THERMAL STORAGE UK

Flexibility for low carbon electric heating

The role of smart thermal storage in providing flexible, low carbon electric heating

October 2022

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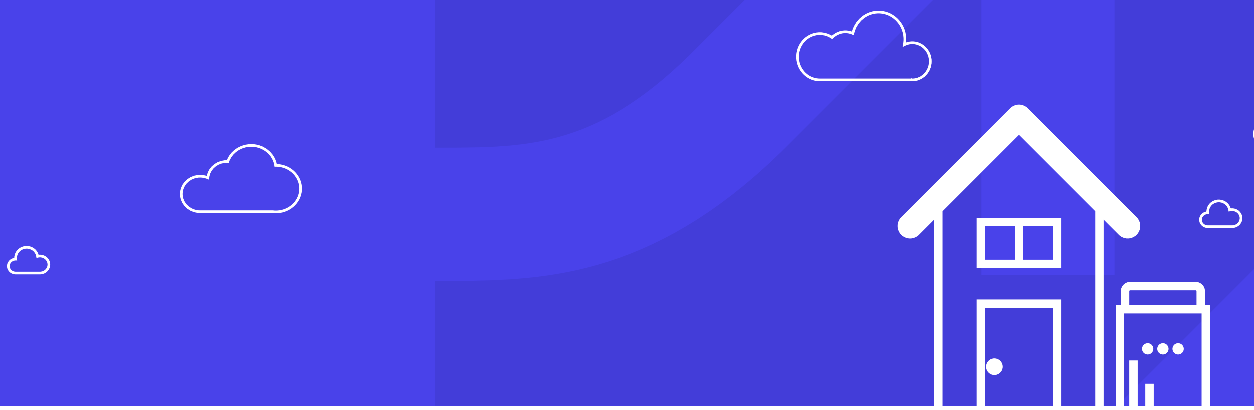
We thank LCP Delta for their work on the analysis used in this report.

Thermal Storage UK

Thermal Storage UK is the trade association representing British companies offering smart thermal storage. We support taking the carbon out of buildings by electrifying heating. Smart thermal stores work with or instead of heat pumps, working with time of use tariffs to maximise the value of renewable generation and provide flexibility to the grid. More information about Thermal Storage UK is available at www.thermalstorage.org.uk



Contents

- Executive Summary 4
- Introduction 9
- Fully decarbonising the electricity system 12
- Decarbonising UK heating systems 14
- What is smart thermal storage? 17
- How to secure flexibility from heat 19
- How much heat flexibility could we see? 20
- What is the potential value of this heat flexibility? 27
- Recommendations to support heat flexibility 29
  - Redesign power markets to value flexibility 30
  - Make it easy to install heating products which can offer flexibility 31
  - Create a level playing field for low carbon heating technologies 32
  - Support and protect people updating their heating systems 33
  - Provide long-term clarity to people and businesses 34
  - Provide high quality training for heat engineers 35
- How LCP Delta approached this analysis 36
- Assumptions in the LCP Delta analysis 38

Executive Summary

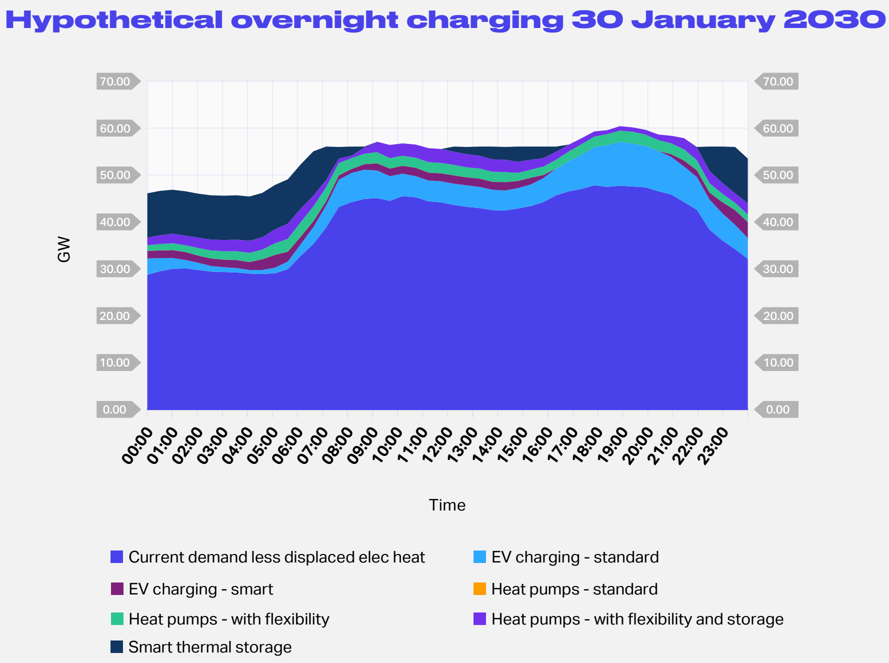
This report sets out the scale and value of heat flexibility from smart thermal storage working with or instead of heat pumps. The flexibility of these smart products provides value for the future electricity system and households as the UK decarbonises. The analysis conducted by consultants LCP Delta estimates that the UK could use smart thermal storage to reduce peak electricity demand on the coldest day by 1.6GW by 2030 by shifting when we produce heat and storing that heat for later. This peak demand reduction from smart thermal storage could increase to 4.1GW if the benefits of flexibility to electricity networks were reflected in pricing. Heat flexibility reduces the use of fossil fuel back-up generation and increases utilisation of wind and solar, reducing emissions by making better use of renewable generation. The report offers recommendations on how to make the most of this valuable flexibility.

The report focuses on dedicated products, sometimes known as heat batteries, which store heat for space heating and/or domestic hot water and respond smartly to price and carbon signals from the electricity system. The LCP Delta analysis considers smart heating products such as those produced by Sunamp, tepeo and Caldera. The LCP Delta analysis does not consider alternative ways to provide heat flexibility, such as pre-heating homes by 2-3 hours or turning heat pumps off or down to avoid winter peaks. The potential scope of heat flexibility may be larger than this report shows.

The analysis shows that heat flexibility may reduce costs to people and the system overall. People charge up their smart thermal storage at times of low cost renewable electricity and use this stored heat to warm their homes at times of expensive peaks. Utilising heat flexibility in 2030 would mean that National Grid ESO would have less need to turn down renewable generators, better utilising the existing networks, reducing the need for additional network investment and improving security of supply.

Indeed, to demonstrate the value at stake, National Grid ESO is currently forecasting that constraint costs could rise to over £3 billion per annum this decade[1] and is designing a flexibility service for winter 2022 / 23 offering people £2 per kWh to turn down or shift electricity consumption. With the right reforms to power market design and if providing heat flexibility was properly valued in electricity systems, heat flexibility could be worth billions per year to the system and households.

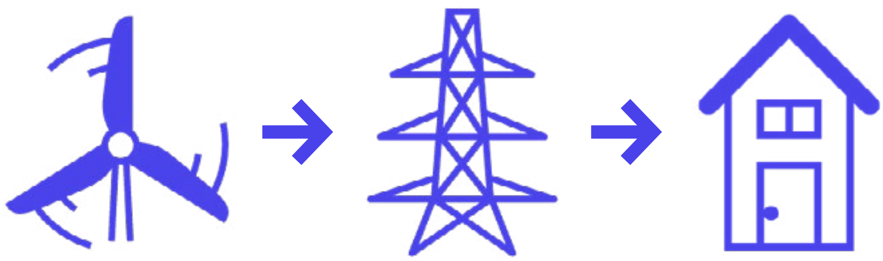
[1]National Grid ESO, 2022 https://www.nationalgrideso.com/document/266576/download



LCP Delta analysis

The LCP Delta analysis looks at 2030 and so is based on 2.4 million homes containing smart thermal storage - with or without a heat pump - for space heating. The potential for heat flexibility in a fully decarbonised power system is much greater. National Grid ESO forecasts in their "Leading the Way" Future Energy Scenarios that Britain will have excess generation 92% of the time by 2050. Both National Grid ESO and the Climate Change Committee see more than 20 million homes in the UK moving to low carbon electric heating by 2050.

Harnessing that heat flexibility to better match supply and demand is an important part of market design. The analysis confirms that heat flexibility is at the heart of the interaction between keeping buildings warm, generating renewable energy and operating the electricity system safely and efficiently. Making the most of this heating flexibility will reduce the cost of investing in network infrastructure and ensure the UK makes the most out of its abundant renewable generation.



Smart thermal storage helps to decarbonise heating in buildings, balance the electricity system and provides a growth and export opportunity for Britain. Innovative manufacturers such as Sunamp, tepeo and Caldera are designing and building thermal storage in Britain and looking to export globally.

We need to apply the same rigorous focus on decarbonising buildings as we have applied to introducing electric vehicles (EVs). Over the last 10 years, the UK has made significant progress in developing EVs and the related charging infrastructure. The UK has introduced standards on EV charging points to manage the increase in electricity demand. Some energy suppliers now offer time of use tariffs to maximise the value of charging EVs. We now need the same rigorous focus applied to decarbonising buildings in a way that benefits people and the electricity system.

Recommendations

To ensure that products such as smart thermal storage are available to provide heat flexibility to the energy system requires legislative and regulatory changes. We offer 16 recommendations on areas for reform. These are summarised in the table below, with more detail on the rationale set out in the last section of the report.

