The fastest path to **decarbonising UK energy** and boosting the economy while we're at it.

THIRTY

Recommendations by

2030

Expert briefing for the Labour Party

October 2019

HOW DO WE PUT THE UK ON THE FASTEST PATH TO ZERO CARBON ENERGY? (AND BOOST THE ECONOMY WHILE WE'RE AT IT)

FOUR TRANSFORMATIVE GOALS – DELIVERED IN 30 RECOMMENDATIONS

We need to act fast. If we begin implementing these goals immediately, we'll be on track with what climate science says is needed: delivering a 77% reduction in energy emissions by 2030 compared to 2010, much more than the 45% climate scientists (IPCC) say is needed globally, making the UK the world's climate leader. If implementation goes very well by the mid 2020's the UK could even be on track for a zero-carbon energy system some time in the 2030's. Either way, if this action does not begin right now, zero-carbon energy will remain a pipe dream for decades to come.

GOAL 1: STOP WASTING ENERGY

UPGRADING ALMOST **27 MILLION** HOMES BY **2030**

As well as upgrading almost all of the UK's homes, we must upgrade every public, commercial and industrial building. To upgrade, we must install energy savings measures like insulation and double-glazing, focusing first on damp homes and areas with fuel poverty.

Reintroduce a zero-carbon buildings standard for all new buildings from 2020

RESULT

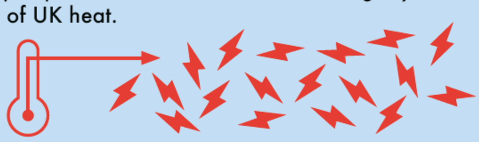
A reduction in total building heat by 20% and electricity by 11%, in the UK.

GOAL 2: DECARBONISE HEAT

Quick-wins implemented wherever possible, covering 22% of heat demand:

- Maximize heat networks in dense urban areas.
- All organic-waste used for bio-methane injected into gas grid.
- Solar hot water where sensible

Begin electrifying heat: Minimum of 8 million high efficiency heat pumps installed in homes and buildings by 2030, supplying 22% of UK heat.



INSTALLATION OF **8 MILLION** HEAT PUMPS

Determine role of cutting edge technologies:

- Investment and trailing of renewable-hydrogen for heating and hybrid-heat pumps in early-mid 2020's
- Implement appropriately based on learnings.

RESULT

There will be a ten-fold increase from today to reach nearly 50% low carbon heat by 2030.

GOAL 3: DECARBONISE ELECTRICITY

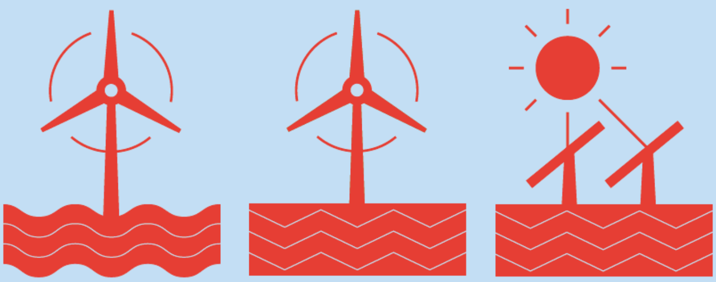
Huge and immediate expansion in established renewable electricity technologies:

- **Off-shore wind:** The UK has the best wind resource in the world. We must install 7,000 off-shore wind turbines, each bigger than the London Eye, a seven-fold increase on today.
- **On-shore wind:** The wind ban should be removed and capacity doubled to 30GW, which equates to 2,000 more turbines.
- **Solar power:** Enough solar panels to cover 22,000 football pitches must be installed, tripling the current UK capacity.

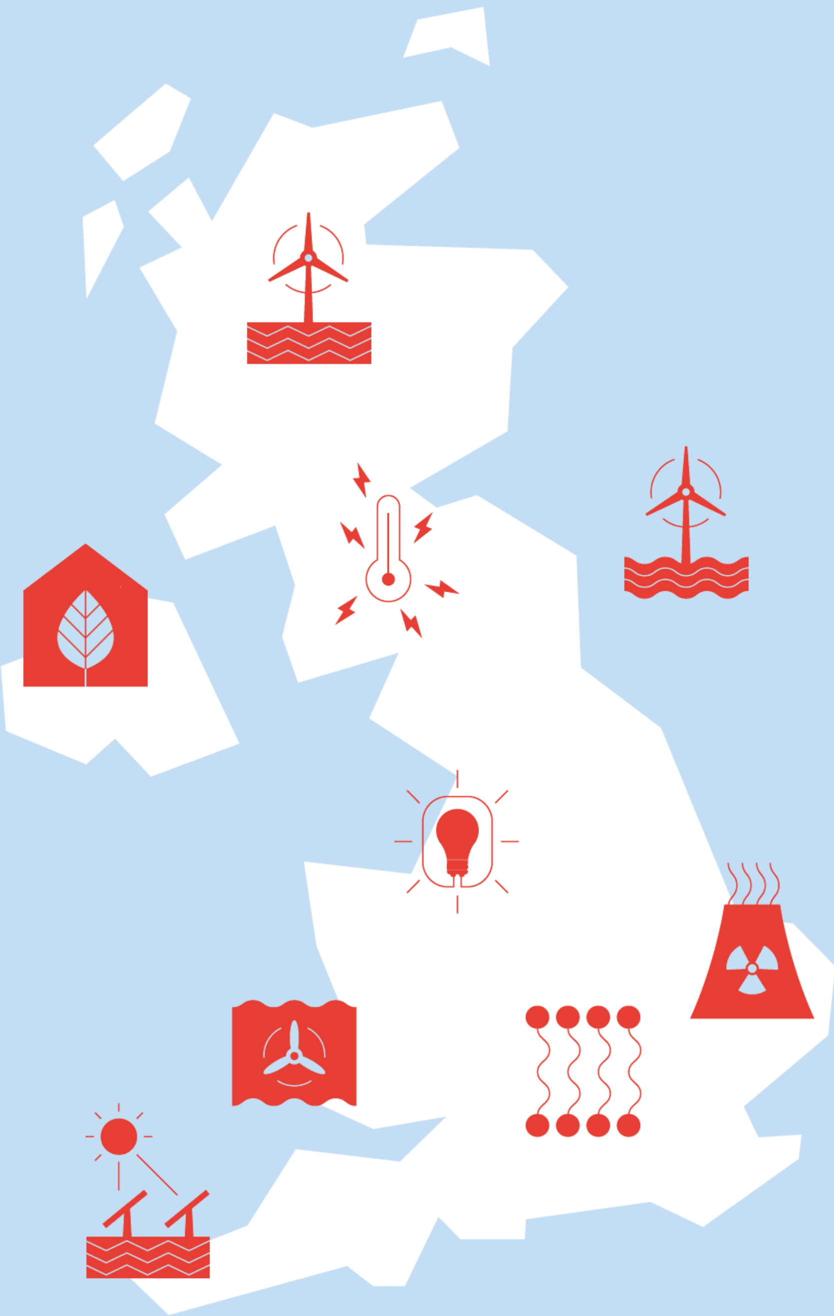
Investment in and trialling of **marine energy**, **carbon capture** and **sequestration (CCS)** and **renewable** or **low-carbon hydrogen for energy storage**, so that by the late 2020s these emerging technologies can be deployed to the appropriate scale by 2030.

RESULT

A total of almost 90% renewable and zero-carbon electricity by 2030.



+7000	+2000	ENOUGH TO COVER 22K
OFF-SHORE TURBINES	ON-SHORE TURBINES	FOOTBALL PITCHES



THE HUGE BENEFIT TO THE UK'S ECONOMY AND THE PUBLIC

UK wide economic benefits that far outweigh the economic costs

BENEFIT OF
£800 BILLION
TO ECONOMY BY
2030

These 4 goals require investment of 2% GDP each year, but result in a significantly more prosperous UK, meaning there is a net benefit of £800 billion for the economy by 2030, equivalent to the entire economy of Holland or Turkey.

A true jobs revolution

850,000
NEW JOBS

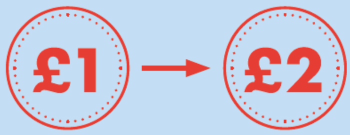
850,000 new green energy jobs across every region of the UK.

UK households will be better off

- Energy bills will not need to increase and could even decrease.
- Household incomes will be 2% higher by 2030.

Will improve government balance sheet

Every £1 of capital investment by UK government to result in nearly £2 back due to more prosperous economy. By 2030 would be enough to fund Crossrail eight times over.

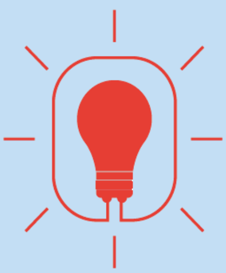


Improve the health of UK public

6,000
AVOIDED DEATHS
PER YEAR BY
2030

- Burning less fossil fuels will result in 6,000 avoided deaths a year by 2030 due to improved air quality.
- Improving UK housing stock lead to 565,000 less cases of asthma by 2030 and 1,500 avoided deaths per year from cold.

GOAL 4: BALANCE THE SYSTEM



"Keep the lights on" by making sure energy supply and demand are always balanced whether the wind blows or not. Through measures like demand-side-management, back-up generators, power and heat storage, interconnectors with Europe, system digitization, smart meters and EV smart charging.

Maximise performance, cost savings and efficiencies by developing a whole system view. Integrating national systems of electricity generation and supply, heat generation and supply, buildings and transportation.

RESULT

The demand for energy in the UK is met by supply 24 hours a day, 365 days a year.

Executive summary

SNAPSHOT

We are facing a global climate emergency, as the UK parliament has recently recognised. In Paris, 2015, world leaders agreed to aim to limit global warming to 1.5ºC. In 2018, the IPCC, the world's climate experts, highlighted that this will require 'rapid and far-reaching' transitions in land, energy, industry, buildings, transport, and cities'. The largest source of emissions in the UK is electricity and heating for homes, the public sector, industry and service sectors.

This expert briefing for the Labour Party aims to identify the maximum contribution of renewable and low-carbon electricity and heat that could be implemented, should the UK be put on a "climate emergency" footing for the next decade. 30 transformational recommendations have been identified to be carried out in phases towards and beyond 2030. These span across four goals: *reducing energy waste, decarbonising heating, decarbonising electricity and keeping the system balanced to ensure security of supply.* Delivering the recommendations will require significant updates to almost every building and national infrastructure system, and changes for every person, business and institution.

The recommendations were developed by a group of independent energy-industry professionals. A highly ambitious view has been taken of what can be achieved based on available and ready-to-be-deployed technologies, current deployment levels, faster than historical development rates, public and business acceptance of change, an appreciation of current UK industrial and workforce capacity and the uncertainties around crucial new technologies. **The recommendations have the support of some of the UK's leading climate experts as at the extreme upper bound of feasibility, but appropriate to the climate emergency we find ourselves in.** This work considers the necessary changes, and demonstrates their viability and likely impacts, but does not consider the policies or interventions needed deliver them.

The thirty recommendations can be briefly summarised as:

- Immediately embark on a vast expansion of offshore wind, onshore wind and solar power.
- Implement a UK-wide programme of upgrading existing buildings to significantly reduce energy wastage and a shift to low-carbon heat. All new buildings to be net zero-carbon.
- Significant investment in research and development for, marine energy and renewable or low-carbon hydrogen for heating and energy storage, and carbon capture and sequestration (CCS) for some heavy industries so that by the late 2020s these emerging technologies can be deployed, alongside current technologies such as nuclear, to the appropriate scale.
- Ensure the lights will stay on and supply and demand can be balanced, with the right updates to infrastructure and the development of whole energy-system approach.

If these recommendations are implemented immediately, the UK can be on track to deliver **a 77% reduction in energy emissions by 2030 compared to 2010 levels. This more than global average 45% cut in emissions that the IPCC climate scientists say is needed and would make the UK a world leader in climate action**. If implementation goes very well by the mid 2020s, the UK could even be on track for a zero-carbon energy system sometime in the 2030s. Either way, these recommendations are the necessary next steps. The IPCC emphasises that 'the next few years are probably the most important in our history'.

Delivering the recommendations by 2030 will bring huge benefit to the prosperity and health of the UK. The UK wide economic benefits will *far* out way the economic costs, with an average required investment of 1.9% of GDP each year resulting in significantly more prosperous UK. This means **a *net* benefit of £800 billion across the UK by 2030**. The work needed for this energy transformation **would generate 850,000 new jobs** across the green energy sector. Households will be better off as a result, with energy *bills* not needing to increase to pay for changes. Due to increased economic prosperity wages can also increase by 2% across the economy. In addition, burning fewer fossil fuels will result in around 6,000 avoided deaths due to improved air quality. Improving the UK housing stock by 2030 can avoid 560,000 cases of asthma and ensure 1,500 less deaths per year from cold.
It is the firm view of the authors that the implemtation of these recommendations should begin right now.

The study team and its objectives

This expert briefing for the Labour Party aims to identify the maximum contribution of renewable and low-carbon electricity and heat in buildings that could be implemented by 2030, should the UK be put on a "climate emergency" footing for the next decade.

Thirty transformational recommendations have been identified that will cut energy emissions quickly and put the UK on a path to zero carbon energy and are in line with the IPCC's 1.5 Special Report recommendations, which sets out how fast the world must decarbonise to keep global warming to less that 1.5°C above preindustrial levels. Electricity and heating across the UK – for homes, the public sector, industry and service sectors – are the UK's main source of GHG emissions. This report focuses on that sector as it is considered the highest priority for action.

This briefing is the product of a working group of industry professionals and experts, with inputs from across the energy sector, over a year-long period. Contributions have also been made by some of the UK's leading energy experts and researchers.

The recommendations were developed through a combination of existing leading research and the project team's own analysis. The evidence base has been drawn from leading research institutions, expert bodies and organisations with a substantive role in the UK's energy system including: National Grid, the government's own energy statistics, research from Imperial College London, UK Green Building Council, Committee on Climate Change, Centre on Innovation and Energy Demand and the UK Energy Research Centre. An annual energy balance model has been developed by the project team to adapt this evidence to the desired increased ambition of this report. Trajectories have been calculated by taking an optimistic view of what can be achieved based on available and ready-to-be-deployed technologies, current deployment levels, faster than historical development rates, an appreciation of current UK industrial and workforce capacity and the uncertainties around crucial new technologies.

The starting point for this analysis was Labour's target for 60% of heating and electricity to come from renewables and low-carbon energy by 2030. The work has since been broadened to consider more generally; trajectories that would deliver an energy emissions reduction for the UK consistent with the climate science yet staying within the extreme upper bound of feasibility.

This work focuses only on providing a technical description of the maximum changes feasible across the UK towards a zero-carbon path, and their impact. It also does not explicitly include any analysis on the levers and policies needed to implement its recommendations. Nor does it state how the necessary actions would be funded.

Based on current evidence, the strategy outlined in this report is considered a best estimate for the most appropriate energy system in 2030 for delivering a path to zero-carbon as rapidly as possible, given existing technologies and Labour's commitments on social justice and a just transition. Because clean energy is a fast-developing technology space, it will be important to keep tracking and revising the strategy to ensure it is up to date and takes advantage of new evidence and breakthroughs.

