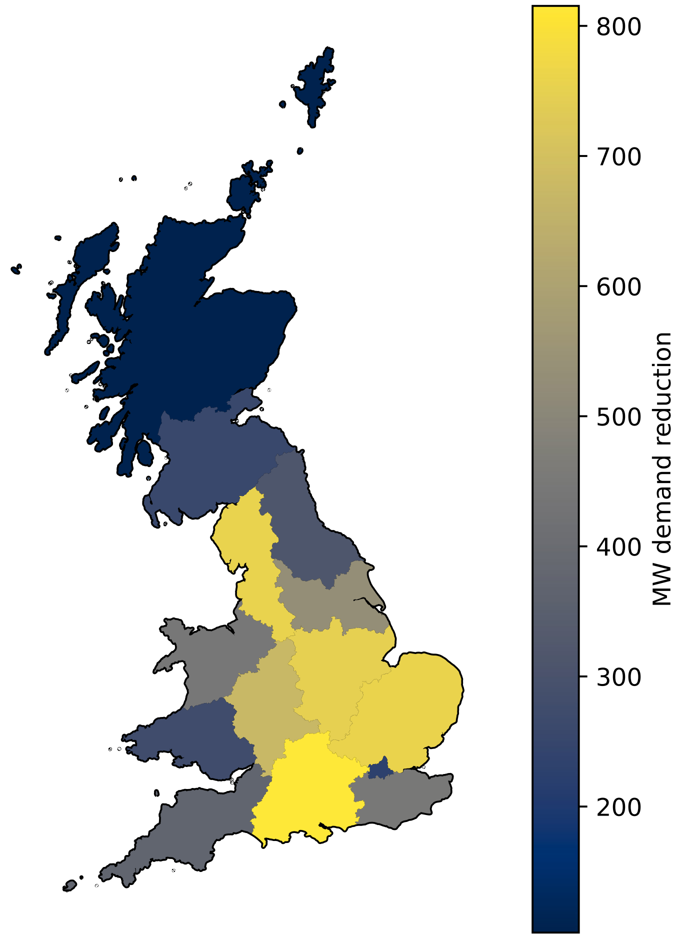
Demand Flexibility Service

With the launch of the Demand Flexibility Service in November 2022, consumers were able to engage with the energy transition in an entirely new way. This allowed customers to receive incentives to reduce their energy usage at specific times and avoid the use of the back-up coal power stations. This is the first time that consumers have played a direct role in balancing the electricity network at scale. However, the DFS was the stepping-stone to other types of Demand Side Response services as we transition to net zero.

DFS saved over 3,300 MWh of electricity as consumers and businesses did their part to reduce demand at key times. In total, this was enough to power nearly 10 million homes at peak times across a single hour throughout Great Britain.[6] 1.6 million households and businesses participated in DFS, delivering demand reduction and helping the grid under strain conditions across 22 events this winter. Figure FL.19 shows the contribution by location. We note at this point that low participation from a region does not imply lower consumer engagement but it also reflects that, whilst DFS was available nationally, not all customers were able to take part through their energy supplier.

Figure FL.19: Regional contribution of the total DFS live events alongside the coordinate shapefiles for all the Distributed Network Operator (DNO) license areas[7]



6 nationalgrideso.com/news/demand-flexibility-service-delivers-electricity-power-10-million-households
7 data.nationalgrideso.com/system/gis-boundaries-for-gb-dno-license-areas

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Regional spotlight

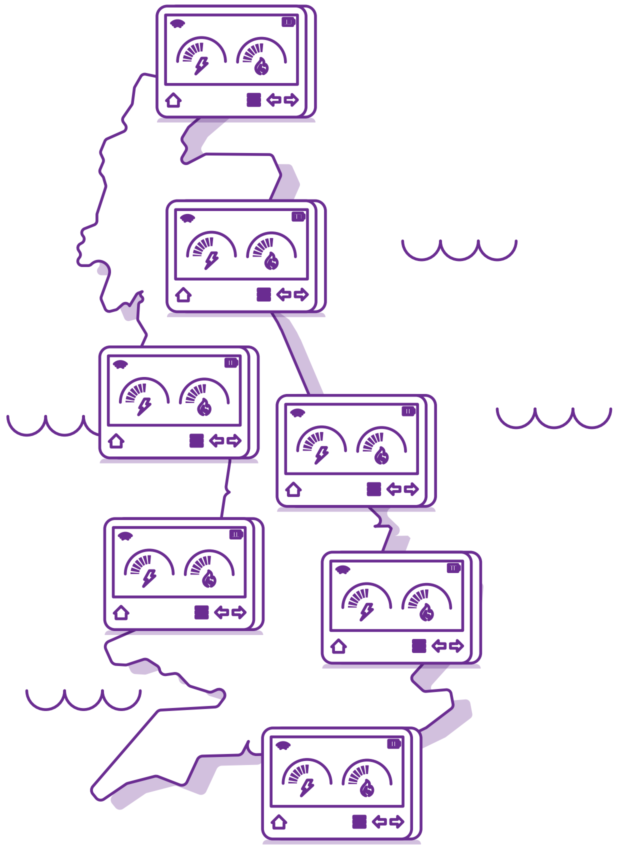
As part of DFS, consumers and businesses in Wales delivered nearly 350 MWh of demand reduction. This level of demand reduction is enough to power roughly 1 million homes, which is around 80% of Welsh households. Consumers and businesses in Wales joined approximately 1.6 million households and businesses across Great Britain in participating in DFS.

Consumers and businesses in Southern England delivered the highest levels of demand reduction, with over 410 MWh reduction across the 22 DFS events held last winter. This is enough to power over 1.2 million homes. Southern England was the only region to deliver over 400 MWh, well above the regional average of 180 MWh.

Across the winter, consumers and small & medium-sized businesses worked with the ESO and 31 suppliers and aggregators to deliver new levels of demand flexibility, unseen on Great Britain's electricity network until now.