Redesign power markets to value flexibility and pass this value to end users

Recommendation 1	Amend the Energy Act 2004 to separate low carbon and fossil fuel wholesale markets.
Recommendation 2	BEIS to provide Ofgem with a clear steer to introduce mandatory half-hourly settlement by December 2023.
Recommendation 3	Amend the Renewables Obligation Order 2015 to reallocate legacy policy costs such as the Renewable Obligation from the electricity bill.
Recommendation 4	Change the Utilities Act 2000 to require energy suppliers to provide at least one time of use tariff for electric heating, starting in December 2023.
Recommendation 5	The government and National Grid ESO develop publicly available whole system modelling that can consider local network constraints, distributed energy assets and the increase in renewables.

Make it easy to install heat products which can offer flexibility

Recommendation 6	Introduce new primary legislation to require that all heating systems from 2025 can provide flexibility.

Recommendation 7	Introduce new primary legislation requiring all low carbon electric heating to meet smart standards by 2025.
Recommendation 8	Update Energy Performance Certificates (EPCs) and the Energy-Related Products (ERP) Framework to incorporate flexibility.
Recommendation 9	Amend the Building Regulations 2010 and any associated schedules to replace the term "hot water cylinder" with "thermal storage".

Create a level playing field for low carbon heating technologies

Recommendation 10	Change the definition of "energy saving materials" in the VAT Act 1994 to zero rate the installation of low carbon thermal storage in all circumstances.
Recommendation 11	Expand the definition of "Eligible Plant" in the Boiler Upgrade Scheme (England and Wales) Regulation 2022 to cover thermal storage.

Support and protect people updating their heating systems

Recommendation 12	Change the Utilities Act 2000 to place a duty on Ofgem to deliver net zero, including in relation to heating.
Recommendation 13	Amend the Consumers, Estate Agents and Redress Act 2007 to extend the advice role of Citizens Advice to helping people choose the best low carbon heating system for their home or business.
Recommendation 14	Add misleading and unsubstantiated green claims to the list of banned practices under the Consumer Protection Regulations (CPRs) and Consumer Contracts (Information, Cancellation and Additional Charges) Regulations 2013.

Provide long-term clarity to people and businesses

Recommendation 15	Introduce new primary legislation setting clear end dates for the sale of fossil fuel heating systems and the sale of fossil fuels for heating.

Provide high quality training for heat engineers

Recommendation 16	Establish a training centre for low carbon heating engineers.

Who this report is for

We recognise that heat flexibility is an underdeveloped area of thinking in the energy sector. That is why we commissioned LCP Delta to undertake this analysis. The report is designed for policymakers working on energy. We hope that the report is useful to those thinking about building decarbonisation and power market reform. We expect the UK and Scottish governments, Ofgem, National Grid, network operators, energy retailers and the National Infrastructure Commission may find the report insightful. Further work is required to refine the analysis and to consider the interaction with potential power market reform options.

A note on the analysis

Projections are difficult, especially at times of deep system transformation over decades. We have aimed to make assumptions that are consistent with UK government forecasts and which err on the side of being conservative. We welcome feedback on any or all of the assumptions we have made. Please provide feedback via the Contact Us section of the Thermal Storage UK website.

One of the reasons that Thermal Storage UK produced this report was the lack of whole system modelling available that allows consideration of the interaction between local network constraints and the impact of distributed electricity demand products such as thermal storage and heat pumps. One of our recommendations in this report is the need for more granular modelling that can consider these distributed assets, local constraints and provide a whole system answer. Our view is that the UK government and National Grid ESO are best-placed to develop this model, which should be publicly available.

Introduction

"Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans"

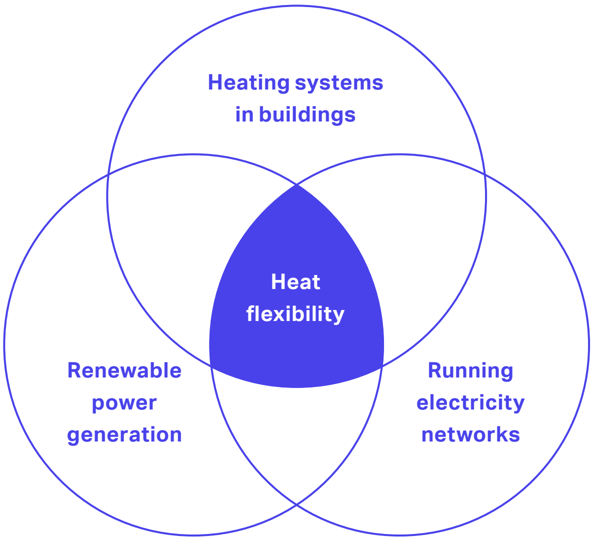
IPCC Sixth Assessment Report, February 2022

The UK is decarbonising to reduce the extent of human-induced climate change and to improve energy security. This requires removing fossil fuels from power generation, heating buildings and the transport system. Britain has rapidly expanded the capacity of its renewable generation and 2020 and 2021 had the highest levels of renewable generation on record[2]. In 2020, renewables contributed 43% of Britain's annual electricity. Thanks to a combination of market design, innovation and private sector financing, progress towards renewables will accelerate during the 2020s.

[2]Office of National Statistics 2022, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables

To reduce carbon emissions and an unhealthy reliance on imported fossil fuels, Britain is expected to stop using fossil gas to heat homes and move to low carbon electricity heating instead during the 2020s and 2030s. This will involve electric heating products such as heat pumps, smart thermal storage and heat networks.

Decarbonising heating in buildings through electrification brings together heating systems in buildings and the electricity system.



This is a significant change from the situation in 2022. Over 90% of homes are heated by fossil fuels, with gas boilers most common. Using electricity for heating is different to using gas. While burning gas for heat accelerates climate change, gas has some useful properties such as the ability to store the gas for later use and to compress the gas to provide some system flexibility. In comparison, the electricity system must balance at all times, with supply (generation) meeting demand (people's electricity needs) within limited voltage parameters. In simplistic terms, electricity network operators must ensure the wires are big enough to carry electricity to meet peak demand and maintain voltage levels.

As with the shift from petrol and diesel cars to electric vehicles, electrifying heat increases overall electricity demand. Indeed, without considering flexibility, electric heating would increase peak demand on cold winter days. Electrification of heat could contribute to annual residential electricity demand increasing by 50% by 2035 and peak demand doubling by 2050[3]. To handle both the additional renewables and the increased demand for electricity in 2030, the energy sector can either build out the network infrastructure or flexibly use smart demand products. The more we develop flexibility on the demand side, the less the UK needs to spend on network infrastructure.

There are four main ways to use electric heating products to provide flexibility:

1. Using dedicated smart thermal storage products to store heat for later
2. Setting heat pumps to adjust their output +/- 1C
3. Using heat pumps to preheat (energy efficient) homes by 2-3 hours
4. Turning heat pumps off or down to avoid the winter peaks

This analysis focuses on the role of smart thermal stores - working with or instead of heat pumps - to provide heat flexibility. The energy efficiency improvements in buildings and changes in behaviour required for alternative paths to such flexibility are outside of the scope of this report.

This report explains the role of smart thermal storage in decarbonising heating and sets out the benefits of thermal storage flexibility for an increasingly renewable electricity system. The report then sets out the analysis on the scale of heat flexibility in 2030 and the value to households and businesses. The report concludes with recommendations for reforms to the electricity system.

[3]National Grid ESO, Future Energy Scenarios (FES) 2022 https://www.nationalgrideso.com/future-energy/future-energy-scenarios

A few points on terminology

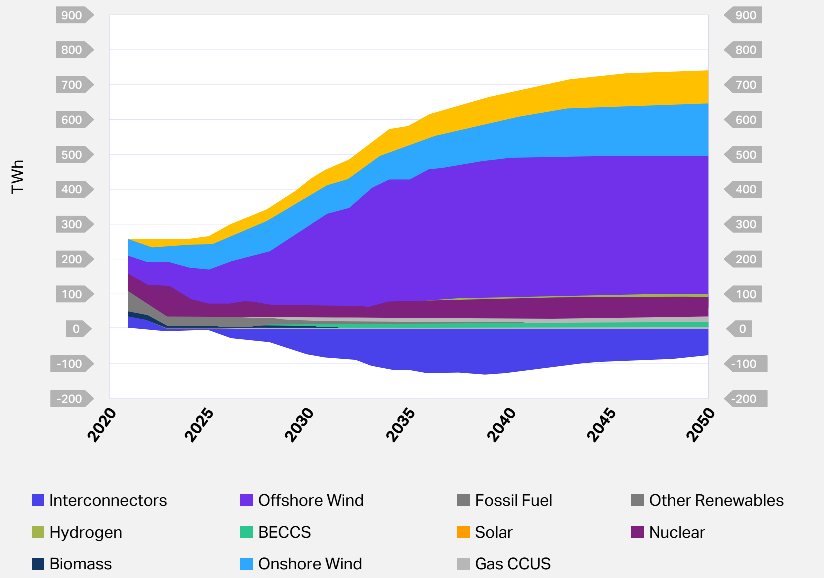
This report is written for those working on energy policy to decarbonise buildings and to design low carbon power markets for flexibility. While we have tried to minimise jargon from the heating and electricity sectors, there is some understanding assumed about the basics of the energy system. A few points on terminology:

- Our analysis covers both space heating (heating rooms) and domestic hot water (hot water from taps). For simplicity, we talk about heating demand to cover both types of heating
- When we discuss smart thermal storage or thermal stores, we cover space heating and hot water. Thermal stores may also be known as heat batteries
- Thermal storage is smart if it can respond to changes in the generation mix, for instance consuming more electricity when renewable electricity is prevalent
- When we talk about heat pumps, we are including all heat pumps but primarily thinking about hydronic air-source heat pumps (heat pumps using radiators)
- All heat pump systems in this analysis are installed with thermal storage for direct hot water. This may be a smart thermal store or may be a hot water tank. In the alternative scenarios, smart thermal storage is also used to provide flexibility for space heating. To provide space heating flexibility, hot water tanks would be too large for most homes
- When we discuss gas, we mean the fossil gas used in the UK to heat homes and produce electricity. As we are focused on a 2030 timescale, this report does not consider the potential implications of hydrogen replacing fossil gas for heating in some or any houses
- We use the term electro-chemical storage to refer to batteries that store electricity. Electro-chemical storage stores electricity for later use; thermal storage stores heat for later use
- When we talk about networks, we mean the wires that connect electricity generation and demand such as heating and transport. In the context of this report, that normally means Distribution Network Operators
- We use “power system” and “electricity system” interchangeably

Fully decarbonising the electricity system

The UK has made significant progress in decarbonising electricity generation. Power sector emissions have fallen by around 68% between 2010 and 2020[4]. The government has provided financial and regulatory support to wind turbines and solar and made it more difficult to burn coal. The private sector has responded by building renewable generation and - before the gas crisis meant fossil fuel prices soared in 2021 - energy bills increased very slightly to pay for this decarbonised British power. As recently as 2013, coal made up 40% of UK power generation. Renewables, backed up by fossil gas generation, have largely now displaced coal. Renewables now make up 40% of power generation. The UK is now looking to fully decarbonise the electricity system by 2035[5].

Electricity generation output by technology (TWh) in Leading the Way



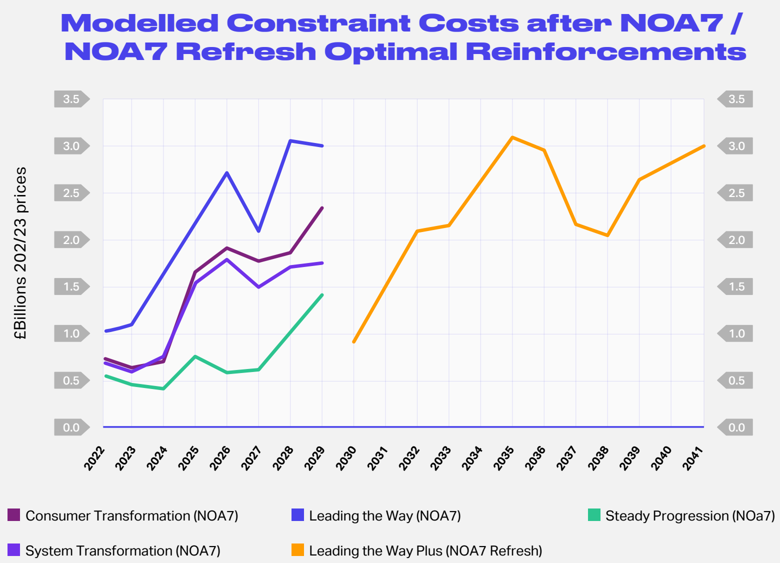
National Grid ESO, Future Energy Scenarios 2022

[4]BEIS 2021, Final UK greenhouse gas emissions national statistics: 1990 to 2020 https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020

[5]https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035

Decarbonising the power sector has involved increasing reliance on gas generators. The system has largely continued to operate on the basis that supply (power generation) must ratchet up or down to meet a fixed volume of demand (what people ask for). On still or cloudy days, this means turning up gas (or even coal) power plants.

While building more renewables will help displace fossil fuels on many days of the year, a fully decarbonised power system requires the ability to store energy and the ability to alter demand. Without flexibility on the demand side, constraints will mean that National Grid ESO will need to turn down renewable generators. Indeed, National Grid ESO is forecasting that constraints will cost consumers £3 billion per year by 2030.



National Grid ESO, Modelled Constraint Costs NOA 2021/22 Refresh – August 2022

Storing energy may involve thermal storage, electro-chemical storage, pumped hydro or even hydrogen electrolysis. Altering demand means encouraging people to change how and when they require energy. This is flexibility. Flexibility becomes even more important as we increase the load on the electricity system through transport and heat.

The government and energy businesses understand the problem and the opportunity that flexibility provides. BEIS and Ofgem have published a Smart Systems and Flexibility Plan 2021[6], which sets out potential savings from a flexible power system as £10 billion a year by 2050. The government is currently undertaking a Review of Electricity Market Arrangements (REMA) and is legislating to establish a Future Systems Operator, in part to deliver the more flexible electricity system we need.

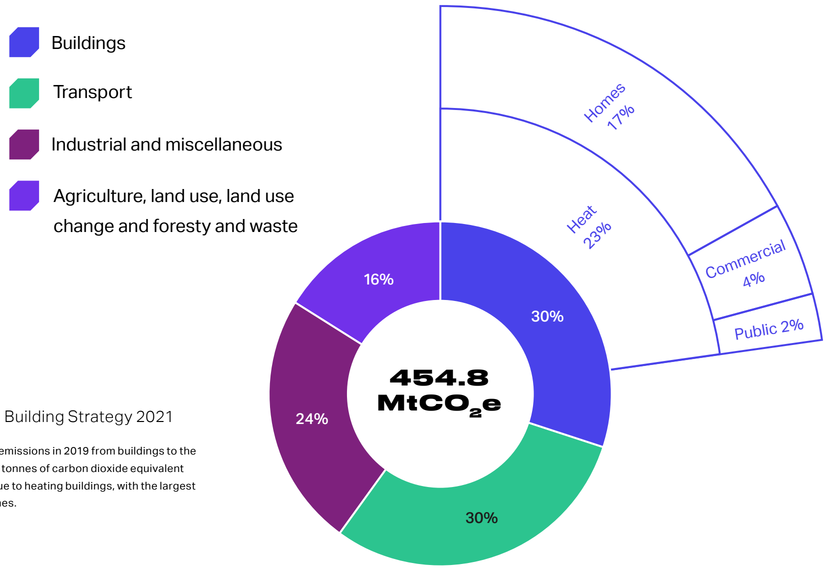
To provide a base case for policymakers, this report uses the existing market arrangements for the power sector. We encourage policymakers working on areas such as REMA to use the analysis as they develop alternative options for future power market design.

[6]UK Government, 2021 Smart Systems and Flexibility Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003778/smart-systems-and-flexibility-plan-2021.pdf

Decarbonising UK heating systems

Heating our buildings is responsible for 23% of the UK's emissions[7]. This is primarily because buildings use fossil fuels such as gas, oil and LPG for heating. 85% of British homes use gas for heating.

UK emissions in 2019



UK Government, Heat and Building Strategy 2021

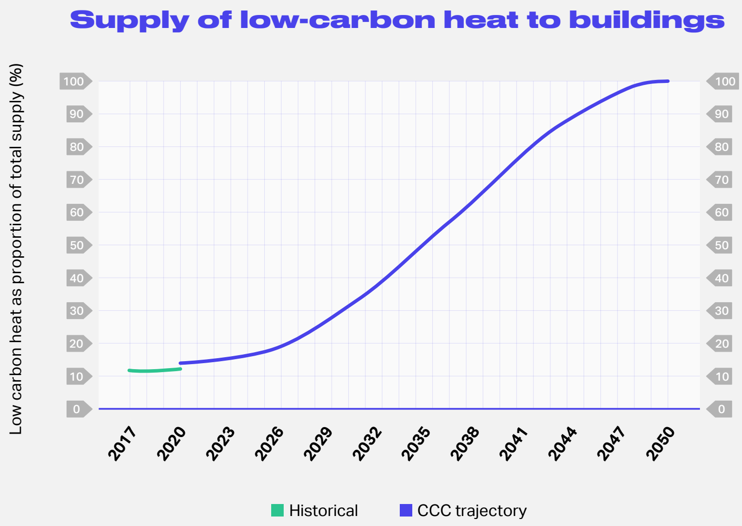
The diagram shows the proportion of emissions in 2019 from buildings to the nearest whole number; of 454.8 mega tonnes of carbon dioxide equivalent ($MtCO_2e$) total emissions, 23% were due to heating buildings, with the largest proportion of this stemming from homes.

Taking the carbon out of our buildings is not easy. British buildings are less energy efficient than the European average. In 2019, approximately 15 million (60%) of homes in England had a lower energy performance, with Energy Performance Certificates (EPC) ratings of band D and below[8]. This means homes require more energy to maintain a comfortable temperature. This problem is exacerbated by existing gas heating systems often being less efficient than expected. This occurs because the systems are set to operate at higher flow temperatures, meaning that even brand new gas boilers may not condense as much as expected. Households have limited knowledge about their existing fossil fuel heating systems and so rely on those installing and serving the products to set them up correctly.

The UK will only achieve its carbon reduction targets by changing how we heat our buildings. The Climate Change Committee (CCC) expects the UK to decarbonise heating through a combination of heat pumps, energy efficiency improvements and flexibility.