Four goals for putting the UK on the path to zero-carbon energy

Success depends on achieving four goals to transform UK energy supply and use within a decade. The report makes thirty recommendations to meet these goals, with high confidence in their shape and scale. The goals are:

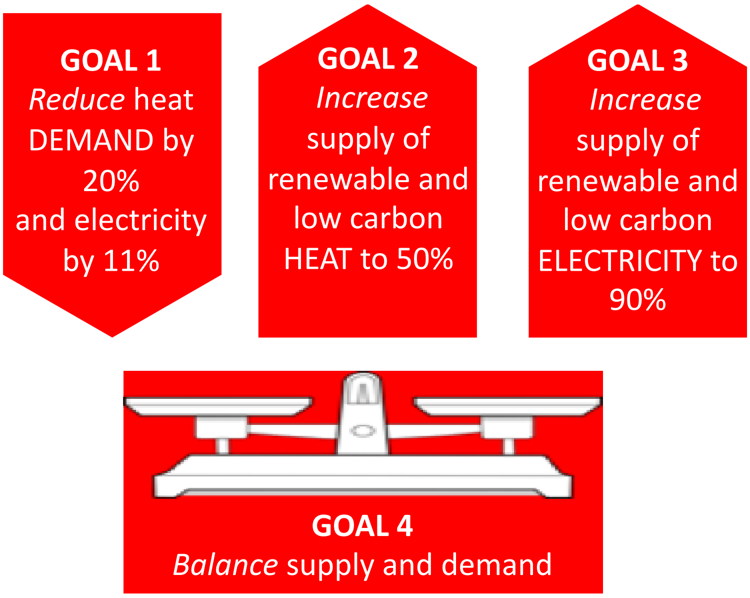


Figure 1 Summary of four key goals by 2030

1. **Reduce energy waste, and thus demand, in buildings and Industry**.
   Target: By avoiding heat waste, a 20% reduction in heat needed in homes, commercial and public buildings and industry, as well as an 11% UK-wide reduction in electricity needed through reduction in energy wastage.
   Urgent actions: An immediate program to improve the energy performance of all buildings and an immediate requirement that all new buildings are constructed to a zero-carbon standard.

2. **Decarbonise heating**.
   *Target***:** Around 50% of remaining heat needs (after reduced waste) from renewable and low-carbon sources.
   Urgent actions: An urgent decarbonisation of heating, taking advantage of locally available heat sources and maintaining the use of gas boilers for the majority of homes. A significant electrification of heat. Increase R&D across emerging technologies such as hydrogen to explore/investigate its deployment at scale

3. **Boost renewable and low-carbon electricity generation**.
   Target: Around 90% of electricity from renewable and low-carbon sources.
   Urgent actions: A program to deliver a more than a tripling in the collective output of solar and offshore and onshore wind within a decade. Immediate and substantial investment and support to bring other key technologies to market at scale within a decade, in particular marine energy and CCS. It is assumed that the UK's nuclear generating capacity is maintained at its current level.

4. **Balance the system.**
   Target: Ensure UK energy infrastructure is in a position to balance 69% of electricity from variable sources like the wind and sun. This will require measures to ensure energy generation, storage and use are all balanced.
   Urgent action: Rapid and extensive update of the grid and implantation of demand side response, preceded by a suitable investigation into the right balance of solutions, delivering a revolutionised system within a decade.

Meeting these goals will only be possible if the urgent action noted above begins immediately. If it does not, then the timeframe for decarbonisation would have to be assessed based on technical and real-world progress made in the intervening period.

Three delivery phases

Action on all four of the goals will need to be undertaken and coordinated in parallel. However, aspects of each will be delivered in phases. There is absolute clarity on the steps required until the mid 2020s. Some areas require further testing before decisions are made in the mid 2020s regarding their later deployment. While entirely approximate and indicative, Table 1 provides a rough summary of the three phases into which most of the recommendations fit.

Table 1 Phases for roll out of recommendations

Phase	Timing (Approx.)	Description
PHASE 1: Immediate action	2020-2024	• Extensive expansion of core technologies. • For emerging technologies, further investment and development to reach market readiness.
PHASE 2: Learn, deepen and accelerate:	2024-2030	• Expanding and accelerating core technologies to be primary energy providers. • Using learnings from phase 1 to decide on final energy mix and growing younger technologies to utility scale
PHASE 3: Post 2030 to zero-carbon	2030-2040	• Beyond the target period, deepening efforts towards delivering a 1.5-degree global warming target (including but exceeding zero carbon by 2040)

The goals are achieved concurrently, with the specific timing for each of the thirty recommendations across each of the three main phases outlined in Figure 2, which is a timeline showing what should be delivered and when. The recommendations are numbered and are grouped according to shared timing.

The full list of recommendations is then summarised on the following page in Box 1. These recommendations form the foundation for putting the UK on a path to zero carbon.

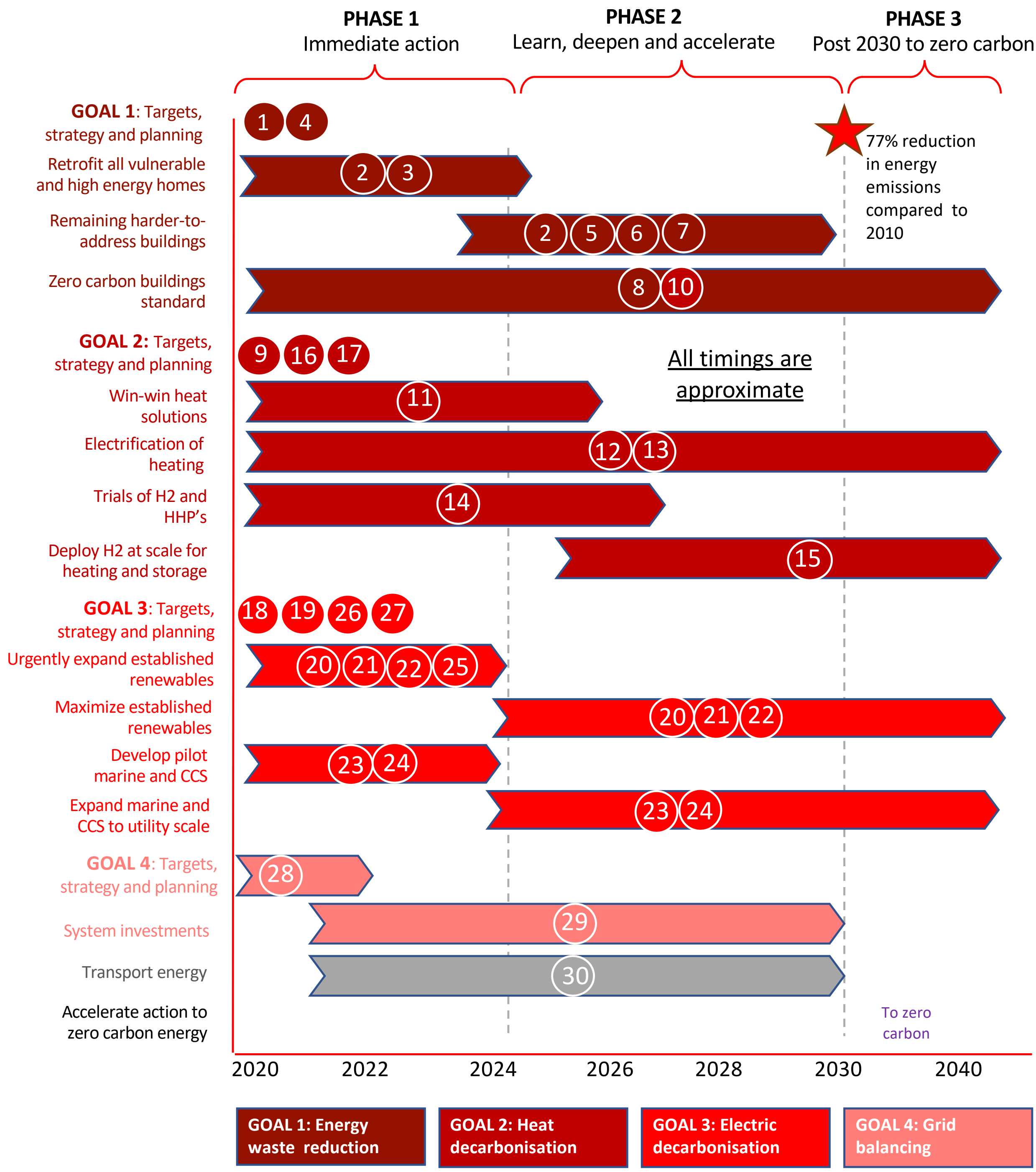


Figure 2 Timeline of recommendations for maximising renewable and low-carbon energy to 2030.

See Box 1 on following page for detail on individual recommendations

Summary of Recommendations

To put the UK on as fast a path to zero carbon as possible, this report makes thirty recommendations, which are summarised below within four goals that need to be delivered in parallel.

GOAL 1 – REDUCE ENERGY WASTE IN BUILDINGS AND INDUSTRY

Energy savings must be maximized if the decarbonisation of energy is to be achievable. It will require the majority of buildings and processes in the UK to become as energy efficient as possible. It will also require approaching energy demand in buildings as an infrastructure challenge, with a well-organized and well-funded national programme to ensure all buildings make good use of electricity. This will be a significant national undertaking, but the benefits to business, families and communities around the UK will be enormous.

Recommendation 1: Reduce energy waste, and thus demand, to the maximum possible extent over the years to 2030, and so set a target to reduce the need for energy across the UK by a minimum of 20% for heat and a minimum of 11% for electricity, relative to current levels.

Recommendation 2: Retrofit almost all of the UK's 27 million homes by 2030 to the highest energy efficiency standards feasible for each building to reduce domestic heat demand by 23% relative to current levels.

- Retrofit the as many homes as possible to EPC level A or B by 2030, making EPC C level the targeted minimum. This is expected to result in 41% of UK buildings reaching EPC A or B, and 44% at EPC C.
- Proactively implement area-based retrofit programmes – including SME buildings at the same time as domestic houses.

Recommendation 3: Ensure this retrofit work targets those homes in most need first.

- Top priority: high fuel poverty and low-quality housing.
- Second priority: homes and buildings with lowest energy performance (those that "leak" the most energy due to poor building design)
- Home retrofits should peak at around 3m per year in 2027.

Recommendation 4: Conduct a root-and-branch review of the range of standards, measures, materials specification and practices of the UK construction industry to maximize the quality, impact and benefit of the retrofit and renovation programme, to add to the work carried out under the Each Home Counts review.

Recommendation 5: Ensure all existing public buildings reach EPC A or B by the mid 2020s, except in extenuating circumstances, with EPC C required as a minimum energy-efficiency standard.

Recommendation 6: Ensure all existing commercial and industrial buildings reach EPC A or B by the mid 2020s, except in extenuating circumstances, with EPC C required as a minimum standard. Work with commercial and industrial sectors to achieve this.

Recommendation 7: Reduce energy use in industry by 11% by ensuring that process efficiency is maximised, waste heat is used on-site to the maximum viable extent and the remaining waste heat is made available to external users.

Recommendation 8: Reintroduce a zero-carbon buildings standard for all *new* buildings from 2020 and seek to ensure all new buildings are constructed full net zero-carbon as early as possible.

GOAL 2 – RADICALLY DECARBONISE HEATING

Recommendation 9: Set a target of 50% renewable and low-carbon heating by 2030, more than a twelve fold increase in output from today. Heating is responsible for over half of the UK's energy-related GHG emissions, and current renewable and low-carbon heating levels are extremely low. Therefore, the urgent expansion of renewable and low-carbon heating is one of the most important aspects of this strategy, as well as one of the most complex – due, for instance, to the scale and shape of heat demand.

Recommendation 10 (Heating Step A): Heat all new buildings by renewable or low-carbon energy only (or as close as possible), with no fossil-fuel heating of any kind (related to recommendation 8), from 2020.

Recommendation 11 (Heating Step B): Deploy quick-win heating solutions at the earliest possible time across the whole country, including: the complete removal of all coal and oil heating; biomethane injection into the gas grid; solar hot water; and the use of waste heat via district heating in dense areas.

Recommendation 12 (Heating Step C): Convert all existing buildings currently using electric heating to renewable or low-carbon electric heating at the earliest possible time, using heat pumps and solar hot water.

Recommendation 13 (Heating Step D): Begin converting buildings currently using natural gas for heating to use heat pumps and hybrid heat pumps, as well as introduce increasing levels of renewable or low-carbon hydrogen blended within natural gas supply. These buildings are the most complex group requiring a complete shift in heating systems over the long term (either to electric or 100% hydrogen) and so should be prioritised after Heating Steps A to C. *Renewable or low-carbon hydrogen* is hydrogen that has be produced without GHG *emissions*, through ether natural gas reformation combined with carbon capture and storage, or through the electrolysis of water using renewable electricity.

Recommendation 14 (Heating Step D): Research and development to demonstrate the long-term role of dedicated renewable and low-carbon hydrogen and hybrid heat-pumps, with three key elements:

- Trials of hybrid heat pump use at scale, to support in peak demand periods.
- Trials of dedicated hydrogen distribution and use for heat at scale – exploring full 100% hydrogen transmission infrastructure and household use. Important to demonstrate long-term feasibility of hydrogen as a 100% low-carbon solution, rather than partial low-carbon when blending with natural gas in existing gas network.
- Research and development towards reducing the costs of renewable and low-carbon hydrogen production, and well as hydrogen storage solutions.

Recommendation 15 (Heating Step D): Significantly expand renewable and low carbon heat in the second half of the 2020s, based on experiences and lessons from Recommendation 14. In particular expand renewable and low-carbon hydrogen, heat pumps and hybrid heat-pumps to appropriate scale and in the appropriate locations.

Recommendation 16: Maintain but do not expand current levels of biomass *heating*; expanding solid biomass for heating should not be a priority solution for direct heat supply.

Recommendation 17: Ensure heat strategy adopts several key solutions to ensure successful delivery:

- Deploy a planned, coordinated and regionally and locally appropriate patchwork of renewable and low-carbon heating technologies across the UK – ensuring technology choices are suitable for each region, zone or location, and that duplication and competing infrastructure is avoided.

- Minimise impacts of system shift – by replicating the successful characteristics of the existing system and providing training and support to workers in sectors experiencing a transition, among other measures that it is understood Labour will develop with the trade unions.
- Build awareness across both the public and industry that electrification of heat will be a multi-decade process.

GOAL 3 – BOOST RENEWABLE AND LOW-CARBON ELECTRICITY GENERATION

This report assumes nuclear output will be maintained at current levels based on Labour's policy that nuclear will continue to form part of the energy mix. This assumes the existing plants that are planned for decommissioning before 2030 are replaced with equivalent capacity, which this report finds could be possible in the time frame.

Recommendation 18: **Set a target of at least 90% of direct (non-transport) electricity demand being met from renewable and low-carbon sources by 2030**, almost a tripling in output compared to 2019 levels of generation.