Introduced by the ESO as an enhanced action to support operation of the national electricity network last winter, DFS was used twice for "live events" in January 2023 to support the management of the network. Whilst the ESO's day-to-day operational tools allowed it to operate the network as normal without the active use of DFS to manage margins, this service demonstrated the level of interest and engagement in consumer flexibility. Consumers and businesses notably delivered their highest output for these live events, 20% higher than the regular monthly or onboarding "test events". These test events successfully demonstrated that DFS can deliver flexibility at scale, enabling consumers and businesses across the country to benefit from shifting their electricity use away from a specific time period.

The ESO is currently undertaking a holistic review of the DFS alongside industry participants and consumers to assess how the service could be improved in future. The outcomes of this review will be published later this summer and will inform decision making around the future evolution of the DFS.



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Regional spotlight

As an example, the peak demand reduction from various regions in Great Britain is illustrated in Figure FL.20 for the 23rd of January 2023, 17.00-17.30. Similar DFS contributions were observed for the next settlement period, when DFS was used again to contribute to peak demand reduction from various regions.

At the ESO, we are working with DFS providers and undertaking further studies and analysis to better understand consumer behaviour and factors that affected DFS participation. Examples include the availability of smart meters and the breakdown of consumers according to location, affluence, house size, household type (number occupants, ages etc.), and low carbon technology installed.

In the future, it is important that consumer flexibility is more than an item of last resort and that, apart from the peak demand periods, is also used in periods of excess renewable generation to reduce associated curtailment or in any other stress periods. Half-hourly settlement system demand and smart tariffs could further enable this by providing a signal to consumers about the varying needs of the system to which their flexibility can respond. This will allow consumer flexibility to become a routine part of efficient system operation.

Consumer engagement plays a crucial role in the transition to a sustainable and secure energy system, while reducing the cost of energy for consumers, but it must be made as easy as possible for consumers to take part.

With a greater variety of technologies on the system in future years, including EVs and heat pumps, far more automation will be needed. There are a few advantages to this; the first of which is that it allows us to increase or decrease demand on a more granular level. The second is that it allows a DSR service to be run more cheaply, as instead of relying on consumers to manually adjust their demand it will be done automatically, meaning it is easier for consumers to participate in the service. For more details on consumer flexibility and the DFS, please see our recent thought pieces here.