[7]UK Government, 2021 UK Heat and Buildings Strategy 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044598/6.7408_BEIS_Clean_Heat_Heat___Buildings_Strategy_Stage_2_v5_WEB.pdf

[8]UK Government, 2021 Net Zero Strategy: Build Back Greener https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf



Climate Change Committee, Progress Update 2022

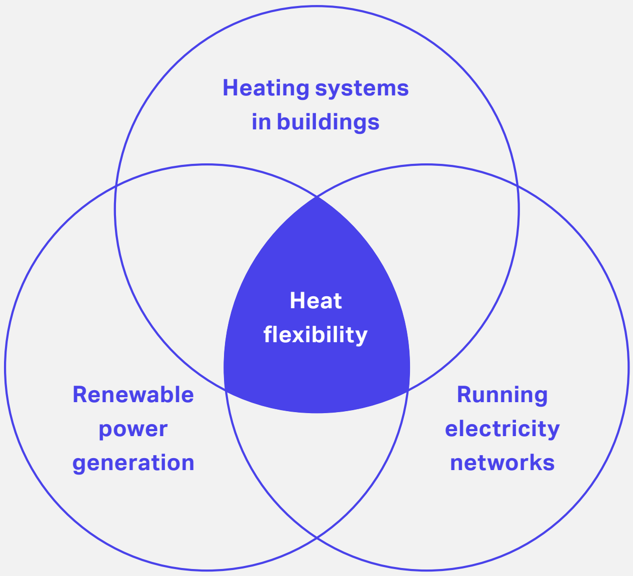
National Grid ESO's Future Energy Scenarios comes to a similar conclusion, recognising the role of smart thermal storage in 2022 as follows:

"But it's not just increased adoption of these technologies which is needed, consumers need to be enabled to change the way they use energy to maximise the benefits of these technologies. For example, charging EVs when electricity supply is high and price is low, or combining heat pumps with thermal storage, enabled by smart devices. This will also require consumers to adopt smart tariffs."

National Grid Future Energy Scenarios 2022

Decarbonising heating in buildings through electrification brings together heating systems in buildings and the electricity system. This is a significant change from the situation in 2022. Over 90% of homes are heated by fossil fuels, with gas boilers most common. Using electricity for heating is different to using gas. While burning gas for heat accelerates climate change, gas has some useful properties such as the ability to store the gas for later use and to compress the gas to provide some system flexibility. In comparison, the electricity system must balance at all times, with supply (generation) meeting demand (people's electricity needs) within limited voltage parameters. In simplistic terms, the electricity system must ensure that there is sufficient generation (including electro-chemical storage) to meet demand for electricity and enough wires exist to carry electricity to meet that demand, including at peaks.

Heat flexibility is central to heating systems in buildings, running electricity networks and making the most of renewable power generation.



Smart thermal storage can help reduce peak demand by shifting when people produce and use heat. Smart thermal storage can work with or instead of heat pumps, with National Grid ESO seeing thermal storage shaving off 32% of air source heat pump evening peak demand. National Grid ESO sees up to 3.8GW of thermal storage by 2050. As we set out in this report, we think this is a conservative estimate of the potential of heat flexibility.

What is smart thermal storage?

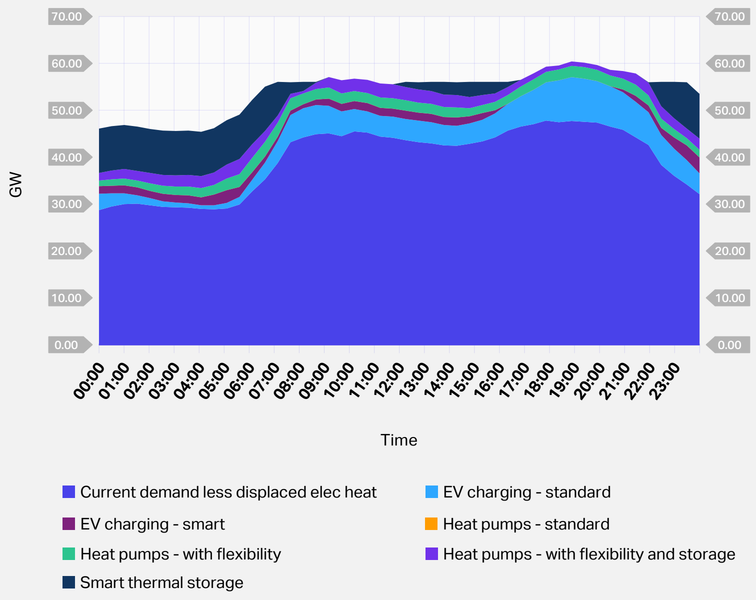
Smart thermal storage products can store heat for use later. These products, sometimes known as heat batteries, may produce heat themselves through direct electric heating or use heat produced by heat pumps or solar panels. The smart thermal store may store heat for hot water or heat for space heating or both. The key attributes of a smart thermal store are:

- the ability to store heat for later use
- to enable the heating system to respond smartly to price and carbon signals and
- fit into a wide range of homes

These attributes are why smart thermal storage is so integral to decarbonising heating at lowest cost.

With the right reforms to the electricity system (as set out in the recommendations section), the profile of a smart thermal store might look like this. The thermal store soaks up excess renewable generation overnight and in the middle of the day and avoids charging during the morning and early evening. The electricity system benefits from reduced peak demand and people are able to access and use heat when they want to keep warm.

Hypothetical overnight charging 30 January 2030



LCP Delta analysis

Smart thermal storage is adaptable to a variety of homes and is easy to install with existing hydronic distribution systems such as radiators. Some thermal stores work well with properties where there is space for a heat pump operating at 55C or less, increasing the efficiency of the overall system. Thermal stores can also operate at higher temperatures, avoiding the internal work required to convert to a low temperature heating system while securing the benefits of low carbon electricity. In all cases, smart thermal storage can be installed when people remove or alter their existing heating systems, whether that system is based on gas, oil or LPG.

Smart thermal storage uses a range of different technologies to store heat and provide flexibility. Some products use phase change materials while others use high density cores. Thermal Storage UK members offer a range of products and the sector is innovating rapidly.

A note on what this report does not consider to be a smart thermal store

The LCP Delta analysis does not consider hot water tanks (including buffer tanks) or storage heaters as not all of these products can respond smartly to real-time price and carbon signals. If set up to operate smartly within the heating system, these heating products may provide additional flexibility to the electricity system. However, to provide sufficient heat flexibility for space heating for most homes, hot water tanks would need to be large.

The LCP Delta analysis does not consider the role of electro-chemical storage in heating. It is possible that some electro-chemical stores will support heating flexibility, for instance providing electricity to heat pumps to avoid peak demand. Smart thermal storage has some advantages over other types of storage such as electro-chemical storage. In particular, thermal storage products are made with readily available materials and with technologies that do not degrade (and lose capacity) over time. In comparison, many types of electro-chemical batteries require rare materials such as lithium or cobalt, which are becoming increasingly difficult to source (though we note that electro-chemical storage manufacturers are working on alternative chemistries for their products).

How to secure flexibility from heat

This report focuses on using dedicated smart thermal storage products to provide heat to people and flexibility to the electricity grid. The LCP Delta analysis also considers setting heat pumps to adjust their output +/- 1C in response to price signals.

We recognise that there are alternative ways to provide this flexibility from heating. The two main alternative ways to use low carbon electric heating products to provide flexibility are:

1. Using heat pumps to preheat (energy efficient) homes by 2-3 hours
2. Turning heat pumps off or down to avoid the winter peaks

The LCP Delta analysis does not consider these alternatives, so the overall potential for low carbon heating flexibility may be higher than stated. There are pros and cons to the alternatives.

Pre-heating buildings

Pre-heating buildings allows the heat pump to run when carbon intensity and electricity prices are lower, then turn off or down to reduce demand. This approach is most likely to work when properties are energy efficient, with good airtightness and minimal heat loss. For instance, pre-heating may work in properties with an EPC rating of C or above. Pre-heating is likely to require behaviour change from those using the heating systems, for instance accepting higher temperatures overnight to ensure sufficient warmth in the morning.

Increasing on / off cycles

Turning heat pumps off and on in response to real-time price signals may boost flexibility and reduce peak electricity demand. However, this on / off approach may reduce the efficiency of the heat pump and increase overall electricity consumption and running costs.

How much heat flexibility could we see?

To understand the potential volume and value of heat flexibility, we commissioned LCP Delta to analyse the future power market of 2030. LCP Delta concludes that:

- If 2.4 million smart thermal stores are installed by 2030, then this thermal storage has the potential to reduce peak electricity demand by 1.6GW on the coldest day. This level of peak demand reduction can be obtained through smart time of use tariffs based on wholesale prices
- The potential for smart thermal storage to reduce peak demand on the coldest day could be as high as 4.1GW by 2030. This requires power market reform to ensure that the benefits of flexibility to the whole electricity system are properly valued
- Heat pumps with smart controls that adjust heat output by +/- 1C in response to price signals provide limited flexibility to shift heat demand
- Smart thermal stores shift electricity consumption away from higher price periods, reducing the use of the most expensive thermal generators, resulting in annual consumer cost savings for capacity mechanism of £106.2 million. In addition, LCP Delta estimates that smart thermal stores provide savings of £49.3 million in Distribution Use of System charges
- The flexibility from smart thermal storage could provide additional electricity system benefits by reducing renewable curtailment or by reducing the volume of supply side flexibility required. For instance, reducing wind and solar curtailment by up to 2TWh per year
- To properly value the flexibility of smart thermal storage requires wider reform of the electricity system, including wholesale markets and network charging. This value could offset the increase in electricity consumption due to the lower coefficient of performance of smart thermal storage

More detail on the results follows. For those interested in the details, the modelling approach and the assumptions used by LCP Delta are at the end of this report.