Recommendation 19: **Rapidly phase out fossil-fuel extraction and use for electricity generation.** Immediately end new coal extraction and phase out coal electricity generation as soon as possible; immediately end fracking for gas; end electricity generation from oil anywhere in the UK by 2022; and reduce the annual operation of gas-fired electricity generation from 130 TWh today to 36 TWh in 2030 – a 72% reduction. The only form of fossil fuel use permitted, whether for power generation or production of hydrogen, should be that coupled with 100% carbon capture and storage, meaning no GHG's are emitted to the atmosphere at any point (See Recommendation 24)

Recommendation 20: **Two and a half times today's onshore wind capacity by 2030**, or 30 GW. Ensuring that together onshore and offshore wind would provide 55% of electricity generated in the UK.

Recommendation 21: **Nearly a seven-fold increase in the offshore wind capacity by 2030**, or 52GW. This would make it the UK's largest source of electricity and be around 7,000 new large-scale turbines (depending on average future turbine size). To maximise the UK's potential, undertake further detailed research to determine the maximum large-scale capacity and ideal distribution of off-shore wind; and the expansion of UK manufacturing capacity and skills.

Recommendation 22: **Almost triple solar PV capacity**, to 35GW, including a mix of building integrated small-scale systems and larger solar farms where appropriate.

Recommendation 23: **Trial and expand tidal energy** to around 3GW of capacity, for instance with:

- at least one medium scale tidal-lagoon demonstration scheme operating by the early 2020s – then, if successful, at least one larger scale tidal lagoon installation by 2030; and
- an expansion of tidal stream to at least 1GW of capacity by 2030.

Recommendation 24: **Trial carbon capture and storage in the early 2020s and expand it to become a significant if still emerging component of the energy mix by the late 2020s.** This is for both power production and hydrogen production. One large plant is expected in the early 2020s and at least two large installations are expected by 2030, with a total capacity target of around 2.5GW. Research-and-development support will be necessary to ensure this. It should be noted that CCS will likely remain a minority contributor to the energy supply, and its inclusion is *not* a loophole for continuation of large-scale dependence on fossil fuels.

Recommendation 25: **Support hydro energy expansion across the UK**, from pico-scale up to medium scale by 2030, adding a further 500 MW to UK capacity.

Recommendation 26: **Do not expand solid biomass use for large-scale *electricity* generation**, though it has been assumed that current generation levels are maintained.

Recommendation 27: **Encourage the adoption of distributed and community energy to accelerate delivery of energy decarbonisation**

GOAL 4 – BALANCE THE GRID

Recommendation 28: **Research shows that there are viable solutions that will enable balancing of demand and supply for the scenario outlined in this strategy. Therefore, there is no need to delay delivery of Recommendations 1-25.** As an example, the lights would stay on with the energy system outlined here_by maintaining current backup gas generation capacity in the 2020s; expanding power storage to at least 20GW; and investing in grid enhancements. This demonstrates that there are definitely workable solutions, and so work on goals 1,2 and 3 can begin in earnest, right away.

Recommendation 29: **Build on analysis in this report to develop a "UK-wide energy infrastructure coordination strategy" to ensure whole system view across electricity generation and supply, heat generation and supply, building retrofit and transportation.** An urgent (completed by end 2020 at the latest) and detailed strategy to ensure delivery that is coordinated and minimises cost and maximises efficiency, and in particular:

- **Identify opportunities for win-win coordination points across sector role out strategies.** Such as installing EV charging or ensuring smart appliances and heating to allow grid balancing in homes when retrofitting, as well as coordination of hydrogen use for localized buildings heating and centralized power storage.
- **Model the ideal mix of energy balancing solutions to ensure supply and demand are balanced.** Including hourly modelling and consulting with regulators, generators, academics and system operators; covering technologies such as: demand side management, back-up/peaking generators, power storage (pumped hydro, batteries, pressurized air etc), interconnectors, digitisation and smart meters, short term heat storage, EV smart charging and vehicle to grid (V2G), role of hybrid heat pumps in meeting peak demand, and so on.
- **Long-term electricity and heat storage** – especially for managing long cold stretches, which becomes more important as we shift from natural gas to other forms of heating, such as hydrogen and electricity based options.

TRANSPORT RECOMMENDATIONS

Recommendation 30: **Expand supply capacity to ensure that electrification of transport is matched by an increase in renewable and low-carbon energy generation.** This study demonstrates that this is feasible based on likely rate of roll-out of electricity vehicles.

Box 1 Full summary of recommendations for maximising renewable and low-carbon energy by 2030

The following experts, **in accordance with their expertise**, acknowledge that these thirty recommendations represent the upper limit of technical feasibility, but should be seen as appropriate to the scale of the climate emergency we find ourselves in:

- **Professor John Barrett,** Energy and Climate Policy, University of Leeds
- **Professor Tim Green**, director, Energy Futures Lab, Imperial College London
- **Dr Rob Gross**, director, Centre for Energy Policy and Technology, Imperial College London
- **Dr Stephen Hall**, School of Earth and Environment, University of Leeds
- **James Price**: Principal Research Associate, The Bartlett School of Environment, Energy and Resources, UCL
- **Russell Smith**, managing director, Retrofitworks
- **Professor Benjamin Sovacool**: Energy Policy, Science Policy Research Unit, University of Sussex
- **Joanne Wade,** deputy director**,** The Association for Decentralised Energy

Delivering the recommendations

The research team based its recommendations on the following key findings.

Delivering the thirty recommendations will require extensive updates to UK energy infrastructure, homes, transport and industry. A new approach to generating, transporting and using energy, will be needed, with systematic updates to outdated infrastructure across the UK. This will have profound effects on, and require careful coordination with, almost all other sectors of the economy.

A UK-wide building retrofit program would need to be at the heart of the transition because heat is the largest use of energy. Homes, commercial and public buildings would all need to meet the highest energy-efficiency standards technically possible.

For the UK's 27 million homes, which **account for 58% of the heating demand, the target of 50% renewable and low carbon heat can be achieved with moderate changes to current heating systems**. The large majority of homes currently relying on gas-grid infrastructure will be able to use the same infrastructure for new energy sources, minimising the modifications needed for households. For those that do undergo upgrade, the technology is tested and works and is already deployed at large scales in other countries. The upgrade will be undertaken at the same time as other updates required by the building retrofit programme outlined above.

While some areas of the transition need further testing and research to confirm the exact approach – particularly those required in the late 2020s – and some elements may change as technologies and public acceptance evolve, this does not affect the shape of the immediate action required. Likely late-stage refinements include: the exact role of renewable-hydrogen for large-scale heat supply; the role of electrification of transport; the scale and application of CCS; the rate at which the aging nuclear fleet can be replaced; and possible performance improvements in key renewable energy technologies. The report makes recommendations to advance these questions, which have little impact on the fundamental recommendations for the coming decade, and no impact on the recommendations for the coming 4 to 5 years.

The lights will stay on. Advances in the technologies and solutions available for managing supply and demand of energy mean that it is feasible to support high levels of intermittent renewables from sources such as the wind and sun. This report draws on research showing that even a partial selection of the cost-effective technical solutions available today to balance energy supply and demand would be more than sufficient to ensure the lights, and crucially heating systems, remain on whenever they are needed.

Electricity, heating, gas, building use and retrofit, and transport will need to be integrated to best balance supply and demand, and minimise costs and maximise efficiency. Therefore, **a whole energy system**

approach is necessary, ensuring planning and implementation for each sector must be part of a fully integrated strategy.

Setting the direction and ambition. While working with exact numbers is important to determine feasibility, any sound strategy allows for shifts in future implementations. In that respect, we suggest that it is the thirty recommendations are adopted urgently. **As technologies develop, costs changes and lessons are learned, and so mild fluctuations in numbers for individual technologies are to be expected** and are less important than following the spirit of the strategy to arrive at a mix that meets ambition of the report.

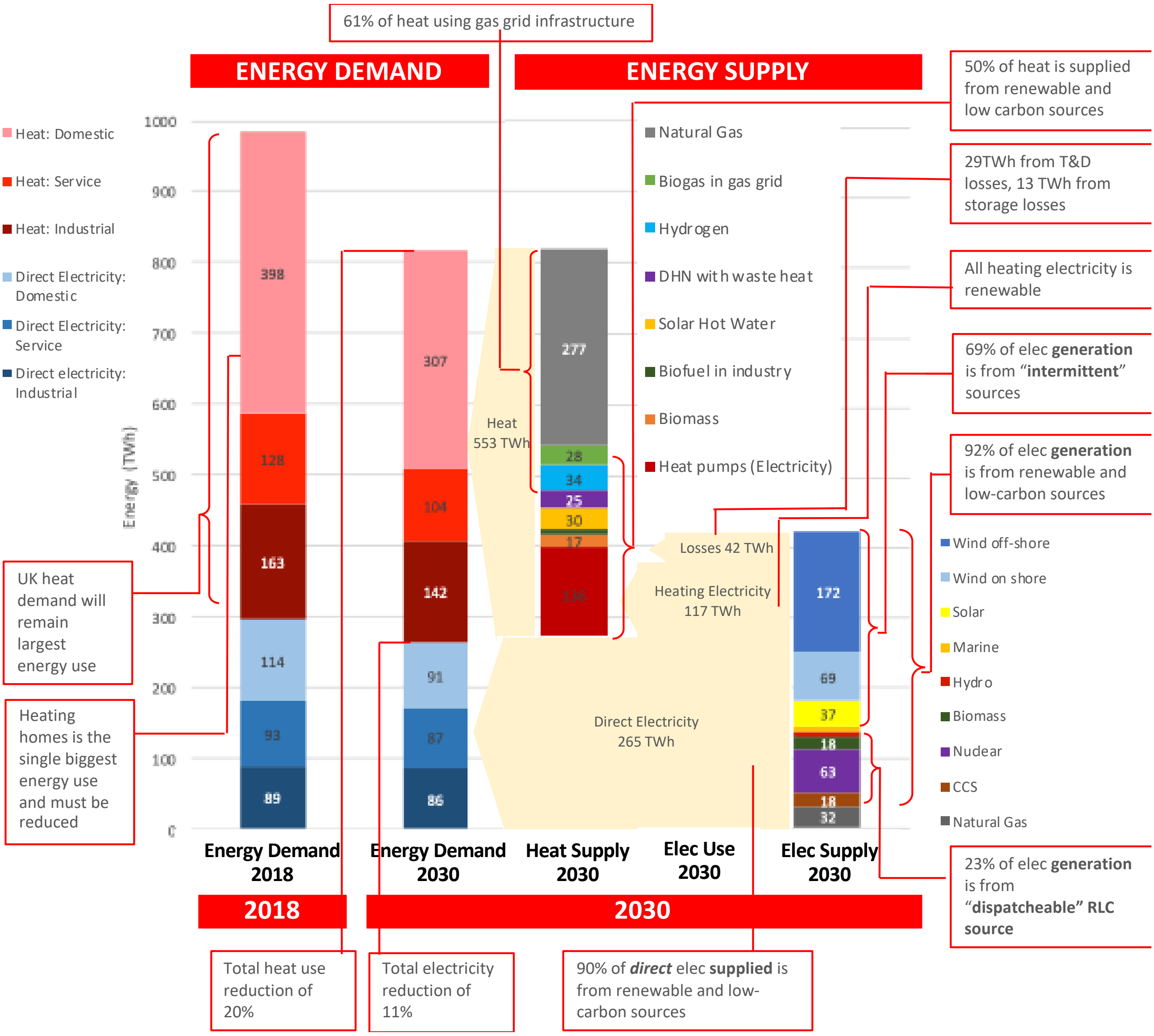


Figure 3 - UK national energy balance in 2030.

*The two vertical bars on the left show energy demand today and in 2030, illustrating the reductions achieved in each sector, and for heat and electricity, by 2030 as a result of energy efficiency measures (For more detail, see Chapter 2). On the right, two bars illustrate how energy demand is met in 2030. The bar labelled 'Heat supply' shows how the mix of heat-supply technologies provides the remaining heat demand in 2030. The bar labelled 'Elec(tricity) Supply' shows the electricity generated in 2030, by which source, and "Elec(tricity) Use" how this energy is split between losses, used as heating electricity and direct electricity. (See **Box 3** for explanation of the various types of electricity use referred to in this study). [Source: Project team's own analysis]*

Emissions targets and climate change

Electricity and heat use in buildings when taken together is the biggest source of emissions in the UK today, 56% in total. The rest being mostly transport, agriculture and waste. Over the last few decades, UK energy emissions have dropped, for instance by 35% from 2010 to 2017, partly due to the relatively low-cost shift away from coal to gas for power generation.

Going forward emissions reductions become more challenging and complex to implement as the "low hanging fruit", have been picked. Further reductions requiring much more reliance on "intermittent" sources, newer technologies and demand side actions.

Delivering the goals and recommendations outlined in this document will result in UK energy emissions dropping to 77GtC02e per year in 2030. As can be seen in Figure 4 electricity emissions will have dropped by more than 80% to just 16MtCO2e in 2030, and heat by almost 50%, an entirely unprecedented shift. This is a net 65% reduction relative to 2017, 77% reduction relative to 2010 (the reference year used by the IPCC to track progress) and 81% relative to 1990 (the reference year used by the Climate Change Act and Kyoto Protocol).

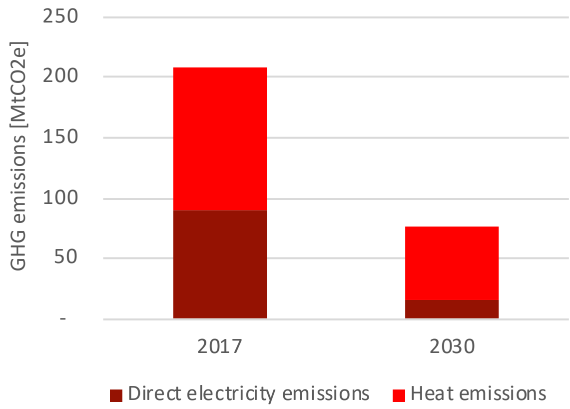


Figure 4 Reduction in UK heat and electricity emissions as a result of implementing the thirty recommendations outlined in this document

This level of reduction is a huge step up from anything proposed before by a UK government, and would place UK far ahead of almost all nations around world, and certainly all comparably sized industrialized nations. It is also a huge step up from current UK law, with the UK's official target defined by the Climate Change Act as zero carbon, but 20 years later, in 2050. However, is this enough based on the climate science? There is very strong evidence to imply that it is:

- **This will ensure the UK comfortably complies with the necessary trajectories outlined by the UK Government's Committee on Climate Change for a net zero-carbon UK by 2050**. Specifically, the CCC's Net Zero Carbon 2050 report, indicates buildings industry and power emissions should have reduced emissions to around 100GtCO_2 by 2050. These recommendations will have more than achieved that reduction by 2030, twenty years earlier than required for the CCC net zero target.
- **The thirty recommendations will ensure the UK demonstrates considerable leadership in relation to the IPCC's "central" global average emissions reduction scenario for 1.5^{o}C.** In its 1.5^{o}C Special Report, the IPCC states that the average of interquartile range across its various model pathways (some of which include removal of emissions from the atmosphere post 2050) would represent a "global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030"[1]. The 77% reduction by 2030 relative to 2010 shows the UK would be is in a substantial leadership position relative to this "central" trajectory.