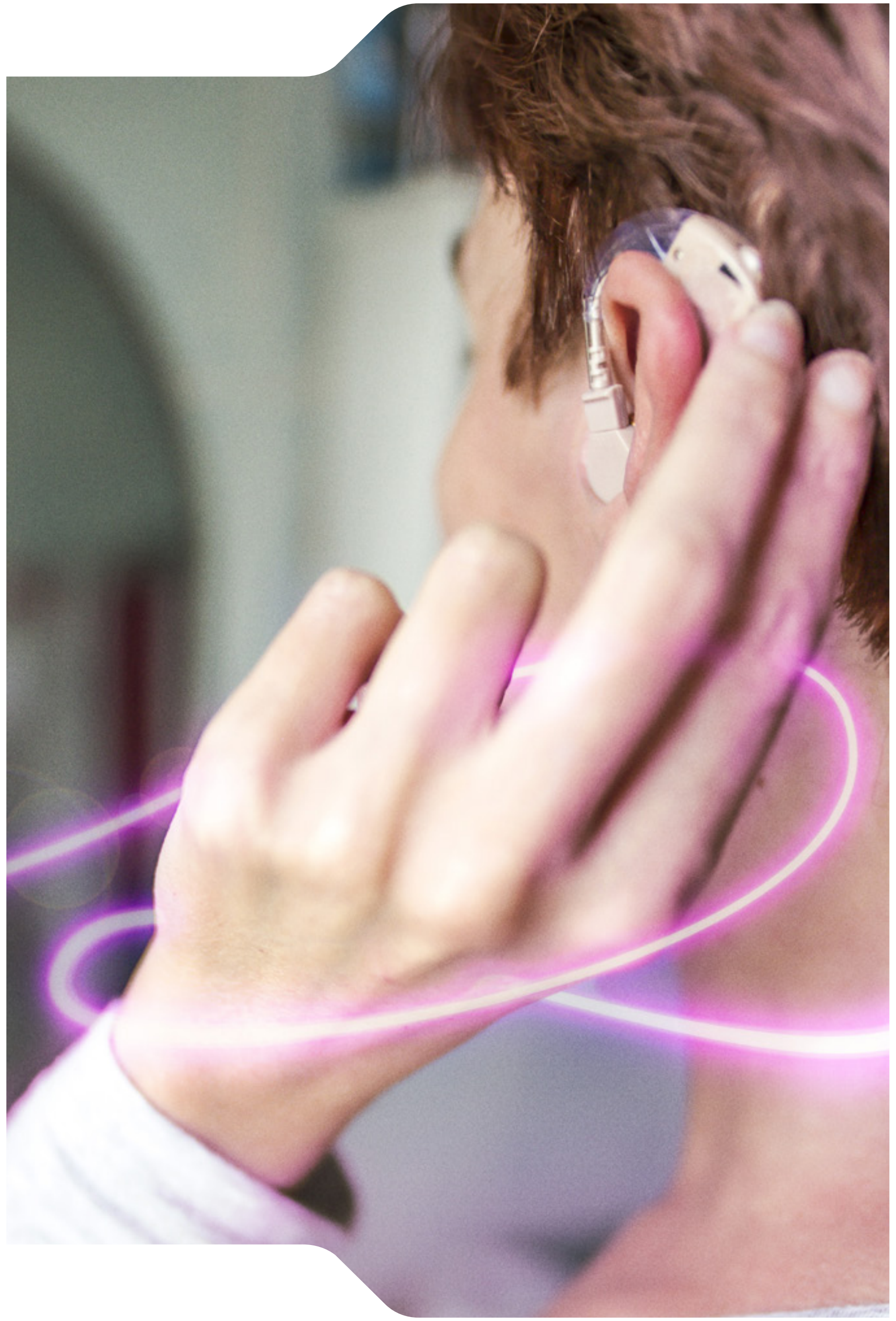

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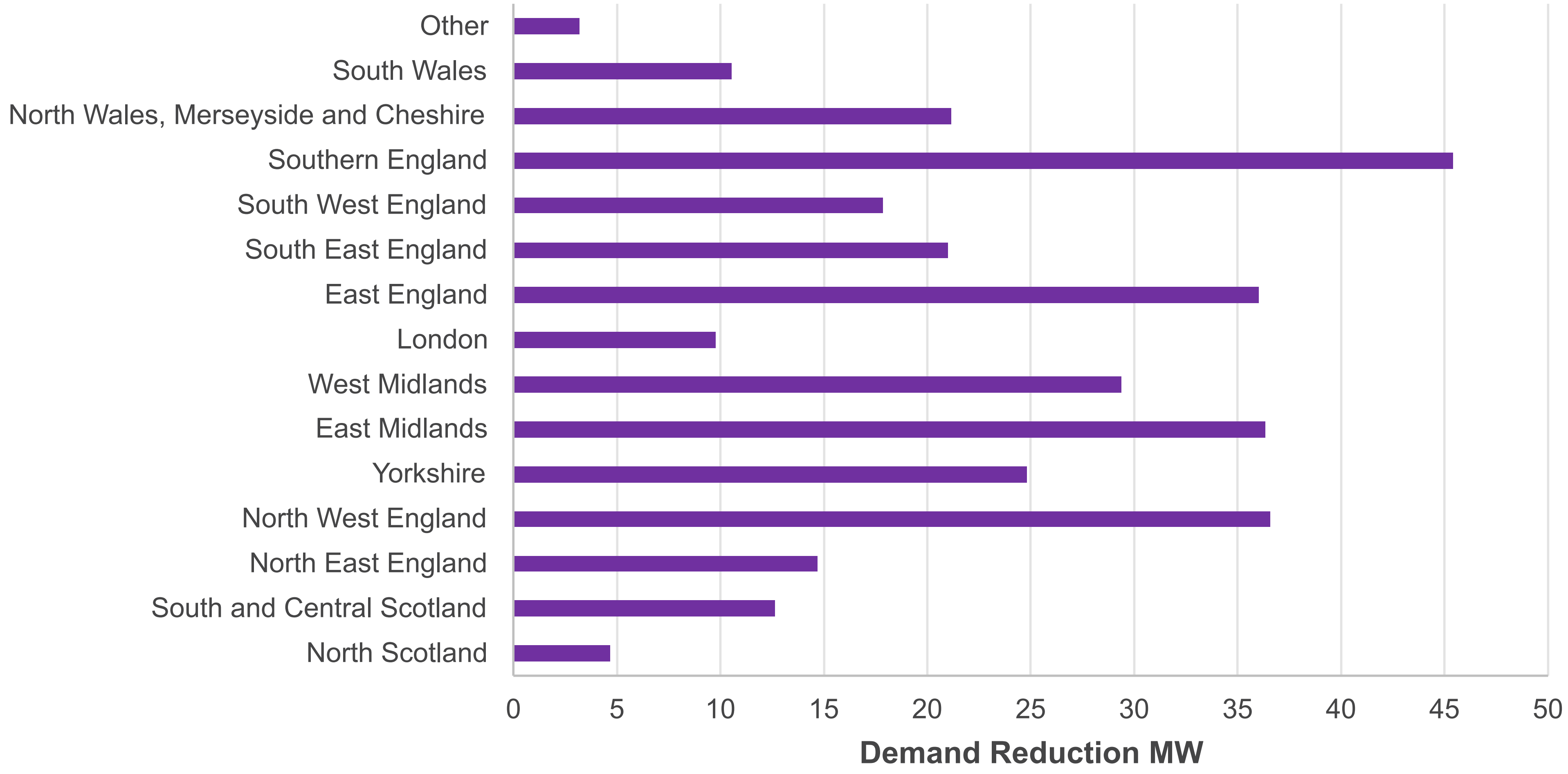
Figure FL.20: Example of DFS live service on the 23rd of January 2023 with a total demand reduction of 324 MW, equivalent to nearly 70,000 households participating in service. This was enough to power approximately 0.5 million homes across Great Britain



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Dunkelflaute period

'Dunkelflaute', refers to a period of cold weather with low light and little to no wind across Northern Europe.[8] Our analysis shows that a range of low carbon flexible technologies, from both the supply and demand sides, are required to maintain security of supply in periods of cold, dark, and still weather in 2050, in the absence of unabated gas generation.

The ESO has a key role to play in tackling climate change by transitioning GB's electricity system to net zero. We already operate the fastest decarbonising electricity system in the world and by 2050, we want to run a fully net zero whole energy system.

In May 2023, 44% of electricity came from zero carbon sources, peaking at 80% on 4th May at 11am. Gas was our largest source of fuel over the month, with 34% of electricity being generated by gas. Wind was our second largest power source, attributing 19.6% of generation. Currently, when the wind is not blowing and the sun is not shining, we rely on fossil fuel generation (Combined Cycle Gas Turbines (CCGTs), Open Cycle Gas Turbines (OCGTs) and coal units), interconnectors and Pumped Hydro Storage to ensure supply meets demand. Burning natural gas to produce electricity was the largest contributor to the generation mix at 38.5% in 2022, compared to 48.5% of zero carbon generation. As we move to net zero, it is imperative that we explore how the system will operate to meet demand without this current reliance on fossil fuels, especially on the days with low renewable generation.

Electricity systems need to match supply and demand; we call this energy balancing. The supply and demand through the transmission system varies as we cannot perfectly predict the flow of electricity, which requires intervention to maintain balance. Variations in demand occur seasonally, within-day due to weather patterns and because of changes in the price of commodities, affecting flows over interconnectors. Variations in supply occur due to weather dependant renewable energy generation and the supply of oil, coal, and gas. As supply and demand vary throughout the day, season, and year, there are fluctuations in the flow of energy meaning the system requires flexibility.

Operating an electricity transmission system also comes with challenges to ensure stability, voltage and thermal constraints are managed second by second. Here, we will not cover operability in depth; more information can be found in the Operability Strategy Report.

Modelling and assumptions

We assessed the operation of the network in 2050 using the extreme weather year of 1985. We focussed on the period from the 19th of February till the 3rd of March, when an extended dunkelflaute period was experienced.