In short, LCP Delta used a cost-optimisation model that compared how heat pumps and smart thermal stores would respond to wholesale price signals in the following three scenarios. The table below shows the split between heat pumps and smart thermal stores in each of the scenarios considered by LCP Delta.

Scenario	Baseline	Alternative 1 Flexible heat pumps	Alternative 2 Flexible heat pumps and thermal storage
Standard heat pumps (default operation on a flat tariff)	4 million (100%)	0	0
Flexible heat pumps (optimised hot water storage and 1°C temperature flexibility on a dynamic tariff)	0	4 million (100%)	1.6 million (40%)
Flexible heat pumps with added thermal storage (optimised hot water storage and space heat storage on a dynamic tariff)	0	0	1.6 million (40%)
Smart thermal stores (optimised for domestic hot water and space heat storage on a dynamic tariff)	0	0	0.8 million (20%)

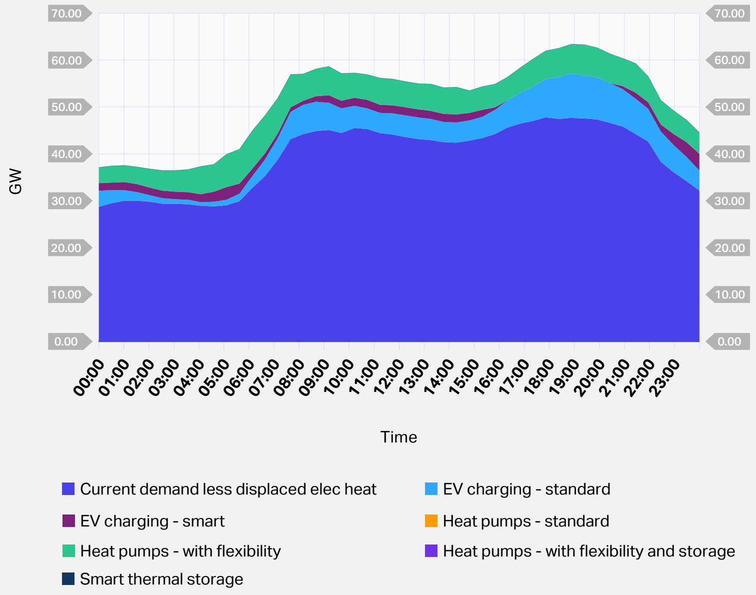
It is important to note that this scenario modelling assumes that smart thermal stores in Alternative 2 displace heat pumps that would otherwise have been installed in Alternative 1. In practice, this overstates the trade off between heat pumps and smart thermal stores. While smart thermal stores may displace some heat pumps, they also have the potential to reach properties where heat pumps may not be the optimal heating solution.

LCP Delta explored how these products would respond to price signals by the wholesale market sent on both the coldest day of the year and on a windy day. The results of the "Alternative 2" scenario, with 2.4 million smart thermal stores operating with or without heat pumps, are set out below.

Smart thermal storage on the coldest day

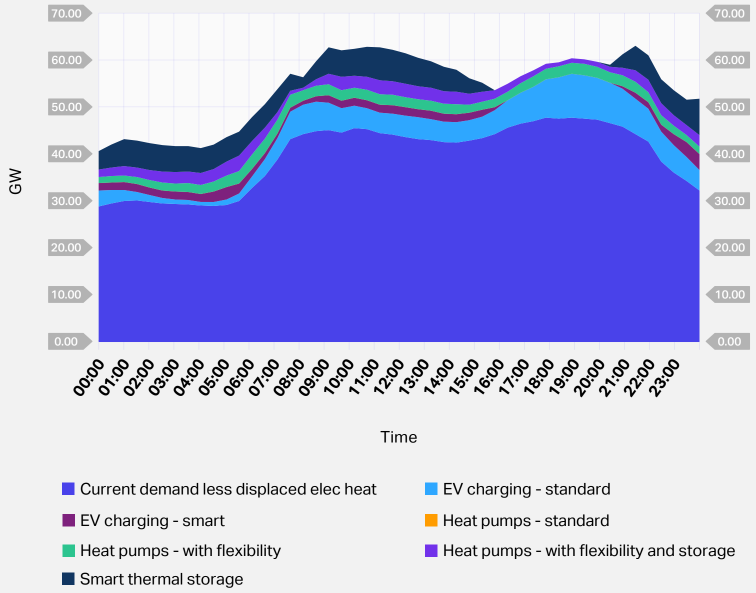
LCP Delta applied their model to the coldest day of 2019, which was 30 January. On this day, there are high heating demands, but relatively constant outdoor temperatures with low wind generation throughout the day. In this scenario, smart thermal storage provides greater flexibility to shift demand out of periods of high pricing and towards those with lower prices. This reduces peak demand by 1.6GW over the baseline scenario. The thermal stores charge up earlier in the day and then are available to discharge over the evening peak.

Baseline scenario on coldest day 30 January 2030



LCP Delta analysis

Impact of smart thermal stores on coldest day 30 January 2030



LCP Delta analysis

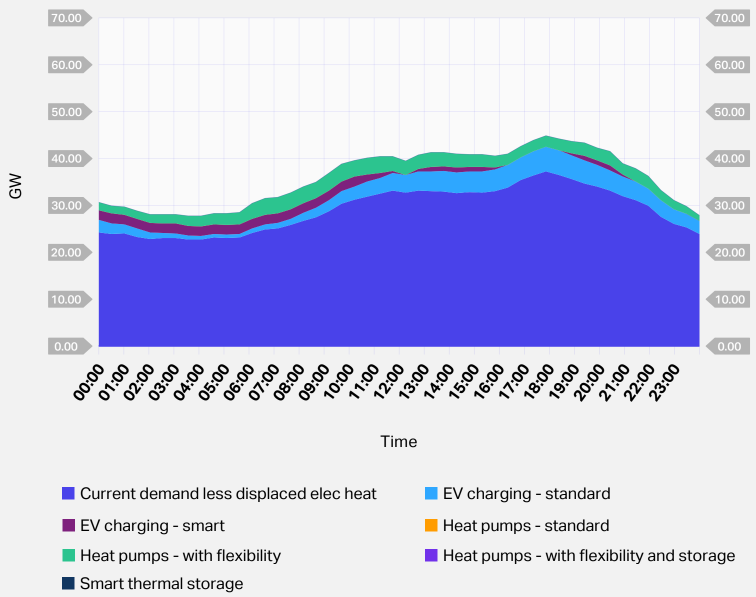
By way of comparison, heat pumps responding to time of use tariffs in Alternative 1 were able to reduce peak demand by 1.3GW.

Smart thermal storage on a windy day

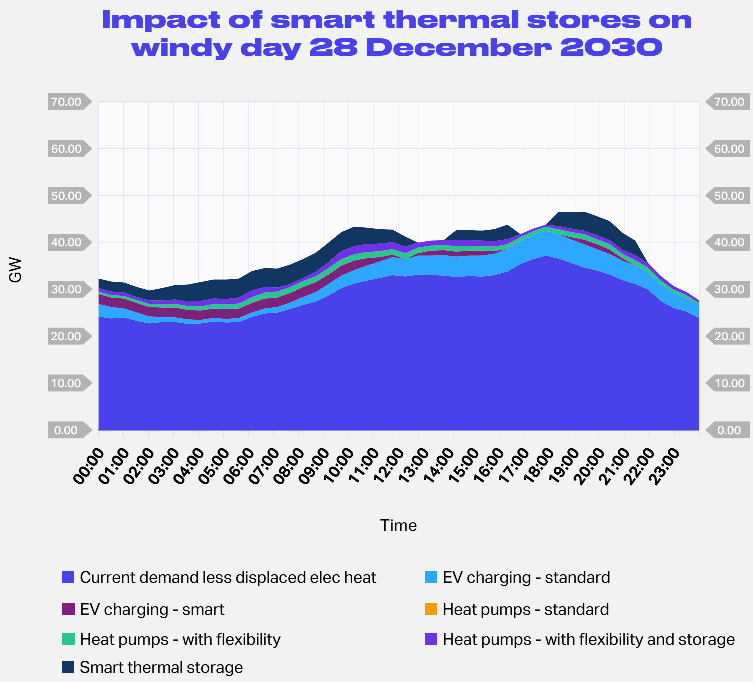
LCP Delta applied the modelling approach to a day (28 December) with high wind generation, particularly during the mid-morning and early evening. On this day, solar generation is relatively low and occurs late morning into lunchtime.

The impact of smart thermal storage and heat flexibility is less pronounced on days where there are longer periods of low pricing and high renewable generation. Indeed, charging thermal storage on days where renewable generation is high, which correlates to prolonged periods of low pricing, results in a slight increase in peak demand. In this windy scenario, the peak demand is lower than the peak demand on the coldest day and the cost of charging the thermal stores is low because of the high volume of renewable generation.