- **Most importantly, delivering the thirty recommendations would go even further, and ensure the UK on track to meet the IPCC's high ambition, "no-overshoot" 1.5ºC scenario, avoiding the need for carbon emissions removal from the atmosphere post 2050, which the authors of this report consider to be the fairest and safest way forward.** All the other above scenarios assume that global emissions budgets are exceeded, and so emissions must be actively removed from the atmosphere in the second half of the century, for instance though bio-energy and carbon capture and sequestration (BECCS). However, such methods are undemonstrated, and almost certainly far more complex, risky and resource and cost intensive than simply avoiding the emissions in the first place. It also may be too late by then in terms of runaway climate change. Instead it is much preferred that a global trajectory be established that simply keeps emissions within the carbon budgets set by the climate science. This is termed a "no-overshoot scenario". The thirty recommendations scenario meets all the specified criteria set out by the IPCC (such as reduced use of fossil fuels, energy demand reduction, GHG emissions reduction and so on), and indeed *exceeds* them, in most cases by a large margin. **Putting the UK in a position of global leadership, and providing a firm scientific basis under which to justify the immediate adoption of all thirty recommendations.**

The economic, employment and health benefits

Delivering the recommendations outlined above would allow the UK to develop a more prosperous, 21st century economy, and address many of the root causes of multiple health issues affecting the UK population. The over-riding conclusion from an analysis of the wider impacts of delivering the recommendations, is that there is a clear economic case for doing so, and so would be justified even were there no such thing as global warming. This is vital because the international leadership on climate change represented by implementing these recommendations, would be valuable if other countries are encouraged to adopt a similar path, which will be greatly encouraged by it delivering wider benefits.

Specifically, delivering the thirty recommendations would[2]:

- **Deliver UK wide economic benefits that *far* outweigh the economic costs**. The recommendations would require and investment of 1.9% of GDP each year, however this would be more than balanced by the resulting value added to the UK economy. The recommendations would result in consistently more prosperous UK between 2020 and 2030. This result in a net benefit (after accounting for costs) of £800 billion for the economy by 2030. This is equivalent to the entire economy of Holland or Turkey. This is even when ignoring the specific costs of climate change, which Nicholas Stern calculated to be between 5-20% of annual GDP over the long term. When considering these avoided costs as well, it is clear the recommendations are the basis for a vastly more prosperous future.
- **Create a jobs revolution, with an average of 850,000 new jobs across the green energy sector across the 2020s**. This would be distributed around the whole of the UK, bringing substantial benefit to all regions. Some of these jobs will be transitions from other sectors, and so efforts will be needed to ensure a just transition. It will also be important to make sure the large volumes of energy equipment is and infrastructure is manufacture and constructed in the UK using UK-based workers. This is something that a UK government will have to work to ensure if the benefits of this plan are to be fully released for the UK.
- **Households will be better off as a result**. Household energy *bills* will not need to be increased to pay for the investments, and due to increased economic prosperity wages can also increase by 2% across the economy. Reduced energy wastage in homes will also help eradicate fuel poverty, benefiting the 2.5m UK homes it currently affects.

[2] All macro-economic impact data is the result of a bespoke modelling exercise undertaken by Prof John Barrett and team at the University of Leeds.

- **The UK population will be significantly healthier** – Burning fewer fossil fuels will result in 6,200 avoided deaths a year by 2030 due to improved air quality. In total this also represents an increased 46,000 life years across the UK population as a result of avoided deaths in 2030, and an average increased life expectancy of UK citizens by 23 days. It is also possible to monetise these mortality and morbidity impacts. This will provide an equivalent value to the UK economy, through gained productive work hours, of £1.6bn, and also an annual saving to the NHS of £400m. By upgrading dwellings through a UK wide home retrofit program, there could be up to 560,000 fewer cases of asthma by 2030 due to reduced damp, and 1,500 avoided deaths from cold.
- **A huge opportunity for business**. Net profits in the private sector could be an extra £500bn over the decade, as a result of this program of work, depending on the policy landscape.
- **Government finances will be improved**. For every £1 of capital investment made by the UK government, nearly £2 will be captured through increased tax revenues due to a more prosperous economy. The cumulative benefit by 2030 would be enough to fund the entire NHS for whole year, or pay for HS2 twice over, or Crossrail more than eight times over.

Towards zero-carbon energy and a zero-carbon UK

The report has not considered post 2030 in great detail because forecasts beyond 2030 are highly path dependent. Also, because **delivering the four goals and thirty recommendations by 2030, is the right level of ambition and the right timeframe**.

Post 2030 work will need to continue to reach to zero carbon, however. Through delivering the thirty recommendations, the only fossil fuel left in 2030 will be a reduced level of natural gas. To reach zero carbon, the UK must remove all gas use from electricity generation, and from heat provision, or ensure that all fossil fuel generation is used only with complete carbon capture and storage.

There are several core decisions, and challenges or factors, that will impact on how the UK reaches zero carbon energy, and how fast it can do so. Choice of heating technology for roll out post 2030 (whether hydrogen, electric or a mix), how any hydrogen used is produced, pace and penetration of transport electrification, overcoming of challenges in balancing the entire heat demand, further increasing overall renewable and low carbon electricity generation and the possible need for seasonal storage. These all create many possible future scenarios, all with different timelines. However, based on a simple analysis based on accelerating action in the 2030s, **it could be estimated that zero-carbon electricity could potentially be anticipated as early as 2034-2040, and zero carbon heating 2036-2040. These do not however form part of the recommendations for this report.** Either way, the best way to accelerate this outcome is to embark on the thirty recommendations that *are* outlined here, as quickly and deeply as possible.

For climate action, energy is the top priority and area that needs most urgent action, however other vital areas that are beyond the scope of this analysis, must also be addressed. This is the right priority, over the right time frame. Yet a full UK climate strategy must supplement this energy strategy with action on non-energy emission sources, largely through ***better production and consumption***. Moving agriculture and food, imported goods and services, aviation and shipping through a shift towards a circular economy. Then the final step will be towards even deeper societal mindset change, that addresses the trajectory of our economy and begins to broaden our vision of progress beyond simplistic GDP growth to include more complete picture of prosperity, including health, wellbeing, clean air, education and so on. Focusing on a ***distributive and regenerative 21st century economics*** that puts people and planet first, so that all humans can live a good life within planetary boundaries.

A vital and pioneering first step

Delivering these thirty recommendations would make the UK a pioneer. No other industrialised country has plans of a similar scale. The scope and pace of change would bring challenges, but also first-mover advantages, and would avoid costly high-carbon lock-in for the country's infrastructure. The UK would build a unique skill and knowledge base supporting the kind of transition that many other countries will need to go through, providing a huge opportunity for the UK to demonstrate industrial leadership.

Energy transition is a nonpartisan concern. **The changes outlined here will require a focus, scale and pace of national action not seen for over a generation**. The UK needs to start retrofitting buildings and deploying renewable and low-carbon energy at massive scale to make an effective transition a reality. It must start doing so right now.

1.

Introduction.

1.1 An energy transition that will benefit everyone

The Labour Party is committed to delivering in one decade an energy transition that will transform Britain's prospects for generations. Making good on that pledge is not just an opportunity to create high-quality jobs, eliminate fuel poverty, and develop skills and industries that Britain can export around the world. It is also a moral imperative to reduce the growing risk from climate change that threatens everyone's future prosperity.

The programme outlined in this report shows that investing to maximise our energy from renewable and low-carbon sources by 2030 is not a pipe dream. Britain has the best natural opportunities for renewable energy of almost any country in the world. If action is taken quickly, in the first parliament of the next Labour government, it is still possible to make up the ground lost under recent Conservative governments and become a leader in the global clean-energy revolution, resulting in greater prosperity and employment.

The faster Britain shifts to a low-carbon economy, the quicker and greater will be the rewards. The longer we prevaricate, the transition that we must inevitably make grows more expensive. Why? Because a delayed transition will need to be much quicker, with less time to test and learn, and so will be more disruptive and risky.

The short-term benefits of maximising energy from renewable and low-carbon sources are huge. By raising every home and public building in Britain to the highest energy-efficiency standards by 2030, the UK will be able to end fuel poverty, eliminate mental and physical illness caused by poor housing, and raise productivity and well-being from schools, hospitals and care homes that are designed to keep people comfortable with the minimum necessary provision of clean energy.

Millions of people will be able to breathe more easily, rather than suffering needlessly with polluted air.

Britain will have made an investment that puts it on a strong footing for the long-term, cutting out the obscene wastefulness of our current, ageing, high-polluting energy system, and making our economy ultra efficient to cope with the demands of a the 21st century.

Once the initial investment is made, Britain will have the comfort of energy security for decades to come, benefiting from the nearly free supply of solar, wind and tidal energy, and protected from the volatility of fossil-fuel prices.

Moreover, we have a moral duty to switch to clean energy. We are the first generation with the data and technology to properly understand the full implications of the damage that two centuries of industrialisation has done to the fragile ecosystem that makes all life possible on Earth. And we are probably the last generation that is able to prevent runaway climate change from threatening the very existence of human civilisation. If we don't cut pollution, the impacts from climate change could reverse all the other gains to people's quality of life that economic prosperity can deliver.

1.2 Project aims and goal

This independent report was request by the Labour Party with a **goal to identify the maximum contribution of renewable and low-carbon electricity and heat in buildings that could be implemented by 2030, should the UK be put on a "climate emergency" footing for the next decade.**

The findings and recommendations presented are intended to inform understanding and policy development. The authors hope that the report will stimulate further research and analysis to contribute to meeting the greatest challenge of our time. This report:

- **Develops an example feasible pathway to maximum renewable and low-carbon energy in 2030** – balancing the challenges of available resources, technology maturity and complexity, cost and disruption.

- **Provides analysis of the technical challenges and opportunities** in relation to the energy choices that need to be made – including drawing together the latest evidence about technologies and approaches, how they have performed and how they are expected to develop.

- **Identifies the main gaps in research** that are important to making policy decisions or advancing technological development.

- **Sets out what a maximum renewable and low-carbon energy UK would look like in 2030.**

- **Identifies the sequencing and timing of actions needed to achieve this aim.**

- **Identifies carbon savings that would be made by achieving this** and provides a comparison with the UK Carbon Budget and any other key UK climate commitments.

- **Includes findings on the wider impacts** of maximising renewable and low-carbon energy by 2030, in particular for public health, employment and the wider economy.

- **The report does not explicitly include any analysis on the levers and policies needed** to implement its recommendations or speculate on how the necessary actions would be funded. Nor does it directly estimate non-GHG impacts.

1.3 Project team

Two main groups have been involved in developing this document.

1.3.1 Expert reviewers

The work, either in whole or in part (according to expertise), has been contributed to, reviewed and/or commented on by a group of the UK's leading energy researchers and thought leaders.

The following experts, in accordance with their expertise, acknowledge that these thirty recommendations represent the upper limit of technical feasibility, but should be seen as appropriate to the scale of the climate emergency we find ourselves in:

Professor John Barrett, Energy and Climate Policy, University of Leeds
Professor Tim Green, director, Energy Futures Lab, Imperial College London
Dr Rob Gross, director, Centre for Energy Policy and Technology, Imperial College London
Dr Stephen Hall, School of Earth and Environment, University of Leeds
James Price: Principal Research Associate, The Bartlett School of Environment, Energy and Resources, UCL
Russell Smith, managing director, Retrofitworks
Professor Benjamin Sovacool: Energy Policy, Science Policy Research Unit, University of Sussex
Joanne Wade, deputy director**,** The Association for Decentralised Energy

Reviews have taken place through a workshop, through direct review input into the report, and/or bilateral conversations.

1.3.2 Authors

This project is the product of a working group of industry professional and experts from across the energy sector. All contributing authors have worked independently from their affiliated institutions, in a purely personal capacity and in their own time.

Lead Author

Tom Bailey - An energy systems and climate change expert with 12 years of experience across the private, public and third sectors. Tom has experience in local, regional and national climate change policy and strategy, carbon inventories, green building design, energy systems optimisation, energy master-planning and sustainable consumption. He has lived and worked in the UK, China and United States and has a BSc in Physics from the University of Manchester and MSc in Sustainable Energy from Imperial College London.

Contributing Authors
Alexander Schamroth-Green – Alexander has spent time working in the public sector in energy policy and now working in the private sector delivering sustainable energy and energy management solutions. He studied Mechanical Engineering.

Archie Luxton – Archie is a mechanical engineer with experience in designing and optimising building energy systems for commercial, industrial and residential buildings in the UK and Europe.

Christina Lumsden – An energy and climate change senior consultant with 6 years of experience. She specialises in low carbon and renewable energy systems; advising a range of clients including private and public on their energy strategies. Her experience also includes emission inventories & modelling, green building design, environmental policies and strategy development. She is a member of the Energy Institute (EI) and in process to become a Chartered Environmentalist with EI.

Donal Brown – Donal is a Research Fellow in Renewable Electricity Business models at the University of Leeds as part of the European Union H2020 project - Prosumers in the Energy Union (PROSEU). Donal is Sustainability Director at an innovative Design and Build practice - Sustainable Design Collective. Donal has past experience in sustainable energy consultancy, and a First class BSc in Environmental Science, Distinction in Climate Change and Policy MSc and PhD in Domestic Retrofit from SPRU.

Ewan Frost-Pennington – Energy and climate change consultant with an MPhil in environmental policy. He is a specialist in the application of advanced modelling methods for maximising carbon reductions, with experience conducting technical, economic and carbon analysis associated with low carbon energy infrastructure.

Jaspreet Singh – Jaspreet is an electrical engineer with a MPhil in engineering for sustainable development. His area of expertise and interests are within energy strategy, commercialisation and engineering and has experience in working in developed and developing countries.

Sara Dethier – An energy and climate change consultant working for an engineering firm, her work focuses on climate, energy and sustainability planning for clients in the public and non-government sectors. She holds an MSc in Sustainable Energy Futures from Imperial College.

William Bailey – An engineer with 4 years experience in the built environment from early stage design to onsite construction. William has experience in green building design and optimisation, mechanical and electrical systems design, energy strategy and climate change mitigation in both the private and public sectors.

1.4 Approach

Understanding the project aim, the main questions of the research team, some key terminology and the methodology will lend perspective to the details that follow in this report.

1.4.1 Clarifying the aim

The specific aim as defined by Labour is: *By 2030, a maximum level of the energy consumed in the UK – both heat and electricity at the point of use – by buildings, industry and other stationary users, will be supplied from renewable or low-carbon sources.* To ensure clarity, the specific usages of key terms applied in this work are described below to provide a more thorough basis for the aim.

Usage of 'renewable or low-carbon':

- Refers only to renewable energy, or low-carbon energy including nuclear.
- Energy systems requiring fossil fuels are not included – such as gas combined heat and power (CHP). The fossil-fuel electricity component of heat-pump heating does not contribute, though the free heat component does.
- The exception is fossil fuels with fully installed carbon capture and storage systems to ensure no GHG emissions are produced during operation.
- See Sections 3.4.2.2 and 4.4 for an exhaustive list of which sources are considered renewable and low-carbon heat and electricity, respectively.