8 renewableenergyhub.co.uk/blog/what-will-dunkelflaute-mean-for-renewable-energy-surge

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Dunkelflaute period

Supply and demand data from Consumer Transformation were used. This scenario assumes significant decarbonisation and lifestyle changes for consumers, as well as a mixture of hydrogen and electrification of heating.

Our BID3 dispatch model simulated supply and demand balance on an hourly-basis, in an unconstrained network,[9] across the dunkelflaute period. All FES scenarios meet the reliability standard set by the government – currently three hours per year Loss of Load Expectation.[10] However, as we move in the future, metrics and standards for measuring resource adequacy may change or be combined with other metrics; for more details on this topic, please see our "Resource adequacy in the 2030s" report. More information on the detailed hourly supply and demand modelling can be found in our recent energy article here.

Why did we choose this period in 1985?

The winter months of the year with cold and cloudy weather often put the largest strain on the system and pose the greatest challenge for the control room to balance supply and demand. The winter months generally see the lowest solar outputs, but have a greater demand for home heating, lighting, and indoor appliances. While wind output is generally higher in the winter months, it has variability within day, week, and season.

Europe-wide cold spell
10 Jan - 19 Jan 1985

"A very cold period with substantial snowfall and a mix of low and high wind speed periods, with load loss result from both cold temperatures and wind speeds."

Cold spell
14 Nov - 1 Dec 1985

"A short period of unusually very cold weather and snowfall, however wind speeds remained moderate throughout, so adequacy issues are caused by temperature."

Wind Drought
19 Feb - 3 Mar 1985

"A very long period of low wind speeds due to high pressure areas over North West Europe causes system issues due to storage not being able to refill."

Following ESO analysis in the "Resource adequacy in the 2030s" report, which we complement in this current FES analysis, we selected a similar period of severe wind drought, when a very long period of low wind speeds was observed in North-West Europe causing system issues due to storage not being able to recharge (3rd box shown above). This period was used in our simulations for the extreme weather year of 1985 and for the predicted year of operation of 2050.

A combination of technologies would be required to meet demand during the week in question. This is primarily due to the total renewable generation dropping from 139 GW at the highest to 14 GW at the lowest point, in the first examined stress period (first valley in Figure FL.21 between hours 29-92).

9 We assumed the transmission network could send power wherever it is needed, meaning that the network was unconstrained in its capacity. The impact of this is that power produced in the north of Scotland via wind turbine generation has no issue in travelling to the south of England where demand is highest. We know that this will likely over or underestimate power flows, but we focused on energy limitations to analyse how the system met demand.

10 LOLE is the expected number of hours when demand is higher than available generation during the year before any mitigating /emergency actions are taken but after all system warnings and System Operator (SO) balancing contracts have been exhausted. It is important to note when interpreting this metric that a certain level of loss of load is not equivalent to the same amount of blackouts; in most cases, loss of load would be managed by actions without significant impacts on consumers. The Reliability Standard set by the Government is a LOLE of 3 hours/year.

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Dunkelflaute period

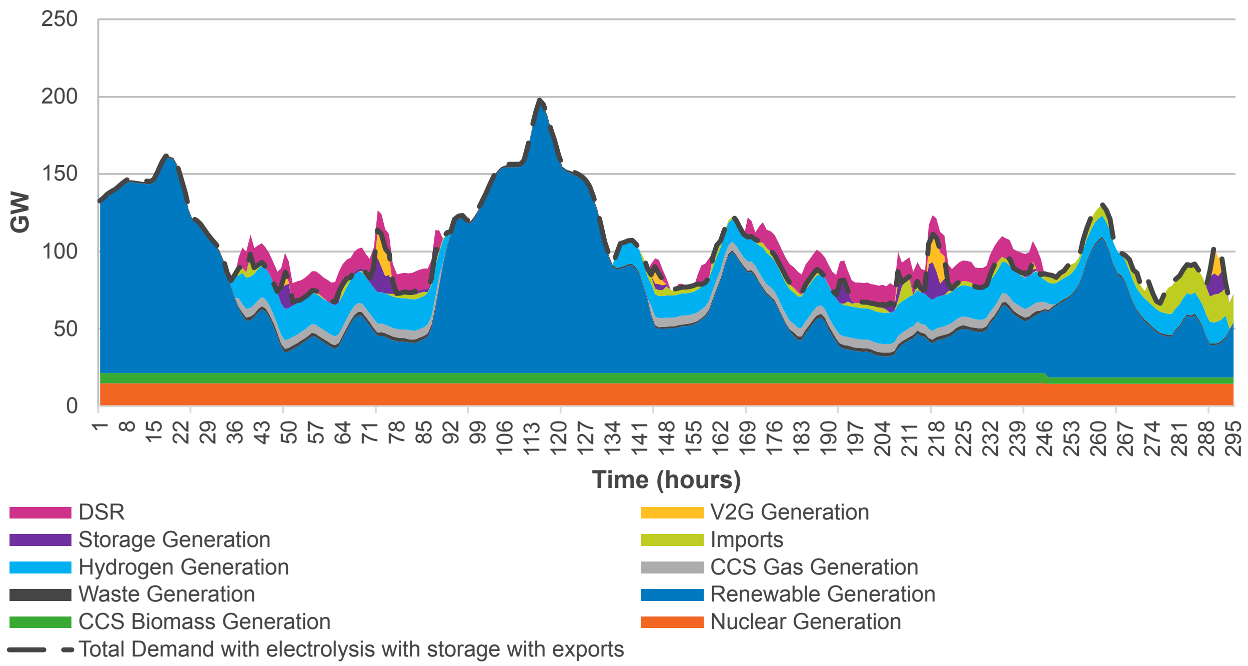
What does generation look like?

Thermal generation from natural gas currently provides between 10% and 50% of our electricity supply each day, depending on the weather. When there is less electricity generation from wind and solar, we rely on natural gas generation to increase output so that supply meets demand. As we move towards a net zero system, we will have a much higher reliance on wind, and other renewable generation that replaces a significant amount of natural gas generation.