Baseline scenario on windy day 28 December 2030



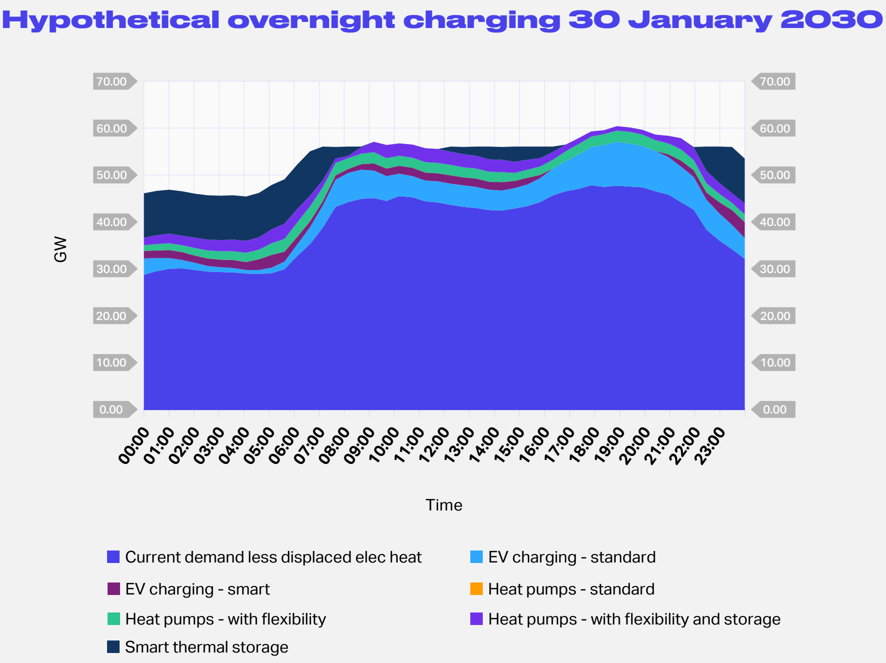
LCP Delta analysis



LCP Delta analysis

While the scenarios modelled by LCP Delta in this analysis shift demand based on cost optimisation, the addition of smart thermal storage technologies would further reduce peak demand if a control mechanism was introduced to cap the level of charging during daytime periods. For instance, shifting the charging of the smart thermal stores from the evening peak to overnight periods of low demand would reduce overall peak demand by 4.1GW.

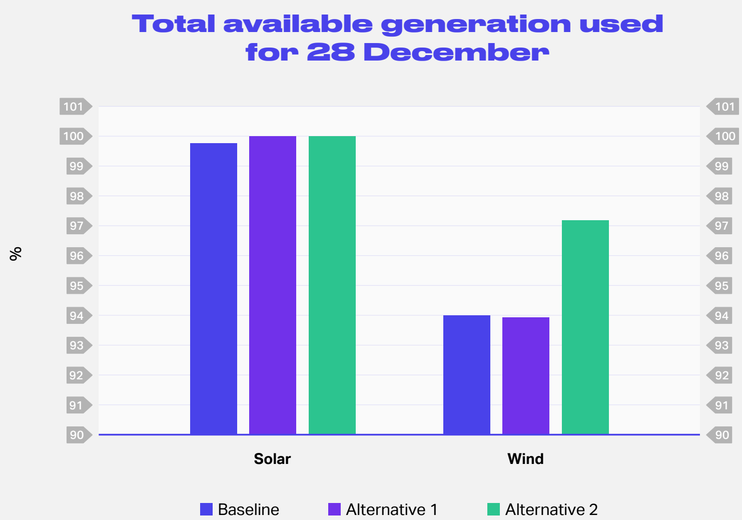
With the correct power market reforms and heating system designs, such as capping peak period charging, the smart thermal storage profile might look more like the graph below. This illustrates the potential for thermal storage to flatten demand over the course of the maximum demand day, greatly reducing peaks and shifting a significant proportion of demand into overnight periods.



Illustrative view of smart thermal storage after market reforms

Other impacts of smart thermal storage

Smart thermal storage increases utilisation of renewables. Smart thermal storage makes better use of renewables by reducing curtailment and reducing the need to use thermal generators burning fossil gas through the capacity mechanism. For instance, see the percentage of total available generation used for 28 December:



Utilisation of renewable generation on 28 December

As heat pump systems are more efficient at converting electricity into heat, an energy system with more smart thermal storage in 2030 will consume more electricity than a system with heat pumps alone. The table below shows energy demand on the coldest day in the LCP Delta analysis.

Scenario	Baseline	Alternative 1	Alternative 2
Standard heat pumps	16.5TWh	-	-
Flexible heat pumps	-	16.5TWh	6.2TWh
Flexible heat pumps with added thermal storage	-	-	6.2TWh
Smart thermal stores	-	-	14.1TWh

On the coldest day, the LCP Delta analysis indicates that smart thermal storage can shift 17.64 GWh of electricity across the day. This is more than the 9.98 GWh of flexibility provided by heat pumps in alternative 1.

The potential for smart thermal stores to provide flexibility occurs across the winter. On an average winter day where the average temperature is at or below 6C, the LCP Delta analysis suggests that smart thermal stores can shift 5.87 GWh of electricity flexibility. Across the 79 days which resemble this average winter day, the smart thermal stores provide 463.79 GWh of flexibility.

With the right market reforms and incentives, the benefits of this flexibility could offset the additional electricity consumption of smart thermal storage. The smart thermal stores will consume electricity at times of lower prices and higher renewables output and the electricity system benefits overall because smart thermal stores reduce peak demand.

What is the potential value of this heat flexibility?

The value of heating flexibility could amount to billions of pounds per year to the system and to households. This value comes in various forms, including better matching renewable generation with demand, reducing payments to thermal generators, making better use of the existing electricity network and reducing the cost of making electricity network upgrades.

Reducing the wholesale cost of electricity for heating

By shifting heating demand to periods where wholesale electricity prices are lower, the cost of heating can be reduced. The wider impact is that demand moves towards periods of lower demand net of renewable generation, and this demand profile is smoothed throughout the day. This reduces the use of high cost, high emission thermal generation and increases the use of lower cost, lower emission renewables.

Reducing the spend on supply side flexibility including the capacity mechanism

When thermal storage technologies shift demand away from periods of high prices, they reduce the requirement for the most expensive, least utilised thermal generators. The need for capacity is reflected in National Grid ESO's calculation of the derated capacity target for the Capacity Mechanism, which aims to ensure an average of 3 hours of underserved energy each year. To estimate the reduction in capacity required, LCP Delta looked at the change in the seventh highest half hour of demand net of renewable generation. LCP Delta estimates savings of £55.4 million to £106.2 million from increasing flexibility for heating demand. The additional flexibility from heat pumps would reduce the need for additional generation capacity by 1.51GW, while the flexibility from heat pumps and smart electric thermal storage reduces the requirement by 2.88GW.

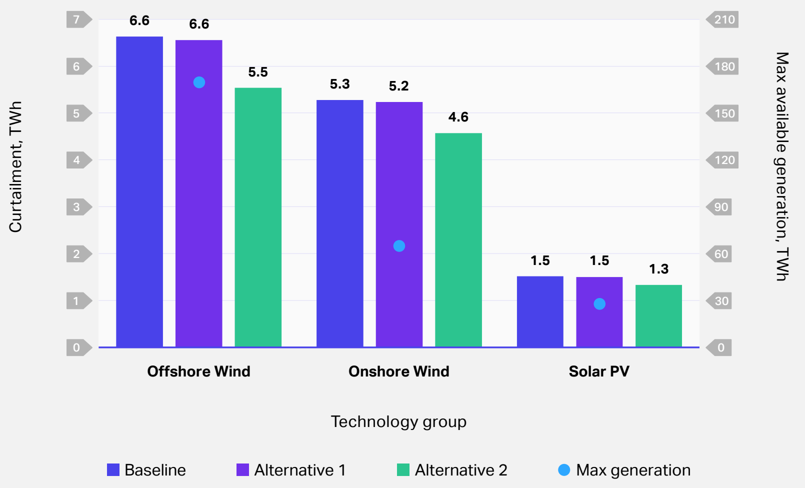
Reducing the need for electricity network reinforcement

Shifting heating demand away from periods of high overall system demand should reduce peak loads on distribution networks. In turn, this would reduce the cost of distribution network reinforcements. These savings could be significant as network costs are forecast to be one of the most significant system costs of the net zero transition. Using Distribution Use of System charges as a proxy for network cost savings, LCP Delta estimates savings of £49.3 million from increasing flexibility for heating demand. This involves shifting demand away from red band times where the highest network charges are incurred.

Reducing electricity network constraint costs

National Grid ESO is currently forecasting that constraint costs could rise to over £3 billion per annum this decade and is designing a flexibility service for winter 2022 / 23 offering people £2 per kWh to turn down or shift electricity consumption. This shows the potential value that heat flexibility can provide to the system. The LCP Delta analysis indicates that, with the right market reforms, there could be significant benefits from demand-side flexibility, both for networks and consumers.

Curtailment in 2030 comparison across scenarios



LCP Delta analysis

To reiterate, renewable curtailment due to locational constraints is not considered in this analysis. The analysis modelled the demand at a national level without consideration of where in the UK that demand will arise and whether there is sufficient network capacity where it does. The analysis shows how demand from smart thermal stores can be shifted to reduce peak demand at the national level, and the same could potentially be done at the distribution level.