Usage of 'energy':
- 'Energy' is used in the context of heating and electricity – in all buildings, including domestic; in industry (buildings and process); and in other sectors such as the commercial, health, education sectors.
- The report's usage does not include fuel or electricity for transport.
- The report's usage of 'energy' exclusively pertains to *useful energy at the point of use*, for example hot water or air entering a building central heating system, or electricity used to power machinery as measured at the socket.
- The usage does not refer to either *fuel energy* or *primary energy*, as either of those would provide perverse incentives such as encouraging swapping to higher carbon fuels to achieve small energy savings.

Usage of '% renewable or low-carbon' figures:
- This percentage refers to the total *annual* energy. It is a percentage of TWh/yr, not of peak energy consumption (GW).
- The aim is an *energy decarbonisation* objective, as well as an *emissions reduction* target. See Chapter 7for anticipated GHG savings related to achieving the energy decarbonisation goal.
- The work covers all the UK, and so includes the regions for which energy policy is administered by devolved governments – in other words, Scotland, Wales and Northern Ireland.

1.4.2 Methodology

The project team addressed four main questions, the answers to which are presented as the four goals for delivering maximum renewable and low-carbon energy by 2030:

> **Question 1: What is the maximum feasible energy demand reduction by 2030** across all stationary energy uses? Which building types will implement which changes at what pace? (Addressed in Section 2)
>
> **Question 2: What proportion of the remaining heat demand can be supplied from renewable and low-carbon sources, and what are these sources**? (Addressed in Section 3)
>
> **Question 3: What renewable and low-carbon sources of electricity are required**? This is based on the resulting electricity demand – accounting for any electrification of heating. (Addressed in Section 4)
>
> **Question 4: How can the described 2030 energy system be balanced reliably in relation to projected demand**? (Addressed in Section 5)

A project team was established around each of these questions. The findings for each section collectively shape the proposals outlined in this document.

This work is based on a combination of the following methods.

1.4.2.1 Drawing together existing leading research

- Project teams researched existing scenarios and analysis similar to the aims of this study. (In other words, those with a similar level of ambition, coving both heat and electricity, and time frame, for a similar country).
- A literature review was undertaken of the modelling and projections from reputable research institutions as well as organizations with a role or responsibility in shaping and/or delivering the UK's long-term energy picture.
- They accessed a wide range of studies looking at future generation trajectories, and the work of a number of organisations that regularly update their own long-term models, including the Committee on Climate Change[3] and National Grid[4]. Some of these even consider very high levels of renewable and low-carbon electricity up to 2030 or beyond. However, none of them sufficiently address the specific goal of maximising renewable and low carbon heat as well as electricity, at a maximum pace. For instance, most do not consider a scenario that reaches a high percentage of all non-transport energy by 2030, though there are many studies many consider how renewables can up to 100% of electricity. The main exception in the CCC's Net Zero Carbon report, which has been relied on extensively where suitable. There have also been some studies by non-academic institutions around a full zero carbon UK by 2030, however none of these were considered to include robust enough trajectories, or included assumption not considered suitable, and so have not been taken as basis for this study.
- Where possible, they incorporated the content, trajectories and proposals from relevant scenarios found in the literature review. For instance, they incorporated detailed research into the energy efficiency opportunities for process energy in industry. They also utilized data that is outside of the scope of this study in terms of trajectory development, but on which the trajectories developed depend.

1.4.2.2 Developing a bespoke energy balance model

- As there are not large numbers of identical scenarios in the literature (with a similar focus on high levels of renewable and low-carbon heat as well as electricity) the next step was to build an annual energy balance model to allow the development of a bespoke 2030 scenario that includes heat and electricity, and to generate numerical outputs around capacity, generation and other factors.
- The project team populated the model with best assumptions and data from the research and work/evidence resources, to build a national picture of what is possible. Given this was not a detailed hourly energy model, these findings were provisional but satisfactory for this type of strategy document. The above steps were applied in a cyclical process to the four fundamental questions that describe the renewable and low-carbon transition. Each question was addressed sequentially, based on the outputs of question 1 and 2, until a viable trajectory was identified. Then solutions were assessed for feasibility, and if elements were not viable, these were addressed. The process repeated until the final solution outlined in this document was identified.
- Detailed or dynamic modelling was not possible given the available resources, and is also not considered necessary for this strategic level of planning. The project teams recommend, however, that after publication, the UK energy research community undertake detailed assessment of this scenario, detailed energy balance modelling, cost-benefit assessments and optimization, and over hourly dispatch models - to help fine-tune the proposals.

1.4.2.3 Expert review

Once a scenario was identified as the preferred trajectory to 2030, it was tested for plausibility with the project experts and industry professionals.

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[3] https://www.theccc.org.uk/publications/
[4] http://fes.nationalgrid.com/fes-document/

1.4.2.4 Ensuring a cost-effective solution that delivers net benefits to the UK

Delivering the most cost-effective solution for maximum renewable and low-carbon energy is a central condition of success for the strategy. While detailed cost optimisation modelling has not been undertaken, each step of the strategy considers all the viable options, compares them on a cost basis, and selects the least expensive option that delivers the necessary outcomes. This cost-benefit analysis has been central to the external review team's role in identifying if elements of the strategy could adopt a more balanced or lower-cost approach.

A note about findings and numbers

All the findings and numbers in this report are considered robust and reliable. However, they are also approximate, based on assumptions and estimates derived from the available information today.

These figures have been assessed to the highest resolution possible given the resources available to this project. However, this is a national-level strategic report, rather than a detailed sector implementation plan.

The level of analysis underpinning this work reflects that needed to clearly articulate a credible national-level transition. Further detailed implementation planning will be required to develop regional and sectoral transition plans.

Box 2 Note about findings and numbers

1.5 Ten years to deliver UK wide renewable and low-carbon energy

High levels renewable and low-carbon energy are feasible if implementation of the recommendations in this report begin immediately. If deployment is delayed significantly, or happens at a slower pace than recommended, further additions will need to be made to the recommendations to address the gap. Current UK Government policy would not achieve the nature and pace of transition proposed – a change in plans is needed.

The global context is fast changing, with prices falling and the private sector leading in a transition to renewable energy in many cases. For instance, the significant reduction in PV and battery prices over recent years was many times faster than had been predicted.

Action on all four of the goals will need to be undertaken and coordinated in parallel. However, aspects of each will be delivered in phases. There is absolute clarity on the steps required until the mid 2020s. Some areas require further testing before decisions are made in the mid 2020s regarding their later deployment. While entirely approximate and indicative, Table 1 provides a rough summary of the three phases into which most of the recommendations fit.

Table 2 Phases for roll out of recommendations

Phase	Timing (Approx.)	Description
PHASE 1: Immediate action	2020-2024	• Extensive expansion of core technologies. • For emerging technologies, further investment and development to reach market readiness.
PHASE 2: Learn, deepen and accelerate:	2024-2030	• Expanding and accelerating core technologies to be primary energy providers. • Using learnings from phase 1 to decide on final energy mix and growing younger technologies to utility scale
PHASE 3: Post 2030 to zero-carbon	2030-2040	• Beyond the target period, deepening efforts towards delivering a 1.5-degree global warming target (including but exceeding zero carbon by 2040)

The goals are achieved concurrently, with the specific timing for each of the thirty recommendations across each of the three main phases outlined in the executive summary, which is a timeline showing what should be delivered and when. The recommendations are numbered and are grouped according to shared timing.

Keeping to the 2030 timeframe with a later start date will be more challenging for a number of reasons:

- The last decade has seen a concerted dismantling of climate change, energy efficiency and renewable energy policies in the UK – for example, the Feed in Tariff (FIT), ECO, Carbon Emissions Reduction Target (CERT), Community Energy Saving Programme (CESP), Green Deal and CCS trial. This has led to a lack of confidence in the private sector and has resulted in a significant drop in investment in many renewable and energy-efficiency activities. This capacity and confidence may take some time to rebuild.
- There is a lack of resources, skills and capacity at the local-authority level after a decade of austerity. Local government would have a vital role in delivering the changes described in this document, and a large part of work in the first parliament would need to be rebuilding local authority capacity to do so.
- Many of the changes outlined in this document are large-scale infrastructure transitions that can take a long time to plan and implement. Indicating that while the level of activity will be the same for throughout the 2020s, the delivery of clear measurable outcomes will increase over time due to ongoing capacity building, and investment in long term projects baring fruits.

The following four sections address each of the core questions in sequence to build the full picture of what maximising renewable and low-carbon by 2030 would require.

2.

Goal 1: Reducing energy waste in buildings and industry.

2.1 Chapter Summary

GOAL 1 – REDUCE ENERGY WASTE IN BUILDINGS AND INDUSTRY

CHAPTER BACKGROUND

Heating homes is Britain's single largest use of energy, and our largest single source of greenhouse gas emissions. Reducing heat and power needed for homes represents the largest opportunity to reduce Britain's energy generation demand.

Much of the energy used to heat homes is wasted because of the county's ageing building stock and low energy-efficiency standards. For every £1 spent on retrofitting fuel-poor homes an estimated £0.42 would be is saved in UK National Health Service spending. Therefore, retrofitting must be the first step. There is little point in investing in renewable and low-carbon energy if it to be wasted due to poor energy conservation – common in the UK's ageing and poorly insulated building stock.

The UK's direct electricity use grew steadily for a century up to a peak of 353TWh in 2006, after which electricity use has dropped every year, to around 297TWh today. Today, the peak electrical demand is 52.7GW and peak gas was around 300GW on the coldest days. Addressing heat demand is vital to reducing fuel poverty, and heat is more complex to decarbonize than electricity.

This chapter addresses demand reduction only; alternative sources of energy are considered in following chapters.

CHAPTER FINDINGS

Maximum levels renewable and low-carbon energy would be easier and cheaper to if energy waste was minimised. The cheapest power station is the one you don't have to build.

There is enormous potential to reduce energy waste – and thus energy demand and generation – by making improvements to the UK's building stock, and through efficiency in industry. This report recommends a **20%** reduction in heat demand across all building types by 2030. A greater reduction would be extremely challenging. Most of this reduction would be achieved in domestic buildings, at 23%, with 19% and 13% for commercial/service and industrial sectors respectively. **Energy-efficiency measures would bring a moderate decrease in electricity demand,** with an 11% saving expected across the board – similar to historical reductions over the last decade.

The backbone of this strategy is a nationwide building upgrade programme with the aim of bringing 24 million homes in the UK up to the highest energy efficiency standards practical, with a minimum of EPC rating C; reducing damp and draughts; improving comfort, health and well-being, security, and safety; and improving community spaces by 2030. This is expected to result in 6.8m homes to EPC A, 6.0m to B and 11.2m to C. It is anticipated that around 3m hard to reach homes will need to be addressed in the early 2030s.

The immediate priority for upgrades will be areas with high fuel poverty and low-quality housing. The second priority will be homes with the lowest energy performance. If the programme is adopted, millions of people will benefit from warmer homes and lower bills and be lifted out of fuel poverty. Targets for the nondomestic sector will also make British industries more competitive by reducing energy costs.

For all new buildings, codes will require standards equivalent to EPC A immediately, followed by a **zero-carbon** requirement by the early 2020s. New buildings are expected to create very little new energy demand.

This strategy will also be a key means of delivering the low-carbon heat and electricity agenda. Mandating these improvements in EPC rating for new and existing buildings will drive the adoption of low-carbon heat sources, such as a heat pumps, and distributed electricity sources, such as PV panels, and also 32rioritize peak demand reductions and increased flexibility, assisting with electricity system balancing all addressed in subsequent chapters**.**

CHAPTER RESOURCES

- The UK Energy Research Centre
- The Association for the Conservation of Energy
- The Centre on Innovation and Energy Demand
- The Committee on Climate Change
- Element Energy

CHAPTER CONTENT

- Background: energy use in buildings today
- The importance of demand reduction
- Home energy efficiency and energy-demand reduction
- Reducing energy waste in the commercial and industrial sectors
- New buildings
- Summary of Recommendations

2.2 Background: energy use in buildings today

The total electricity generated in the UK in 2017[5] was around 320TWh, including transmission losses of around 7.5%,[6] meaning direct electricity consumption in the UK was about 297TWh. This direct electricity consumption (See Box 3 below for outline of different electricity demand types) amounts to approximately one third of the energy used. The other two thirds of energy are used for heating, primarily supplied by the gas grid. Total heat use was around 689TWh, with homes contributing to well over half of that in total.

Figure 5 shows the breakdown of heat and electricity use by buildings in three sectors: domestic (homes), the service sector, and industry. Power used in homes for lighting and appliances is the UK's biggest direct electricity need, making up 35% of 'direct electricity demand' – electricity demand for power only, not including electric heating. (See the box Categories of Electricity Demand for more detail.) Heating homes is the single largest use of energy in the UK, accounting for nearly 60% of all heat used, and almost 40% of all energy needs.

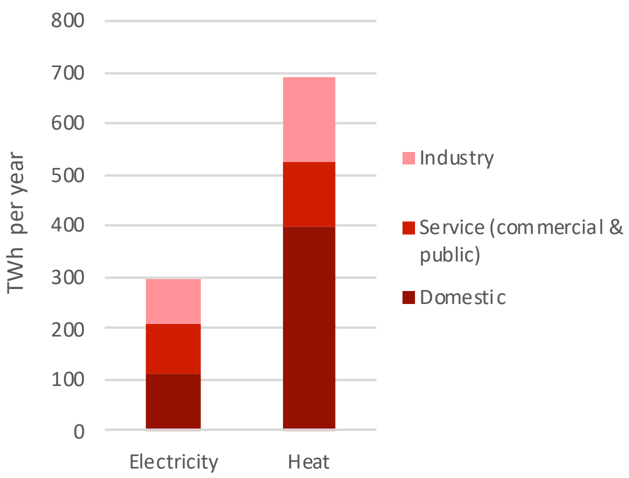

Figure 5 UK energy demand break down (various sources).

Figure 5 shows the breakdown of heat consumption by end use, to heat spaces, for hot water (for cooking, cleaning or other "in building" uses) or to drive industrial processes.

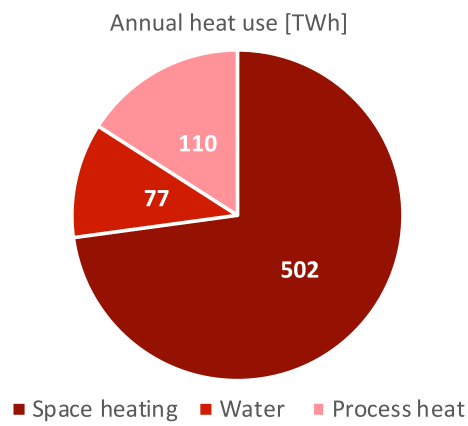

Figure 6 Breakdown of UK heat demand by end use

[5] 2017 is the most update to date available data at the time of writing
[6] https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

As noted in the introduction, this study does not focus on transport energy. However, in Chapter 6 the potential impacts of including the electrification of transport are considered.