Fig. FL.21 shows the generation stack per hour for the examined stress period in 2050. The demand line on Figure FL.21 shows total demand, which includes storage recharge, hydrogen production by electrolysis and interconnector exports. The first low point (between 29 and 92 hours) shows offshore wind power dropping to 14 GW. Despite this, even during this low wind power output period, the demand was met constantly through the dispatch of other flexible supply and demand sources, such as demand reduction, energy storage, dispatchable thermal generation and interconnector flows. It is worth mentioning here that as the total UK wind fleet becomes more geographically diverse, and/or deeper in the North Sea, where more floating wind turbines will exist, this will increase the minimum wind power output we are likely to observe in the future.

Taking a close look at the stress period between 29 and 92 hours in Fig. FL.22, the model determined the optimum supply side, storage, and demand side flexibility options to fill the gap created from the lack of wind.

Figure FL.21: Generation stack from the 19th of February till the 3rd of March 1985 for the simulation year of 2050 in GWh



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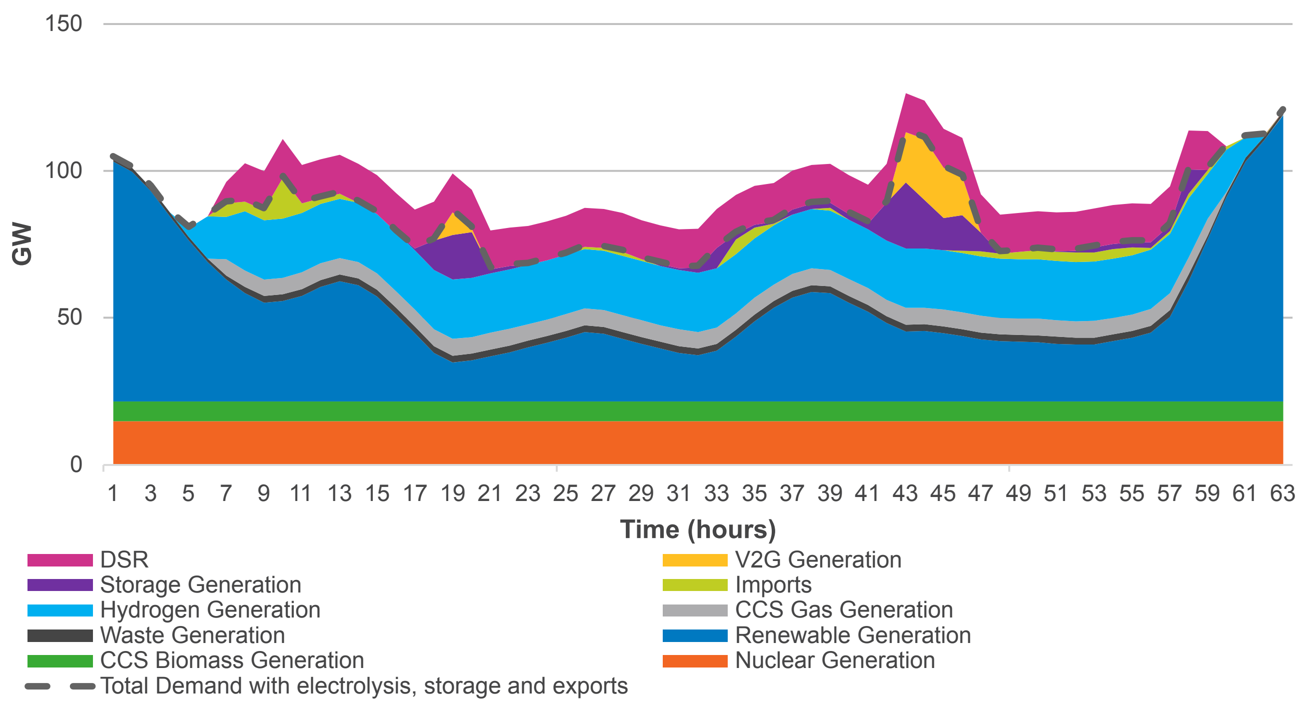
Dunkelflaute period

Figure FL.22: Generation stack for the first stress period between 29-92 hours (GWh)



The biggest contribution of flexibility came from hydrogen fuelled generation, followed by DSR, CCUS, storage and interconnectors. Fig. FL.22 shows that hydrogen fuelled generation was used constantly during the constrained period. This reiterates the importance of LDES as we move towards net zero and encounter different weather patterns. 6 TWh of electricity produced from hydrogen fuelled generation was used in this period. Considering that the scenario being analysed is Consumer Transformation, this hydrogen is assumed to be mainly electrolytic and hence, it came primarily from hydrogen storage. With an assumed round-trip efficiency of 55%, this leads to a significant hydrogen storage requirement of 10.9 TWh, which is equivalent to two thirds of the UK's natural gas storage capacity at the end of 2022. All these highlight the importance of hydrogen storage as we decarbonise the grid and move towards net zero in 2050.

DSR contributed significantly through demand reduction and Vehicle-to-Grid operation/generation during the period of low wind as well as electricity storage. Electricity storage provided 200 GWh of energy in this period, as wind output was falling. The model chose to start this stress event with the storage 100% full and to almost completely empty, just before the end of this stress period (end in Figure FL.22). Fig. FL.23 shows the behaviour of storage during the first constrained period. Total storage starts full at the beginning of this period 100% State of Charge (SoC) and operates almost constantly till the end of the strained period, when it becomes empty (0% SoC). Once the stress period had ended, it then started recharging the storage, so that it would be ready to discharge during the next stress period between 176-246 hours.

BECCS and nuclear were running baseload during the stress period, whereas a certain amount of gas with CCUS and energy from waste were also dispatched to meet demand.