A more detailed bottom-up analysis would model the optimal location and capacity of thermal storage based on local grid constraints. For example, this would show the potential value of smart thermal storage in absorbing excess generation and reducing generation constraints in Scotland, where there is a significant volume of intermittent renewable generation and constraints on export capacity.

If locational constraints were considered, we expect that the overall level of renewable curtailment would be higher than shown in this analysis and the avoided curtailment due to heating flexibility would be larger.

Recommendations to support heat flexibility

This report provides evidence of the potential scale and value of heat flexibility to the electricity system, to people and businesses and to reduce emissions. The LCP Delta analysis indicates that 2.4 million smart thermal stores could reduce peak demand by 1.6GW on the coldest day of the year. However, LCP Delta indicates that the flexibility potential of thermal storage could be as high as 4.1GW if the network benefits of flexibility are properly valued.

To make the most of the flexibility provided to the electricity system by space and hot water heating, we need to reform the wider market and regulatory arrangements of the UK power system. We recommend changes in the following six areas:

- Redesign power markets to value flexibility and pass this value to end users
- Make it easy to install heat products which can offer flexibility
- Create a level playing field for low carbon heating technologies
- Support and protect people updating their heating systems
- Provide long-term clarity to people and businesses
- Provide high quality training for heat engineers

Some of the reforms below require changes to legislation. The recommendations assume that the measures outlined in the Energy Security Bill are introduced, including establishing a Future System Operator and introducing standards for Energy Smart Appliances.

Redesign power markets to value flexibility

Much of the existing energy legislative architecture dates back to privatisation and liberalisation in the 1990s. The legislative framework and energy governance requires updating for net zero. While the value of flexibility is largely recognised on the generation side, we recommend valuing flexibility on the demand side. Thermal Storage UK proposes the following changes.

Recommendation 1. Amend the Energy Act 2004 to separate low carbon and fossil fuel wholesale markets.

Develop pricing signals that reflect the lower cost of renewables in the wholesale electricity market, rather than the marginal cost of imported fossil fuels. Such splitting increases the price differentials between periods of high renewable generation (when prices and emissions are low) and periods of high fossil fuel generation (when prices and emissions are high).

Recommendation 2. BEIS to provide Ofgem with a clear steer to introduce mandatory half-hourly settlement by December 2023.

Mandatory half-hourly settlement ensures the charges that energy suppliers face reflect the costs and carbon intensity of energy at different times of day. This accurately values the electricity produced, improving the ability and incentive for energy retailers such as energy suppliers and aggregators to offer time of use tariffs. We recommend a legislative backstop to reduce the risk of delays to the programme.

Recommendation 3. Amend the Renewables Obligation Order 2015 to reallocate legacy policy costs such as the Renewable Obligation from the electricity bill.

Reducing the artificial cost difference between electricity and gas will encourage the transition to low carbon electric heating. The Renewables Obligation is the largest legacy policy cost on energy bills and so we recommend starting with that policy cost. Alternatively, the government could achieve a similar outcome by moving generators from the Renewable Obligation to the Contracts for Difference scheme.

Recommendation 4. Change the Utilities Act 2000 to require energy suppliers to provide at least one time of use tariff for electric heating, starting in December 2023.

Along with reforms to half hourly settlement and wholesale prices, requiring suppliers to offer time of use tariffs for electric heating will facilitate the transition to low carbon electric heating. This is the same approach as the government adopted in creating the Smart Export Guarantee.

Recommendation 5. The government and National Grid ESO develop publicly available whole system modelling that can consider local network constraints, distributed energy assets and the increase in renewables.

The UK government and National Grid ESO should undertake granular modelling that can consider the role of distributed assets such as heat pumps, EVs and thermal stores and the value of these demand products for managing local constraints. A more detailed bottom-up analysis would model the optimal location and capacity of thermal storage based on local grid constraints. For example, this would show the potential value of smart thermal storage in absorbing excess generation and reducing generation constraints in Scotland.

We recommend that this modelling is publicly available. This modelling would help heating product manufacturers, networks, councils, housebuilders and others to plan for the electrification of heat and transport and decarbonisation of electricity generation.

Make it easy to install heating products which can offer flexibility

Flexible heat products provide an opportunity to take advantage of intermittent low carbon generation such as offshore wind and provide warmth and comfort to people's buildings. The government could encourage this transition by making it easy to install flexible heating products such as smart thermal storage. Thermal Storage UK proposes the following changes.

Recommendation 6. Introduce new primary legislation to require that all heating systems from 2025 can provide flexibility.

Requiring heating systems to provide flexibility makes the best use of smart technology (including smart meters and sensors) and minimises the total cost to the energy system of decarbonisation. Flexibility could occur through pre-heating energy efficient homes or by installing smart thermal storage.

Recommendation 7. Introduce new primary legislation requiring all low carbon electric heating to meet smart standards by 2025.

Setting standards for smart appliances in heating - including smart thermal storage - will ensure interoperability, data privacy and cybersecurity. Such standards will maximise the value of flexibility that heating can provide to the energy system and minimise the risk of grid instability. The government is already taking steps towards this recommendation in the Energy Security Bill. We recommend that the standards are created at pace, building on the standards for Electric Vehicle charging.

Recommendation 8. Update Energy Performance Certificates (EPCs) and the Energy-Related Products (ERP) Framework to incorporate flexibility.

The current EPC and the ERP frameworks give limited consideration to flexible heat products. These frameworks will need to adapt to smarter time-of-use tariffs and changes in the electricity system. The current situation is perverse as fossil gas boilers can receive higher energy label ratings than low carbon electric heating products and are more likely to be recommended in the EPC to households.

One option is to introduce a flexibility factor that would provide higher energy performance ratings to products that can offer flexibility. We recommend that considering flexibility forms part of wider reform of the EPC and ERP frameworks to avoid misleading people about the emissions associated with different heating products. This requires updating the Standard Assessment Procedure (SAP) that the EPC is built on.

Recommendation 9. Amend the Building Regulations 2010 and any associated schedules to replace the term "hot water cylinder" with "thermal storage".

Thermal storage is a more neutral term that better reflects different storage mediums and shapes of the storage product. This could be split into "thermal storage for hot water" and "thermal storage for space heating" if required. "Cylinder" suggests a spherical product that stores heat in hot water.

Create a level playing field for low carbon heating technologies

The government should encourage the transition from fossil fuel heating to low carbon heating and maintain a level playing field between low carbon heating technologies. Thermal Storage UK proposes the following changes to the legislative framework:

Recommendation 10. Change the definition of "energy saving materials" in the VAT Act 1994 to zero rate the installation of low carbon thermal storage in all circumstances.

Zero rating thermal storage when installed as the heat source (rather than ancillary to a heat pump or solar) would encourage the transition to low carbon technologies and provide parity between low carbon electric heating options (e.g. smart thermal storage and heat pumps).

Recommendation 11. Expand the definition of "Eligible Plant" in the Boiler Upgrade Scheme (England and Wales) Regulation 2022 to cover thermal storage.

Allowing thermal storage to access the Boiler Upgrade Scheme in England and Wales will provide a level playing field between low carbon electric heating technologies. The government could also look to include smart thermal storage in schemes such as the Energy Company Obligation.

Support and protect people updating their heating systems

The legislative framework governing the support and protections in place for people updating their heating systems should reflect net zero. This will maintain people's confidence in the transition from one heating system to another and ensure that any issues are quickly and fairly rectified. Thermal Storage UK proposes the following changes:

Recommendation 12. Change the Utilities Act 2000 to place a duty on Ofgem to deliver net zero, including in relation to heating.

Providing Ofgem with a clear duty to deliver net zero would empower Ofgem and code bodies to facilitate the transition to low carbon heating and transport at lowest cost. Such a duty may also encourage Ofgem to explore more deeply issues such as heating and energy efficiency, which it has limited vires over today.

Recommendation 13. Amend the Consumers, Estate Agents and Redress Act 2007 to extend the advice role of Citizens Advice to helping people choose the best low carbon heating system for their home or business.

Resourcing a respected consumer group like Citizens Advice to provide advice on heating will give people and businesses the confidence to change their heating systems and building fabric. The Energy Saving Trust could also provide this role, as it already does in Scotland.

Recommendation 14. Add misleading and unsubstantiated green claims to the list of banned practices under the Consumer Protection Regulations (CPRs) and Consumer Contracts (Information, Cancellation and Additional Charges) Regulations 2013.

This would limit the practice of energy suppliers claiming an electricity tariff is renewable or green when it is backed by paper certificates that provide little to no additionality. Those people who are keen and able to reduce their carbon emissions would then recognise the benefit of shifting when they consume electricity to low carbon periods.

Provide long-term clarity to people and businesses

For both businesses and households, investing in energy products such as heating appliances is a significant commitment. Manufacturers and generators face multi-year lead times and significant capital investment. This is why the legislative framework should provide long-term clarity to people and market participants about what technologies and fuel sources are acceptable to achieve net zero. This long-term clarity will provide homeowners, businesses and the government time to adapt their homes and products. Thermal Storage UK proposes the following changes:

Recommendation 15. Introduce new primary legislation setting clear end dates for the sale of fossil fuel heating systems and the sale of fossil fuels for heating.

This will provide people with long-term clarity on when they need to change their heating systems. It will also clarify for companies selling fossil fuel heating systems that they must change their business model.

Provide high quality training for heat engineers

The legislative framework should support the high-quality training of heating engineers required to deliver net zero. Thermal Storage UK proposes the following changes:

Recommendation 16. Establish a training centre for low carbon heating engineers.