CATEGORIES OF ELECTRICTIY DEMAND

Direct electricity demand – electricity used 'at the socket' to power electrical appliances, lighting, and the like. The largest user of direct electricity in the UK is homes; industry and commercial buildings follow, each using similar quantities. Direct electricity is the vast majority of all electricity use historically. It also includes plug-in electric heating and storage heaters. It does not include building-integrated electrical heating, such as from heat pumps. The remainder of this chapter deals only with this electricity demand, and all discussion of demand reduction focuses on *direct electricity* only. (Note – Even though transport is not part of the target, typically the available data on UK wide direct electricity demand will also include *conventional* electricity for transport, mainly traction for trains, and hence this is included the figures used throughout, however this is a very small proportion of total and so is not expected to impact on conclusions. Electricity for road vehicles is considered as a separate demand below).

Heating electricity demand – electricity used on site to power building-integrated electric heating such as heat pumps. The electrification of heat, and thus heating electricity demand, is likely to expand very significantly over the coming decades, as outlined in Chapter 3.

Total electricity demand – the sum of the direct electricity demand and heating electricity demand. Total electricity demand is the amount of electricity that must be generated to 'keep the lights and heaters' on, and the volume against which the level of renewable and low-carbon deployment is judged.

Total electricity generated – the total electricity demand minus the 7.5% of electricity lost in transmission from the generator to the user. Because thermal energy lost in the wires, more electricity must be generated than used. Total electricity generated is the volume of electricity for which Chapter 4 develops a renewable and low-carbon generation plan.

Vehicle electricity use – electricity used by electric vehicles. As noted above, the increased electrification of transport is not a core focus of the study, and therefore the expected build-up of electric vehicle (EV) electricity use is not a prime focus of this report. However, since it is expected to increase very significantly as electric vehicles become more and more common, Chapter 6 considers the impact of including this transport electricity on total electricity demand, and what this would mean for the deployment of renewable and low-carbon energy by 2030, and renewable and low-carbon electricity generation in particular.

Box 3 Categories of electricity demand

Table 3. UK Direct Electricity Demand in 2017.[7]

Electricity demand type	Demand (TWh)	Proportion (%)
Industrial	89	30
Commercial	93	31
Residential	114	38
Total	**297**	**100**
Supplied[8]	**320**	**na**

[7] National Grid FES 2018 Data Work Book, http://fes.nationalgrid.com/fes-document/
[8] Including transmission losses.

Electricity demand in the UK has dropped since 2006. UK electricity demand increased from 155TWh in 1965 to a peak of 357TWh in 2006.[9] Since then demand has dropped steadily, by on average 2.4TWh/yr[10] to 297TWh. See Figure 7.

There are multiple potential reasons for the drop in electricity demand, including: energy-efficient appliances, deindustrialisation, and slower than historical GDP growth following the financial crisis.

There is growing evidence that both macro- and micro-rebound effects are a strong counter balance to the effect energy efficiency activity for electricity.[11] This is due to a micro rebound effect, whereby household savings from reduced energy costs are used to buy more products which then in turn use more electricity. Macro rebound is the economy-wide impact of reduced energy costs: greater reinvestment across the economy leads to greater economic growth, which drives electricity use back up.

The trajectory of electricity use under current policies and economic conditions, a 'business as usual' case, is uncertain due to the difficulty in quantifying the impact of the above factors, and the rebound effect. If the current trajectory of the last decade – in which demand has dropped (see Figure 6) – were to continue, UK electricity would drop to 253TWh by 2030. However due to the potential impact of rebound, the modelling behind this work assumes that rebound will cancel this out 'natural decrease'. This ensures that we do not double count the impact of electricity energy-efficiency measures.

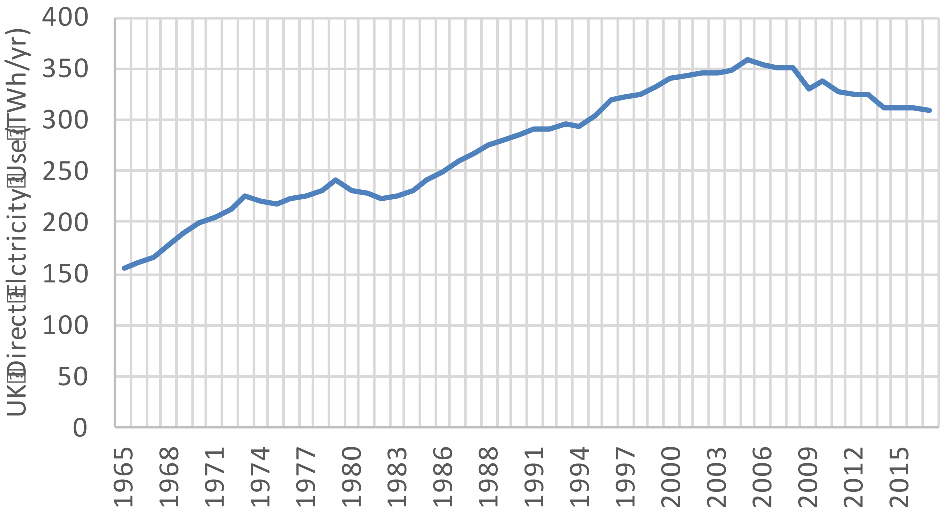

Figure 7 UK historical total electricity use[12]

2.3 The importance of demand reduction

If the UK is to maximise renewable and low-carbon energy by 2030, reducing energy waste, and thus demand – particularly for heat – is a crucial first step for several reasons.

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[9] Graph drawn with data from BEIS: https://www.gov.uk/government/statistical-data-sets/historical-electricity-data
[10] Team's own calculations.
[11] https://www.sciencedirect.com/science/article/pii/S0306261918304653
[12] Graph drawn with data from BEIS: https://www.gov.uk/government/statistical-data-sets/historical-electricity-data

The UK has a high scale of annual heat demand and waste. Currently the UK uses 689TWh of heating energy, compared to 297TWh of electricity (excluding losses). Heat use is so high because the UK is a temperate country with several months of cold weather, with a building stock that is ageing and not built to the same energy-efficiency standards as other cold countries such as in Scandinavia. Huge amounts of heat are wasted each year in poorly insulated buildings around the country.[13]

Large peak consumption requires large supply infrastructure. As demonstrated in Figure 16, heat demand at its peak is nearly six times larger than electricity demand. This means the current gas grid has six times the 'energy capacity' of the current electricity grid, at around 300GW and 60GW respectively. Without reducing demand, transitioning from gas to a renewable or low-carbon source would require meeting part of the 300GW of peak heating demand, and so any reduction in peak reduces the scale and complexity of low-carbon systems needed. **Therefore reducing the peak heat demand is one of the primary requirements for delivering maximum renewable and low-carbon energy by 2030.** New research may imply that actually the peak heat demand for the UK domestic sector, which makes up the majority of demand at peak times, is lower than expected[14]. If so then this would ensure the target is easier to deliver.

Heat is harder to decarbonise. As outlined in Section 3, transitioning to a large-scale supply of renewable and low-carbon energy for heat is significantly more challenging than doing so for electricity. Reducing heat demand is extremely important, though, and it represents the most complex element of delivering maximum renewable and low-carbon energy by 2030. Our efficiency-first approach therefore reduces the amount of renewable and low-carbon heat that is ultimately needed.

Recommendation 1: Reduce energy waste, and thus demand, to the maximum possible extent over the years to 2030, and so set a target to reduce the need for energy across the UK by a minimum of 20% for heat and a minimum of 11% for electricity, relative to current levels.

2.4 Home energy efficiency and energy-demand reduction

The vast majority of homes that will exist in 2030 already exist today, and the majority of heat energy consumed in those homes is due to space and water heating. It is therefore necessary to understand the condition of existing homes, and how they can be improved.

Reducing the need for heat has the biggest potential for energy-demand reduction. Heat demand can be reduced by 20% across all building types. The largest chunk of this reduction is achieved in domestic buildings, at 23%.

2.4.1 Current domestic heat consumption and the state of the UK housing stock

The primary means of identifying the energy performance of UK homes is the Energy Performance Certificate (EPC). EPCs are rated A-G with 'A' being an exemplary dwelling. *Figure* 8 shows the current breakdown of domestic EPCs in England and Wales based on the end user licence (EUL) file – a sample of more than 4 million EPC records.[15] The EUL file provides a representative sample of the England and Wales housing stock from the wider EPC data.[16] Figure 8 demonstrates that the majority of homes in England and Wales are EPC D or lower.

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[13] F. Fylan, D. Glew, M. Smith, D. Johnston, M. Brooke-Peat, D. Miles-Shenton, M. Fletcher, P. Aloise-Young, C. Gorse, 'Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor in the United Kingdom,' *Energy Research and Social Science*. 21 (2016) 190–198. doi:10.1016/j.erss.2016.08.002. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/211180/FuelPovFramework.pdf.

[14] S.D. Watson et al., 'Decarbonising domestic heating: What is the peak GB demand, School of Architecture', Building and Civil Engineering, Loughborough University, 2019

[15] The EUL data set provides a 'weighting' correction, as it is assumed homes without a current EPC are likely to be older and less efficient.

[16] DECC, Lower Super Output Area: Energy Efficiency Band for Heat Map 2015, London, UK, 2015.

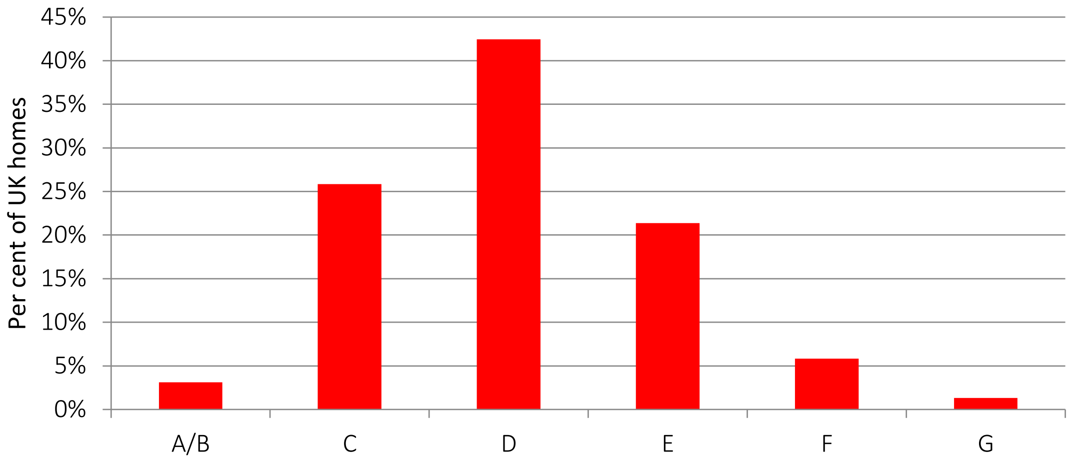

Figure 8. Estimate of EPC % breakdown across total housing stock of England and Wales in EUL dataset, including weighting rating for biases. Source: DECC[17]

Energy demand target same, heat pump contribution and solar and PV are all the same.

2.4.2 The impact of retrofitting most homes in the UK

Work has been undertaken in a parallel study to identify the impact of retrofitting as much of the UK housing stock as possible by. 2030. This work, which is currently under development**,** considered a range of policies and interventions that could applied to unlock the retrofit of existing homes. The policies that were considered include:

- Minimum energy efficiency standards in social housing
- Minimum energy efficiency standards in private rented housing
- Minimum energy efficiency standards in owner occupier housing at the point of sale
- 5% VAT on extensions/renovations
- Variable stamp duty

Using these policies, the modelling estimate the changes that would be applied in homes across the UK using an cost optimised dispatch model.

The level and rate of the CCC's central scenario means technologies are deployed at a rate informed by their historical deployment and follow a traditional S-curve trajectory for market diffusion. It includes all energy-efficiency measures deployable to 2035 that are estimated to be cost-effective according to criteria used by the UK government to appraise public policies and projects. The central scenario uses a discount rate of 3.5% and accounts for energy cost savings, but also places a monetary value on improvements in comfort and air quality, as well as on reductions in greenhouse gas emissions. Measures are cost effective when the discounted sum of these private and social benefits exceeds the associated capital and other costs. This level of deployment is broadly consistent with an overall approach taken across all sectors of the economy that meet the CCC's 5th Carbon Budget at least cost. This scenario alone would deliver 65TWh of savings or approximately 16% of current heat consumption.

The CCC's central scenario takes limited account of the wider macroeconomic benefits of a retrofit program, which are expected to deliver a high return on investment in terms of economic growth, job

[17] DECC, Energy Efficiency Statistical Summary 2015 Energy Efficiency Deployment Office, 2015.

creation and government tax receipts as modelled by Cambridge Econometrics in the Building the Future Report.[18]

The model assumes all measures deemed cost effective in the government's current narrow definition are exploited. In addition, it assumes that half of the remaining technical potential for building fabric and heat control measures – energy efficiency – is exploited. This scenario assumes that significant technological and process innovation is realised and that costs are driven down through economies of scale. This scenario also takes account of the wider health, electricity system, economic and employment benefits, as outlined in Rosenow et al. (2017) and by Cambridge Econometrics.[19]

The modelled scenario assumes that, of the possible technical potential:

- 84% of heating control and upgrade measures are installed
- 50% of available homes are fitted with waste water heat recovery
- 60%* all remaining boilers not replaced by low carbon heat are upgraded (*40% of homes will have zero carbon heat)
- 60% of homes have enhanced double glazing
- 62% of homes have floor insulation
- 66% of solid walls are insulated
- 88% of remaining lofts are insulated
- 92% of cavity walls are insulated
- 59% of other building fabric measures are deployed.

The modelling also assumes a significant additional role for wastewater heat recovery systems (WWHRS). These work by extracting heat out of the water as it washes down the drain pipe of a bathtub or shower.

These numbers are all significantly less than 100% for the following reasons.

- The UK's 1.3 million **heritage homes** were built before 1947.[20] These homes are much harder, slower and more expensive to retrofit, with fewer solutions available. (Solid wall insulation, for instance, is not an option.)
- **Smaller, space-constrained properties** have fewer technological options and so it is more expensive and complex to reduce demand for them.

Figure 9 shows the range of measures involved applied based on the modelled scenario, the percentage of the measures' deployment in each scenario, and their technical potential. This reflects the recommended deployment by 2030 for delivering maximum renewable and low-carbon energy by 2030.