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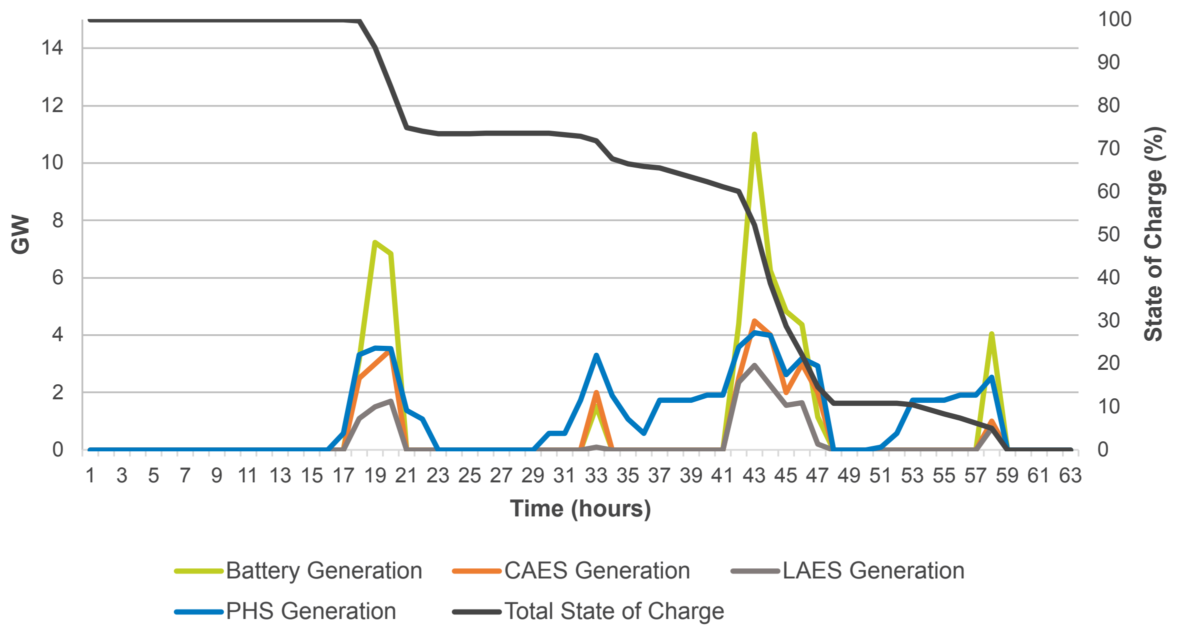
Dunkelflaute period

Figure FL.23: Storage generation from various technology types (GWh) and total state of charge (%). Types assumed include battery storage, compressed air energy storage, liquid air energy storage, pumped hydro storage



By further analysing the imports shown in Figures FL.21 and FL.22, it was found that overall, they did not contribute significantly during the first stress event. This is mainly because Europe (Belgium, Ireland, and Netherlands) was in a more strained situation during the dunkelflaute event and required UK exports as an additional support to cover their demand needs (please see weather correlation maps in the footnote).[11] Therefore, imported flows from Europe were smaller overall, with an improvement observed at the end of the whole examined period (beginning of March in Fig. FL.21). This was a result of improved conditions in the rest of the Europe, and of being cheaper to cover UK demand in this way rather than dispatching gas with CCUS in the UK. On the other hand, the UK was mainly importing from Norway during the stress period, acting as a hub to the rest of Europe. This is due to Norway having a large hydropower capacity, which is not weather-dependent.

It is important to note that the utilisation of dispatchable plants (gas with CCUS, hydrogen CCGT and waste) and of flexible (electricity storage, DSR, V2G, flows) technologies was driven by the system marginal price per hour, which will be shown in the next section. As the marginal price increases or decreases, different technologies come on the system to meet demand.

11 Energies | Free Full-Text | A Brief Climatology of Dunkelflaute Events over and Surrounding the North and Baltic Sea Areas (mdpi.com)

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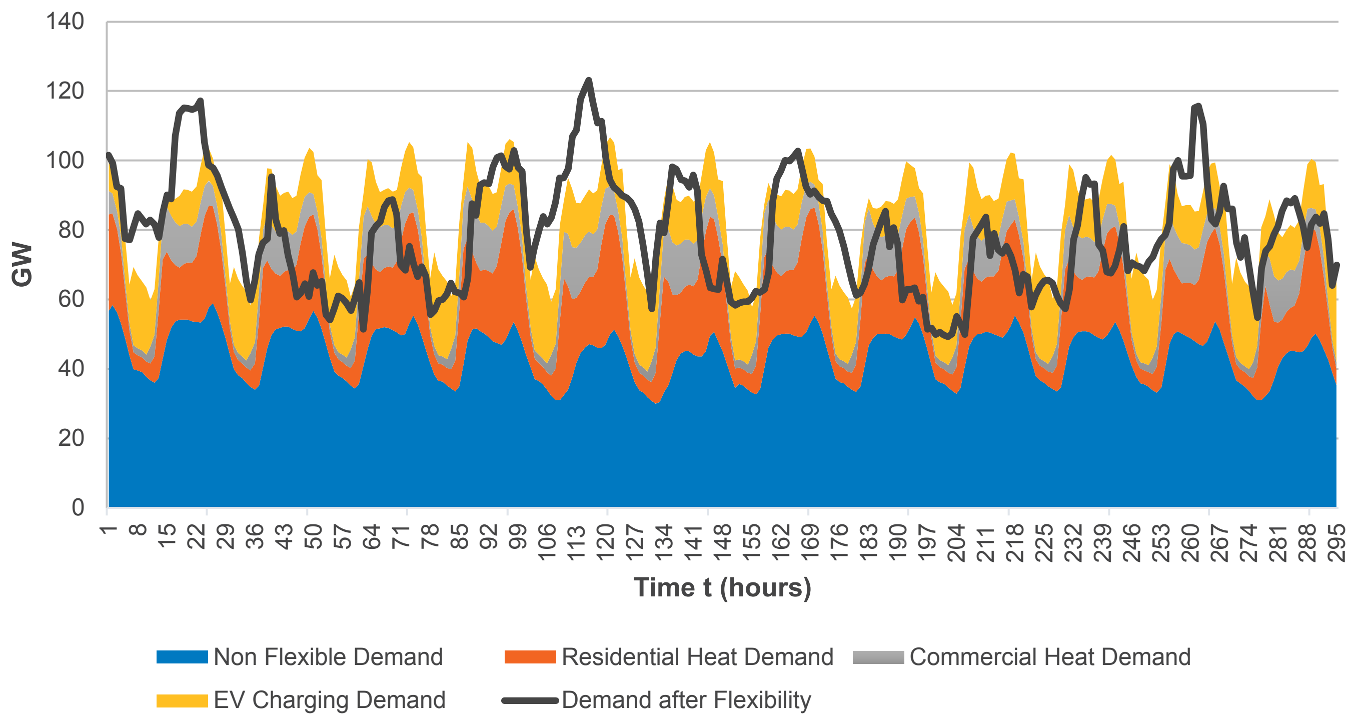
Dunkelflaute period

What does demand look like?