This training centre would ensure heating engineers have all of the skills required to install low carbon electric heating, including thermal storage. This would include heat loss calculations, appropriate sizing, electrical work and ensuring smart flexibility. This would build on the training provided by the Chartered Institute of Plumbing and Heating Engineers (CIPHE).

This training centre would help ensure that those installing and servicing a range of heating systems do not misrepresent the environmental or cost credentials of those products and provide impartial advice to people and businesses.

How LCP Delta approached this analysis

The analysis involved comparing three scenarios:

- **Baseline** - hydronic heat pumps installed in an additional four million homes relative to a 2019 baseline. This is in line with the UK Government's ambition to install 600,000 heat pumps a year by 2028 and is similar to National Grid's "Consumer Transformation" Future Energy Scenario. All four million heat pumps have a thermal store for direct hot water and operate on a flat electricity tariff. LCP Delta assumed a temperature dependent COP of about 3 on average, with 1 kWh of electricity becoming 3 kWh of heat.
- **Alternative 1** – all four million heat pumps are optimised to a dynamic electricity tariff reflecting wholesale electricity prices. Hot water is generated outside of peak periods and stored for when it is required. In addition, ±1°C of flexibility against set temperature requirements is allowed to enable pre-heating ahead of morning and evening peak demands.
- **Alternative 2** – 20% of the four million heat pumps are replaced with smart thermal storage systems. These are designed to charge and store heat outside of peak periods. A COP of 1 is assumed, with 1 kWh of electricity becoming 1 kWh of heat. Half of the remaining 1.6 million heat pumps are equipped with additional thermal storage for space heating. All four million electric heating systems are optimised to a dynamic time of use tariff.

The table below shows the volumes of heat pumps and smart thermal stores in each scenario.

Scenario	Baseline	Alternative 1 Flexible heat pumps	Alternative 2 Flexible heat pumps and thermal storage
Standard heat pumps (default operation on a flat tariff)	4 million (100%)	0	0
Flexible heat pumps (optimised hot water storage and 1°C temperature flexibility on a dynamic tariff)	0	4 million (100%)	1.6 million (40%)
Flexible heat pumps with added thermal storage (optimised hot water storage and space heat storage on a dynamic tariff)	0	0	1.6 million (40%)
Smart thermal stores (optimised for domestic hot water and space heat storage on a dynamic tariff)	0	0	0.8 million (20%)

It is important to note that this scenario modelling assumes that smart thermal stores in Alternative 2 displace heat pumps that would otherwise have been installed in Alternative 1. In practice, this overstates the trade off. While smart thermal stores may displace some heat pumps, they also have the potential to reach properties where heat pumps may not be the optimal heating solution.

The approach

To calculate electricity demands in 2030, LCP Delta estimated hourly electric vehicle (EV) and electric heating demands and added these demands to the hourly historical demand for 2019. Weather and demand patterns for 2019 were used as 2019 was a fairly typical year in terms of weather conditions and demand was not affected by COVID-19 lockdowns. Average daily temperatures in 2019 are shown in Figure 3 of Appendix 1.

The hourly electricity supply mix was then simulated using LCP Delta's electricity market forecasting model. The wholesale energy prices from the simulation were then used to optimise the operation of smart EV chargers and smart thermal storage in the Alternative 2 scenario. The total electricity demand profile was then updated and the electricity market simulation was re-run.

LCP Delta's in-house power market modelling tools take an agent-based approach in which individual assets operate in a way which maximises their own profitability. Their view of the profitability of generating is based on a bottom-up estimate of the costs of turning on, generating and paying charges for using the network, as well as operational limitations such as minimum up and down times.

In each hour, individual assets bid to change their generation, either up or down, to follow the profile of demand net of renewable generation. The price in the market is set at the marginal cost of generation.

Overlayed on this behaviour is the optimisation of storage technologies, which respond to price differentials in the market to charge at lower prices and, where possible, generate at higher prices.

It is worth noting that large-scale shifting of thermal loads may impact electricity prices. For instance, shifting a large proportion of heat into low-cost periods may result in this period becoming higher cost. This could lead to the smoothing out of pricing. One exception to this could be night-time charging where the demand from other electricity loads is so low that prices are likely to remain low even after the additional demand from smart thermal storage is added.

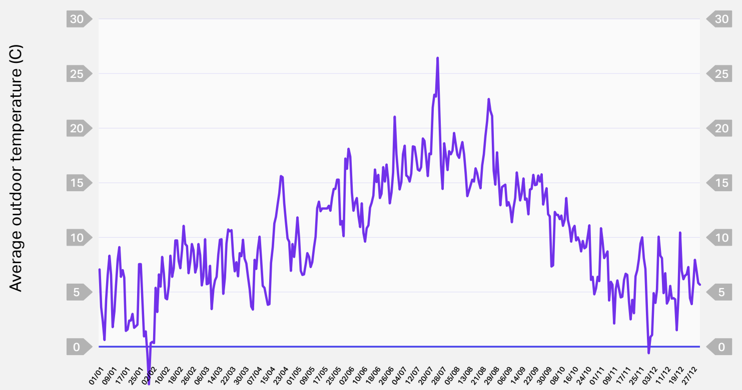
Assumptions in the LCP Delta analysis

To forecast the value and volume of heat flexibility in 2030 requires assumptions about a range of inputs. This includes the mix of generation assets, temperatures, the capacity and efficiency of heating technologies and take up of those heating products and network investment. We have aimed for a set of reasonable assumptions that broadly match the UK government's view of 2030. However, we acknowledge that 10-year projections are uncertain, especially at times of fast and deep system transformation. We welcome feedback on any or all of the assumptions we have made.

Weather

- This analysis is conducted for the whole of Great Britain and does not consider variations in temperatures between for instance Scotland and the south-coast of England. In practice, regional temperature variations will affect regional heating demand.
- Weather patterns, including wind and solar output are similar to 2019
- Weather data from 2019 incorporated wind speeds and solar irradiance.
- Average temperatures are similar to 2019 and look as follows:

2019 temperatures modelled for 2030

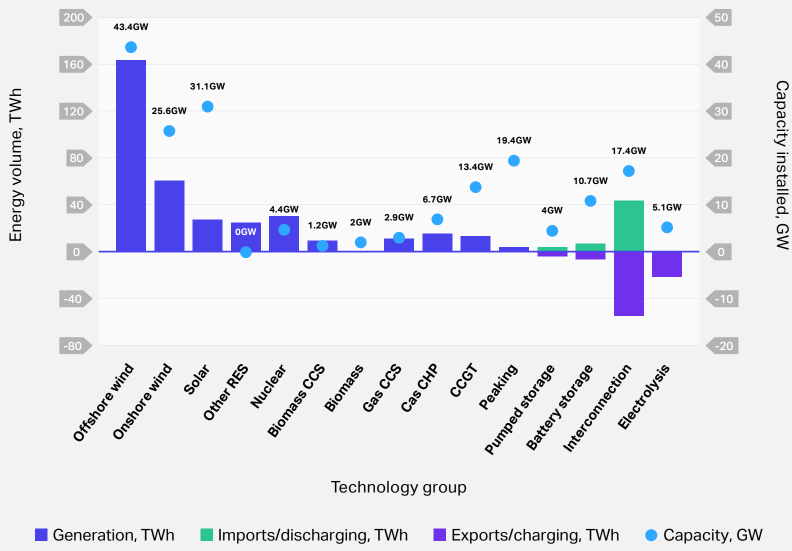


LCP Delta analysis

Generation mix

The 2030 generation mix is based on the UK government's stated ambition in the British Energy Security Strategy. The baseline modelling scenario is set out below.

Power market scenario (baseline)



LCP Delta analysis

The weather data is converted into generation availability for each half hour for offshore wind, onshore wind and solar PV. This captures both the locations of generation in 2030 and technology characteristics such as higher average load factors and wind turbine heights.

Power system

- No major changes to wholesale markets such as locational pricing
- Smart time of use tariffs are available to manage heating loads
- Excluding balancing and reserve markets and wider investment and policy costs

Heating systems

- In all three scenarios, it is possible to electrify heating in 4 million UK homes
- In this analysis, smart thermal stores are only installed in existing properties, with no installations in new builds
- Smart thermal storage heating systems were assumed to have an overall efficiency of about 85% after accounting for heat losses from thermal stores
- Smart thermal storage average capacity is 50 kWh
- Heat pumps achieve an average SCOP of 3.2, varying by building type

- It was assumed that the majority of heat pumps installed by 2030 and beyond to 2050 are hydronic (e.g. air- to- water) heat pumps
- Indoor temperatures were assumed to be 21°C on average when occupied during the day with a 16°C setback

Buildings and electric vehicles

- Only residential electrification of heat was considered in this analysis as the majority of heat pumps installed by 2030 are expected to be in homes
- The average energy efficiency of domestic properties improves to EPC C-rating
- Average heat demand is 10,000 kWh for gas and 2,850 kWh for heat pumps
- Of the 4 million homes in the analysis, 1.5 million homes are new builds with low heat demand, 2 million are average homes with average heat demand and 0.5 million are larger homes with high heat demand
- There are 9.5 million battery electric vehicles and 3 million plug-in hybrid electric vehicles
- Few electric vehicles are expected to have vehicle to grid capabilities by 2030, so electric vehicles were not treated as a potential source of generation

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