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[18] P. Washan, J. Stenning, M. Goodman, *Building the Future: The economic and fiscal impacts of making homes energy efficient, (*European Climate Foundation; 2014. http://www.energybillrevolution.org/wp-content/uploads/2014/10/Building-the-Future-The-Economic-and-Fiscal-impacts-of-making-homes-energy-efficient.pdf
[19] https://www.housingnet.co.uk/pdf/Building-the-Future-Final-report_October-2014_ISSUED.pdf
[20] https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf

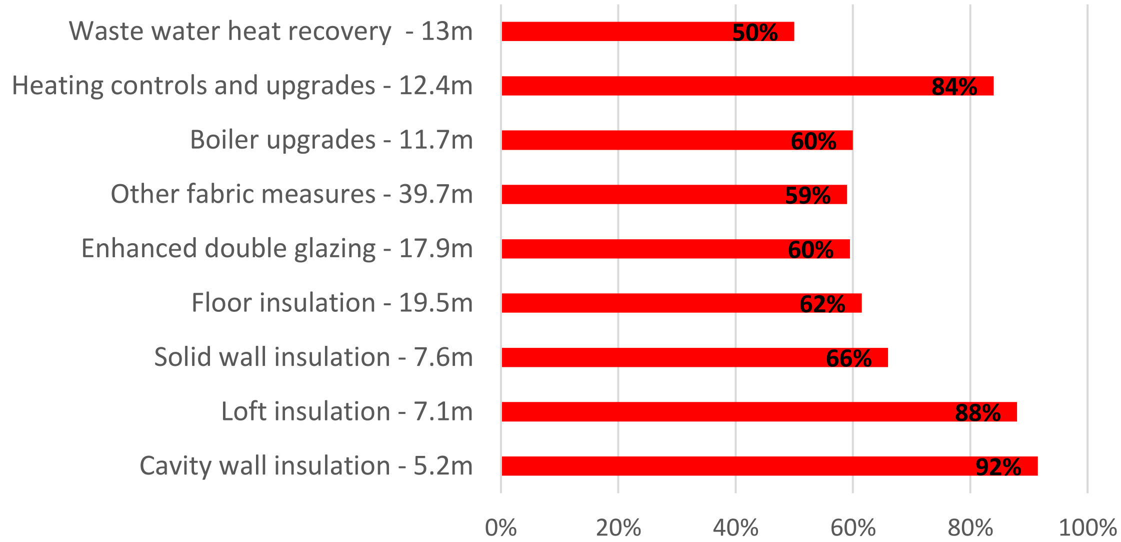

Figure 9 Domestic energy efficiency measures exploited as percentage of technical potential (number of installations) in 2030

The varying levels of energy-efficiency deployment projected for 2030 reflect the variation in the current levels of deployment, the nonlinear nature of the costs of deployment and the varying suitability of UK homes for certain measures. The detailed savings potentials for each measure are described in Appendix D.

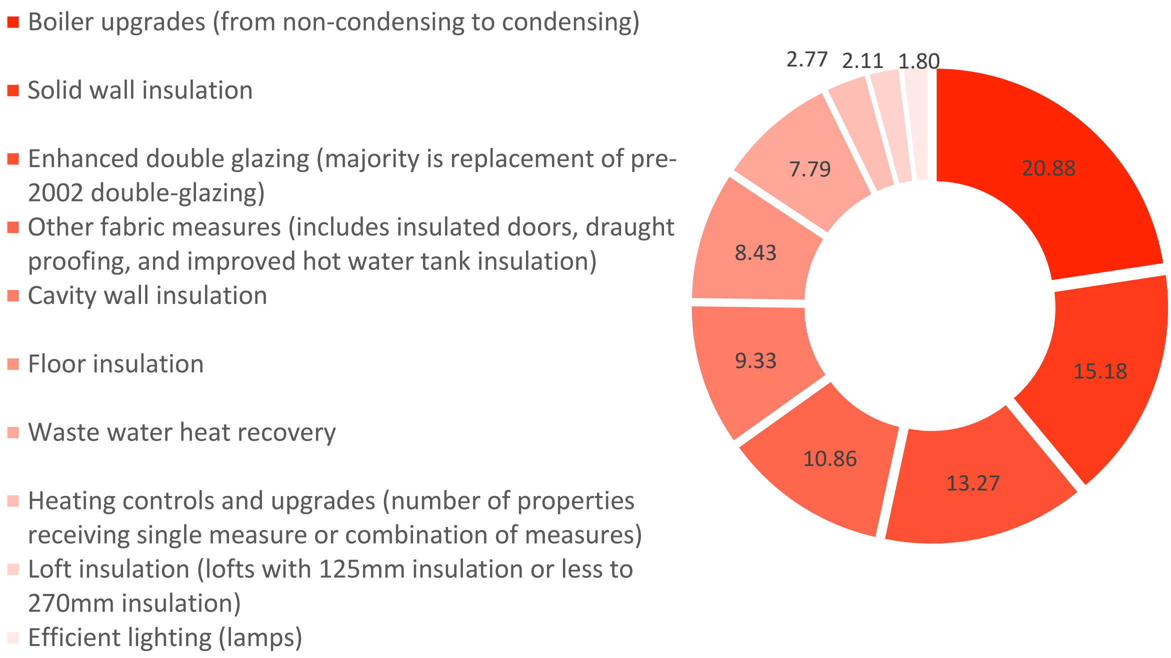

Figure 10 Demand only savings (TWh) from housing stock

The scenario includes savings from the deployment of solar thermal hot water systems. However, because this is a contribution to heat demand, this has been accounted for in the following chapter on heat demand reduction, and solar hot water is not considered in the savings estimated in this chapter.

Almost homes have had demand reduction measure installed. A small portion of hard to get to homes may take slightly longer. Figure 10 provides and indicative example of the numbers of homes targeted to 2030 and beyond. As can be seen the base rate of renovations of around 500,000 homes per year is assumed, and then an increase until a peak of around 3m homes in 2027 after which levels drop.

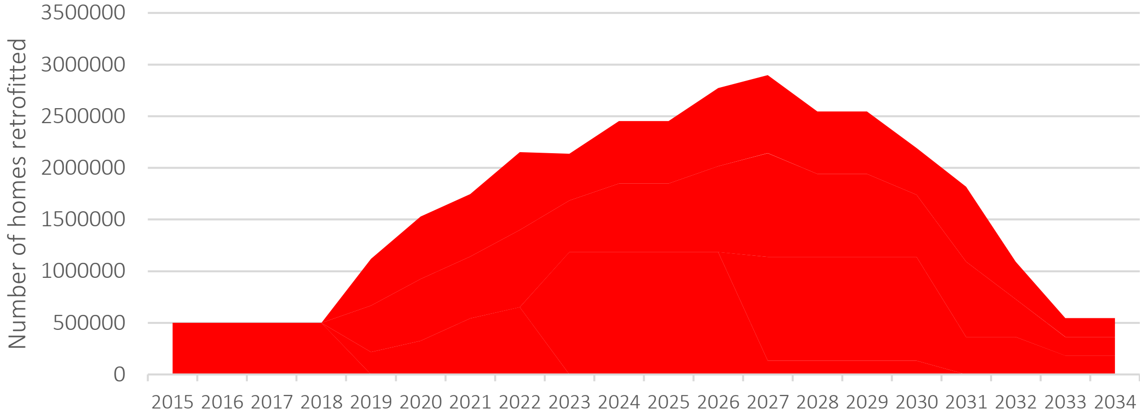

Figure 11. Figurative rollout of UK building upgrade programme by million homes (these numbers are indicative only, not a target or projection).

This recommendation is in line with Labour Party policy that 4 million homes be upgraded in the first parliament to at least EPC band C, and A or B in most cases. This is a lower rate than will be essential in subsequent parliaments because of the time it will take to get rebuild confidence and capacity in the sector, and awareness and willing among energy users. This is for several reasons, including the significant lack of capacity in local government, which will have a key role in delivering this programme, after continued reduction in their capacity by recent Governments.

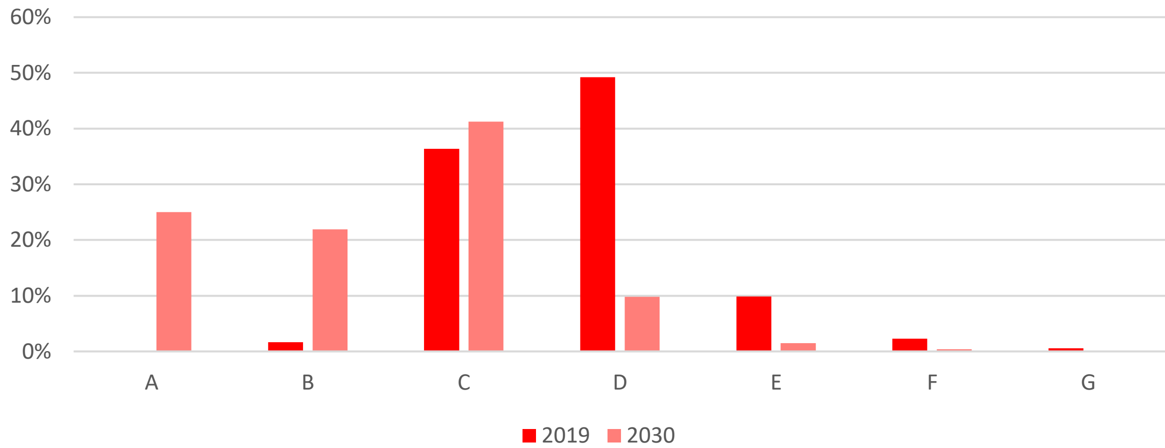

Figure 12 Proportion of UK homes in 2030 at different EPC levels. Source: Project teams own analysis

Figure 12 above shows the proportion of homes today and in 2030 that achieve different EPC levels under the scenario modelling. Table 4 below include the equivalent absolute numbers in millions of homes in 2030.

Table 4 Number of homes at each EPC level in 2030 (Source: Project team modelling)

In our scenario, heat energy demand from domestic buildings reduces from **398TWh to 307TWh** in 2030 – a saving of **91TWh,** or **the equivalent of the entire energy use of almost 8 million homes**.

Table 5. Cost effective and extended ambition domestic heat demand reduction scenarios.

	Electricity savings (TWh)	Heating fuel savings, gas and oil (TWh)	Total heat demand savings (TWh/%)
Total savings	5.24	85.38	90.62
Saving as % of heat demand	1%	21%	23%

Recommendation 2: Retrofit almost all of the UK's 27 million homes by 2030 to the highest energy efficiency standards feasible for each building to reduce domestic heat demand by 23% relative to current levels.

- Retrofit the as many homes as possible to EPC level A or B by 2030, making EPC C level the targeted minimum. This is expected to result in 41% of UK buildings reaching EPC A or B, and 44% at EPC C.
- Proactively implement area-based retrofit programmes – including SME buildings at the same time as domestic houses.

2.4.3 Impact on fuel poverty

Improving efficiency will reduce fuel poverty through lower bills and will improve public health. One in ten UK households are in fuel poverty, and are sometimes forced to choose between heating and other essential expenditures such as travel, clothing or even food. This often leads to underheating in winter, creating serious health problems – particularly for young children and the elderly. It is estimated that of the 31,100 excess winter deaths in England and Wales in 2012 and 2013, 30-50% were due to cold indoor temperatures. Improved winter warmth and lowered relative humidity have proven benefits for cardiovascular, respiratory, and mental health.[7] Hence, for every £1 spent on retrofitting fuel-poor homes an estimated £0.42 is saved in UK National Health Service spending. The retrofit programme will also bring improvements to lighting, damp, draughts, security, safety and community spaces.

See Section 8.6 for further discussion on fuel poverty impacts of this strategy.

Recommendation 3: Ensure this retrofit work targets those homes in most need first.

- Top priority: high fuel poverty and low-quality housing.
- Second priority: homes and buildings with lowest energy performance, those that "leak" the most energy.
- Home retrofits should peak at around 3m per year in 2027.

2.4.4 Improving retrofit quality, specification and standards

Retrofit and renovation measures have the potential to deliver not only energy savings, but also improved property values, internal comfort, air quality, and health and wellbeing of the building's occupants.[21]

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[21] Willand, N.., Ridley, I.., Maller, C.., 2015. Towards explaining the health impacts of residential energy efficiency interventions - A realist review. Part 1: Pathways. Soc. Sci. Med. 133, 191–201. https://doi.org/10.1016/j.socscimed.2015.02.005

However, there is significant documentary evidence of a large negative 'performance gap' between modelled energy savings and realised outcomes.[22] More insidiously, in some cases well-meaning insulation programs have led to damaging unintended consequences, including worsened air quality, moisture build up and structural damage.[23] Moreover, the recent Grenfell Tower tragedy has shown that current fire standards and prevention methods may not be fit for purpose and may in this case have been aggravated by the chosen materials in the building's retrofit.

- Improved business and delivery models for retrofit and renovation, including the role of community groups and local authorities and their partnership with the private sector in delivering a 'whole house' approach to retrofit.
- Better understanding of moisture transfer, air quality and the building-physics implications of undertaking retrofit and renovation, possibly through new quality standards and monitoring.
- The certification and approval of insulation and other materials with a focus on their impact on the above issues as well as fire safety and internal air quality.
- Better consideration of the sustainability, embodied energy and CO_2 of insulants and other construction materials.
- A systemic review of UK fire safety and materials specification standards within and beyond the UK Building Regulations.
- Upskilling, training and education of the workforce and supporting soft infrastructure commensurate with the scale of a nationwide retrofit programme.

Recommendation 4: Conduct a root-and-branch review of the range of standards, measures, materials specification and practices of the UK construction industry to maximize the quality, impact and benefit of the retrofit and renovation programme, to add to the work carried out under the Each Home Counts review.

2.4.5 Electrical saving potential in homes

There is extensive opportunity to reduce domestic electricity use for lighting, appliances, processes and other needs. This would drive down the UK's energy intensity (the amount of energy required per GBP in the economy). Based on work done by Rosenow et al. (2018)*,* Table 6 shows the assumed electrical savings potential by measure, largely driven through a tightening of product-efficiency standards. [24] The assumption made in this work is that, through an ambitious programme of action, all these savings can be captured by 2030.

Table 6. Domestic direct electricity savings potential.

Electrical Efficiency Measure	2030 UK Saving Potential (TWh)
Efficient lighting/lamps (from incandescent to compact fluorescent, and from halogens to LEDs)	6.4
Cold appliances (A+++)	7.1

[22] Mcelroy, D.J., Rosenow, J., 2018. Policy impplications for the performance gap of low-carbon building technologies. Build. Res. Inf. 1–13. https://doi.org/10.1080/09613218.2018.1469285
[23] Davies, M., Oreszczyn, T., 2012. The unintended consequences of decarbonising the built environment: A UK case study. Energy Build. 46, 80–85. https://doi.org/10.1016/j.enbuild.2011.10.043
[24] J. Rosenow, S. Sorrell, N. Eyre, The remaining potential for energy savings in UK households (2018). Based on earlier work: Element Energy & EST (2013), minus the number installed in 2014-15 (CCC, 2016)

Wet appliances (number of appliances where replacement with A+++ washing machines, A-rated tumble driers, and A+ dishwashers)	2.8
Efficient ovens (A+)	0.9
Efficient televisions (A++)	6.0
Total	**23.2**

Figure 13 provides a comparison of the energy-efficiency strategy outlined in this document with other comparable scenarios for UK homes. This comparison clearly demonstrates this approach to be sufficiently ambitious but also commensurate with previous scenario modelling.