The renewable generation in the examined stress period falls rapidly, as explained earlier, but we also see a drop in demand during this period (blue line in Fig. FL.24). As the marginal price of electricity generation increases, demand side flexible options respond, leading to a reduction in overall demand during the first stress period. The latter is illustrated in Fig. FL.24 via the black line showing flexible demand which has a significantly different pattern to the inflexible and periodic demand profile. We note here that more studies are needed to understand how consumers will behave under extreme weather conditions and the figures shown constitute the potential contribution from DSR.

As shown in Fig. FL.25, when the system marginal price is low, hydrogen production via electrolysis is at high levels and all electricity storage technologies charge. Exports via interconnectors are also present, due to lower system prices and power needs across Europe. Low price periods correlate with the periods of high renewable generation shown in Figures FL.21 and FL.22, respectively. When the system marginal price is high, the UK would export power to the rest of Europe for similar reasons and the system demand drops significantly via DSR, V2G and heat flexibility from the residential and commercial sectors (heat pumps and district heating).

Figure FL.24: Non-flexible demand profiling alongside demand line after flexibility (GWh)



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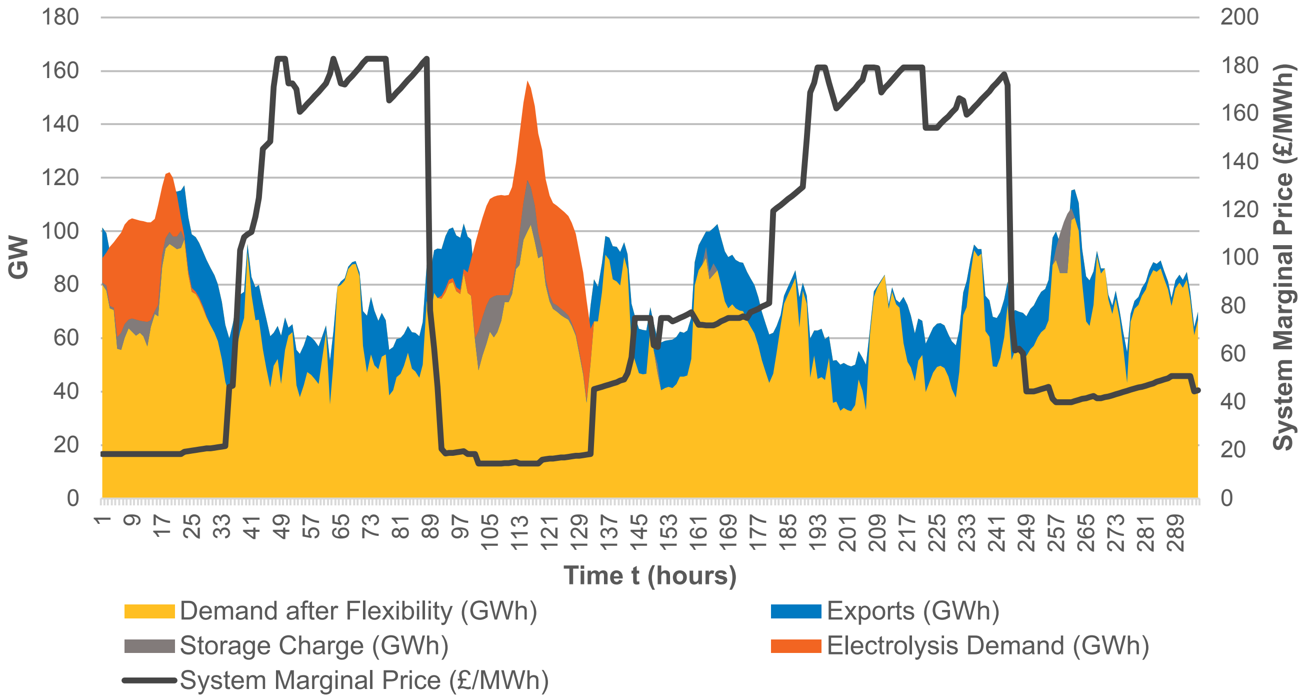
Dunkelflaute period

Figure FL.25: Decomposition of total demand shown in Figure FL.21 into its individual elements (GWh)



Overcoming the challenges of a dunkelflaute period

Electricity storage, DSR, dispatchable thermal generation, gas with CCUS, hydrogen CCGT power generation and interconnection with neighbouring countries will all play a vital role to achieving the flexibility required during a dunkelflaute period. However, there are some challenges that need to be overcome so these technologies become fully available in 2050.

Many of these technologies, such as LDES, typically have long lead-times for deployment that could be much longer than the timescales in the current Capacity Market mechanism, which is currently the main mechanism for delivering new capacity to ensure security of supply. Additional research and development efforts are required in new forms of LDES to prove technical and commercial viability.

DSR will be increasingly important in managing stress periods and can enable consumers to save on their cost of energy during high price periods. As shown in Figures FL.21 and FL.22, the DSR potential from residential, commercial, and industrial sectors was significant (reaching 30-50 GW increase or decrease for some hours) during the low wind periods. The Demand Flexibility Service, launched by ESO during November 2022, showed consumer willingness to participate in DSR, but this was only the starting point. Appropriate market reform, signals and technology advancement are needed to ensure effective DSR levels in the future, as well as better understanding of how consumers will behave under extreme weather conditions.

As we move towards 2050, cars are primarily electrified, increasing electricity demands and requiring strategies to manage how they are charged, and how system costs are recovered.

Dunkelflaute period

Increasing implementation of smart EV charging is an essential action to reduce curtailment of renewables. Commercial trials of V2G business models are required to explore their viability and contribution to system services. It also requires current challenges to be addressed, such as the slow rollout of charging infrastructure.

Access to hydrogen storage for the power sector is complex and requires a range of technologies to be available. This could include technologies such as: electrolysis near to renewable generation to absorb excess output, hydrogen pipelines to transport the hydrogen to LDES, salt cavern storage for weekly or seasonal storage of hydrogen and hydrogen power generation such as CCGTs to convert the stored hydrogen back to power. Business models for the transport and storage of hydrogen are lagging those for low carbon hydrogen production. These must be delivered to reduce investor uncertainty and ensure that hydrogen storage is developed alongside production.

We continue to improve our understanding of risks due to weather patterns to ensure adequacy in a fully decarbonised system with high levels of weather-dependent generation. For planning purposes, a range of different scenarios and weather events will need to be examined to cover a range of possibilities.

Location needs to be considered when deploying flexibility as for some technologies, such as energy storage, interconnectors, DSR or electrolysis, more value can be delivered in some locations than others and help reduce curtailment. The growth of distributed flexibility (flexible energy resources, such as storage, EVs, heat pumps and thermal storage, connected at distribution level) is a key enabler to achieving net zero. A market-wide strategy, including government targets, policy support and market reform is required to facilitate significant growth in distributed flexibility.

Overall, implementation of market reform and digital infrastructure improvements, as well as network upgrades are needed for flexible technologies to meet the necessary flexibility requirements in 2050. Net zero and adequacy are not jeopardised if investment in clean and reliable technologies are brought forward to ensure the system is balanced even at times of low output from weather-dependent generation towards 2050.

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Glossary

Acronym	Description
ASHP	Air Source Heat Pump
ACS	Average Cold Spell
BEV	Battery Electric Vehicle
BESS	Battery Energy Storage Systems
bcf	billion cubic feet
bcm	billions cubic metres
BECCS	Bioenergy with Carbon Capture and Storage
BUS	Boiler Upgrade Scheme
CfE	Call for Evidence
CM	Capacity Market
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
CO_2	Carbon Dioxide
CCC	Climate Change Committee
CoP	Coefficient of Performance
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power
CAES	Compressed Air Energy Storage
CNG	Compressed Natural Gas
CPAs	Construction Planning Assumptions
CfD	Contract for Difference

Acronym	Description
DCC	Data Communications Company
DFS	Demand Flexibility Service
DSR	Demand Side Response
DESNZ	Department of Energy Security and Net Zero
DACCS	Direct Air Carbon Capture and Storage
DPAs	Dispatchable Power Agreements
DNO	Distributed Network Operator
DFES	Distribution Future Energy Scenarios
EV	Electric Vehicle
ECM	Electricity Capacity Market
EMR	Electricity Market Reform
ESO	Electricity System Operator
ETYS	Electricity Ten Year Statement
EBD	Energy Background Document
EPG	Energy Price Guarantee
NZMR	ESO's Net Zero Market Reform
FiT	Feed-In Tariff
FEED	Front End Engineering Design
FCEV	Fuel Cell Electric Vehicle
FHS	Future Homes Standard
FSO	Future System Operator

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Glossary

Acronym	Description
GW	Gigawatt
GWh	Gigawatt hour
GB	Great Britain
GHG	Greenhouse Gas
GGR	Greenhouse Gas Removal
GDP	Gross Domestic Product
GSHP	Ground Source Heat Pump
HGVs	Heavy Goods Vehicle
HND	Holistic Network Design
HAR	Hydrogen Allocation Round (HAR)
HPBM	Hydrogen Production Business Model
I&C	Industrial & Commercial
IT	Information Technology
IPCC	Intergovernmental Panel on Climate Change
ICE	Internal Combustion Engine
IAS	International Aviation and Shipping
IEA	International Energy Agency
kWh	Kilowatt Hour
LULUCF	Land Use, Land Use Change, and Forestry
LED	Light Emitting Diode

Acronym	Description
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LAES	Liquid Air Energy Storage
LA	Local Authority
LDZ	Local Distribution Zones
LDES	Long Duration Energy Storage
LOLE	Loss Of Load Expectation
LCT	Low Carbon Technology
LSOA	Lower Super Output Area
MJ	Mega Joule
$MtCO_2e$	Mega Tonnes of CO_2 Equivalent
MW	Megawatt
MWh	Megawatt Hour
CH_4	Methane
mcm	million cubic metres
MPIs	Multi Purpose Interconnectors
NGET	National Grid Electricity Transmission
NTS	National Transmission System
NDC	Nationally Determined Contributions
NTV	Near threshold voltage
NET	Negative Emissions Technologies

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Glossary

Acronym	Description
NZHF	Net Zero Hydrogen Funding
NOA	Network Options Assessment
NZS	New Zealand Energy Strategy
N_20	Nitrous oxide
NSTA	North Sea Transition Authority
PV	Photovoltaic
PHEVs	Plug-in Hybrid Electric Vehicle
PHS	Pumped Hydro Storage
R&D	Research & Development
SHET	Scottish Hydro Electricity Transmission
SPT	Scottish Power Transmission
SERL	Smart Energy Research Lab
SoC	State of Charge
SSF	Supply Side Flexibility
SAF	Sustainable Aviation Fuel
SO	System Owners
TWh	Terawatt Hour
ToUT	Time Of Use Tariff
TEC	Transmission Entry Capacity

Acronym	Description
TO	Transmission Owners
UKCS	UK Continental Shelf
UK	United Kingdom of Great Britain and Northern Ireland
UN	United Nations
V2G	Vehicle-to-Grid

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Thanks for your time, we hope you found FES 2023 interesting and useful!

Continuing the Conversation

In terms of next steps, we now move into our main stakeholder engagement stage of the FES cycle, using your comments and questions about FES 2023 to inform our future analysis and insights. We're also increasing the regional focus of our work, and would especially welcome your local insights.

Similar to previous years, we will be using FES 2023 as a basis for the next iteration of 'FES - Bridging the Gap to Net Zero'. If you'd like to know more, please click here.

Ways to connect and stay in touch

Keep an eye out for any surveys, energy articles and engagement opportunities via our FES newsletter. If you are not already subscribed, you can do so via subscribers.nationalgrid.co.uk, the ESO website nationalgrideso.com or use the FES email address opposite.

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Access our current and past FES documents, data and multimedia at: nationalgrideso.com/future-energy/future-energy-scenarios.

Get involved in the debate on the future of energy and join our LinkedIn group Future of Energy by National Grid ESO.

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