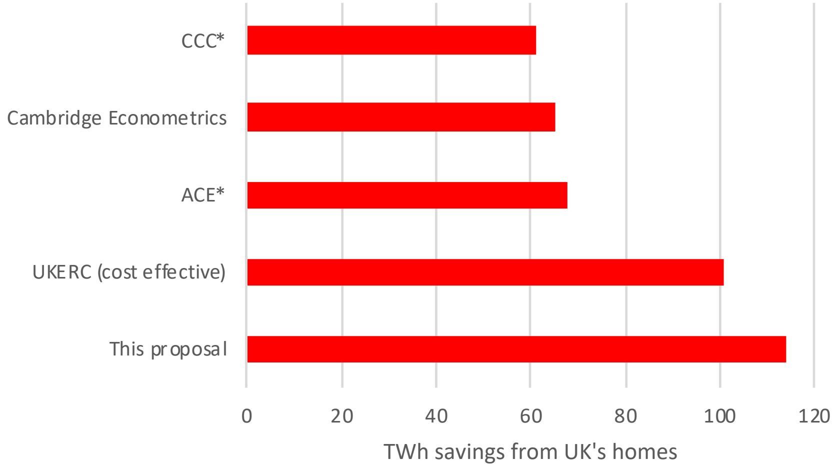

Figure 13. Comparison with other domestic retrofit scenarios:

**Estimated from heating carbon factor of 200g/kWh*

2.5 Reducing energy waste in the commercial and industrial sectors

The following section sets out the current UK fuel consumption statistics for commercial buildings and industry based on final energy consumed for heating, hot water and industrial processes in TWh. We then explore the potential to reduce energy demand from commercial buildings and industry, to be consistent with the overarching goal of maximising renewable and low-carbon energy by 2030.

2.5.1 Current UK energy consumption for commercial buildings and industry

While space and water heating continue to dominate energy consumption in the services sector, industrial processes dominate energy demand in the industrial sector. Based on analysis from Department for Business, Energy and Industrial Strategy (BEIS) statistics outlined in 2017, 163TWh of industrial energy was for heat (summarised in Figure 14).

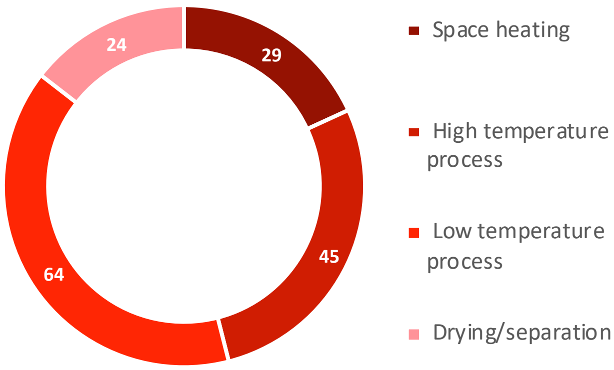

Figure 14. Industrial energy demand breakdown in 2017 (TWh). [Source: See Appendix D]

89TWh was used by industry for electricity based on National Grid's Future Energy Scenario worksheet.[25]

As Figure 15 shows, the service sector (nondomestic buildings, not including agriculture) consumes 128TWh is for heating.

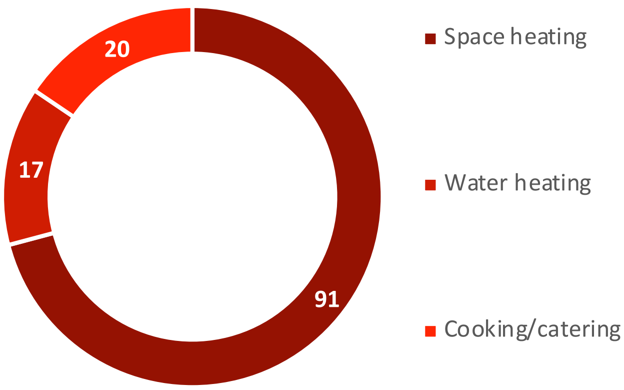

Figure 15. Service sector energy demand breakdown in 2017 (TWh). [Source: See Appendix D]

93TWh was used by the service sector for electricity based on National Grid's Future Energy Scenario worksheet.

In the following sections we outline the savings potential from these sectors. We first turn to savings from nondomestic buildings in the service sector before addressing savings from industry. The consumption data is taken from BEIS *Energy Consumption in the UK* statistics. The savings potential from commercial and industrial buildings is largely based on data from the CCC's fifth carbon budget central scenario, where these savings are brought forward five years to 2030.[26] However, we complement this with evidence taken from the "The potential for recovering and using surplus heat from industry" report for DECC by Element Energy on the potential for recovering and using surplus heat from industry.[27]

[25] http://fes.nationalgrid.com/media/1432/fes-data-workbook-v30.xlsx
[26] CCC, Fifth Carbon Budget Dataset - Committee on Climate Change (2016). https://www.theccc.org.uk/publication/fifth-carbon-budget-dataset/ (accessed August 17, 2018).
[27] DECC, Final Report, The potential for recovering and using surplus heat from industry, 2014. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/294900/element_energy_et_al_potential_for_recovering_and_using_surplus_heat_from_industry.pdf.

2.5.2 Service (commercial and public) sector energy demand reduction potential

Properties in the service sector include all public administration buildings across education, health and government sectors as well as commercial buildings for offices, communication and transport, hotel and catering services, sports and leisure and warehouses.

The savings for this sector are based on:

- A range of fabric energy efficiency measures such as wall, floor and roof insulation, efficient windows and doors and draught-proofing.
- The retrofit of efficient heating ventilation and cooling, heat emitter and distribution-efficiency measures as well as control systems and heat energy management strategies.

However, here we do ***not*** include savings from:

- The installation of low-carbon heat sources such as solar hot water or heat pumps, as these are addressed in Chapter 3.
- Savings from microgeneration technologies, such as solar PV, as these are dealt with in Chapter 4.
- Efficient electrical appliances, often understood as those covered by product policies. For simplicity we assume any savings from these appliances are cancelled out by increased appliance use as has been the case historically.

To identify the savings from nondomestic buildings we adopt the central scenario as outlined in the CCC's fifth carbon budget.[28] However, we cast these savings goals forward by 5 years, from 2035 to 2030, to reflect the greater ambition required to deliver maximum renewable and low-carbon energy by 2030. This level of deployment is broadly consistent with an approach taken across all sectors of the economy that meets the 5th carbon budget at least cost.

Table 7. Summary of consumption and savings from service sector by 2030.

	Heating Electricity (TWh)	Natural gas for heating (TWh)	Oil and other for heating (TWh)	All heating (TWh)	Direct Electricity (TWh)
Source of savings					
Public buildings	1.0	4.9	0.21	6.1	1.1
Commercial buildings	4.4	13.2	0.57	18.4	5.1
Total Savings (TWh)	5.4	18.0	0.78	24.2	6.2
2017 Demand (TWh)[29]	29	84.8	14.1	128.3	93.0
Remaining demand in 2030 (TWh)	23.6	66.7	13.4	104.1	87
Total Savings (%)	**18%**	**21%**	**6%**	**19%**	**7%**

The most significant energy efficiency savings are those from more efficient boilers (3.8TWh), reducing room temperatures (5.1TWh) and programmable thermostats (9.1TWh).

Together these measures will allow a 19% saving in heat energy and 7% in electricity.

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[28] Committee on Climate Change, *The Fifth Carbon Budget: The next step towards a low-carbon economy* (2015), 130.

[29] BEIS, *Energy Consumption In The UK*, Department for Business, Energy and Industrial Strategy, 2017. https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (accessed July 13, 2018).

Recommendation 5: Ensure all existing public buildings reach EPC A or B by the mid 2020s, except in extenuating circumstances, with EPC C required as a minimum energy-efficiency standard.

Recommendation 6: Ensure all existing commercial and industrial buildings reach EPC A or B by the mid 2020s, in extenuating circumstances, with EPC C required as a minimum standard. Work with commercial and industrial sectors to achieve this.

2.5.3 Industry energy demand reduction potential

In this section we consider energy consumption from industrial sources (163 TWh/year) including:

- space heating
- high temperature industrial processes
- low temperature industrial processes
- drying/separation

These heating needs are met by 40TWh of electricity, 86TWh of natural gas, 7.5TWh of petroleum and 22TWh of solid fuels.[30]

The data used for industrial energy efficiency is from the central scenario outlined in the CCC's fifth carbon budget.[31] As for service-sector buildings, we cast these savings goals forward by 5 years, from 2035 to 2030, to reflect the greater ambition of the this study. Again, this level of deployment is broadly consistent with an approach taken across all sectors of the economy that meets the fifth carbon budget at least cost.

The reduction in energy demand in the industrial sector can be achieved in a variety of ways, including:

- increases in process energy efficiency
- process optimisation
- switching fuels and re-using waste heat

These savings involve specific measures to certain subsectors, which are detailed in Appendix D.
The approach has been to take the sector-by-sector, solution-by-solution savings potential identified by the CCC's fifth carbon budget central scenario dataset, and assess each for suitability for energy savings, within the context of this work. The focus has been on the sectors that have demonstrated the largest potential for savings: refineries, paper and pulp, iron and steel, glass, and food and drink. Chemicals, ceramics and cement have not been included. This is not because effort and research should not be devoted to these subsectors, but rather because the main options for decarbonising them are either large-scale expansion of biomass use (not a strategic recommendation of this study; see Appendix B), or the use of CCS, which is still expected to be an emerging solution in the period leading up to 2030. Thus, for this analysis, the energy demand for these subsectors is assumed to remain relatively constant towards 2030.

Taken together these measures produce relatively modest savings because the majority of efficiency measures have already been exploited – due to the high relative share of energy costs and the economies of scale in industrial processes, contrasted with the high transaction costs involved in smaller scale domestic and non-residential efficiency (seeTable 8). [32]

[30] See Table 32.
[31] Committee on Climate Change, *The Fifth Carbon Budget*, 130.
[32] S. Sorrell, J. Schleich, E. O'Malley, S. Scott, The Economics of Energy Efficiency: Barriers to Cost-Effective Investment., Edward Elgar, Cheltenham, 2004

A large amount of heat demand can be reduced by matching waste heat sources and heat sinks (in other words, processes that require heat input) in the main heat-intensive sectors (refineries, iron and steel, glass, food and drink, paper and pulp). This transfer of heat is typically performed using heat exchangers for high-grade waste heat, and heat pumps when it is necessary to provide a heat top-up. An in-depth study in 2014 by Imperial College and Element Energy identifies 48 TWh/year of waste-heat sources throughout the UK from the main heat-intensive industries, which is more than 20% of the total industrial energy use. [33] The report identifies a technical potential of 11 TWh/year of heat energy savings by connecting heat sources and sinks. The technical potential includes contributions from on-site heat re-use, over-the-fence supply to another large industrial user and conversion to power. All heat-intensive industrial sectors examined contribute to this potential. It is this economic potential, at the social discount rate, that we chose to adopt in this strategy.

These sources of savings have been compared to estimates of 2017 industrial energy demand as derived from UK government data (see Appendix D) to develop an estimate of the likely industrial energy demands for heat and electricity in 2030, after a decade of ambitious energy demand reduction. These savings are summarised in Table 8.

Table 8. Summary of consumption and savings from industry by 2030.

	Electricity (TWh)		Natural gas (TWh)		Solid and other fuel (TWh)		Petro-chemicals and biomass	Total heat	Total direct electricity
	Heat	Elec	Heat	Elec	Heat	Elec	Heat		
Source of savings									
Refineries	0	0	0.3	0.38	0	0	0	0.3	0.38
Paper and pulp	1.3	0.1	1.64	0.17	0.1	0.01	0	3.02	0.3
Iron and steel	0.1	2.5	0.79	0	0.3	0.08	0	1.18	2.57
Glass	0.1	0	0.7	0	0.06	0	0	0.81	0
Food and drink	2	0.3	2.18	0	0.05	0	0	4.27	0.28
Waste heat (sources and sinks)							0	11	0
Total savings	3.5	2.9	13.6	0.6	0.51	0.09	0	20.6	3.5
2017 demand (TWh)[34]	39.80	51.81	86.02	11.64	22.34	2.55	14.4	162.6	89
Remaining demand in 2030 (TWh)	36.3	48.91	72.4	11.09	21.83	2.46	14.4	142.0	86
Total savings (%)	**15%**	**6%**	**7%**	**5%**	**22%**	**4%**	**0%**	**13%**	**3%**

A modest additional use for industry waste heat is to provide hot water to district heating networks. The Element Energy report identifies 28 TWh/year of waste heat that could be supplied at a cost of no more than £90/MWh, providing 100°C water at the facility gate (excluding transmission and distribution), without a requirement for major plant redesign. The contribution from industrial waste heat is modest compared to that potentially available from the power generation sector (even with conservative assumptions on heat supply from the power sector).[35] We have assumed that 8TWh will be recycled for industrial processes, meaning a maximum of 20TWh can be projected.

[33] DECC, Final Report.

[34] Based on calculations using data summarised in Appendix and from BEIS*, Energy Consumption In The UK*.

[35] This potential is likely to reduce as thermal plants come offline as the power sector shifts towards large volumes of solar and wind power to meet the Labour Party's 60% renewable and low-carbon energy targets.

The use of waste industrial heat for external customers does not reduce net industrial energy consumption, so this heat should be viewed as a source of heat rather than a savings, and therefore factored into scenarios of district heating in Section 3, rather than included here.

Combined the heat and electricity savings represent a total 11% saving across all energy.

Recommendation 7: Reduce energy use in industry by 11% by ensuring that process efficiency is maximised, waste heat is used on-site to the maximum viable extent and the remaining waste heat is made available to external users.

2.5.4 Summary of the impact on demand reduction

Table 9 shows 20% heat savings across the domestic, service and industrial sectors, resulting in a total remaining demand across all sectors in our 2030 scenario of **553TWh.** [36]

Table 9. Heat demand saving potential for domestic, service and industrial sectors in 2030.

	Domestic	Industrial	Service	Total
Total savings (TWh)	90.62	20.6	24.2	**135.4**
Current Demand (TWh)	398	162.6	128.3	**688.9**
Total saving (%)	23%	13%	19%	**19.6%**
Remaining demand (TWh)	307.4	142.0	104.1	**553.5**

Table 10 shows the total direct electricity savings from homes, commercial buildings and Industry, producing a total savings of 32.28TWh or 12% of demand.

Table 10. Summary of possible electricity savings.

Direct electricity demand saving	Total
Source of savings	
Homes	23.2
Service buildings	6.19
Industrial buildings	3.54
Total savings (TWh)	32.9
Today's direct electricity demand	297
Today's direct electricity generation (including losses)	320[37]
2030 direct electricity demand	265
2030 direct electricity generation (including loses)	282
Savings (%)	11%

[36] While the savings for the domestic and service sectors only include those resulting from heating and hot water, the industrial savings and the total include savings from electrical efficiency in industrial processes.
[37] National Grid FES 2018 Data Work Book, http://fes.nationalgrid.com/fes-document/

Table 11 shows the final direct electricity and heat demand for today and 2030 as set out in this chapter. These 2030 figures are used in the following chapters as the starting point for the maximum renewable and low-carbon energy by 2030.

Table 11. Summary of energy demand in 2030

Energy demand (TWh/yr)	Today	2030	Savings
Heat demand	689.8	553	20%
Direct electricity demand	297	265	11%
Total	986	819	17%

2.6 New buildings

Buildings built between now and 2030 will constitute a small proportion of all buildings in 2030, however, they represent a vital chance to ensure new high carbon demand is not created, and instead a zero carbon building approach taken. The significance of new buildings could increase under the Labour Party's plans to build up to 300,000 new homes a year, or around 3 million new homes by 2030 – representing 10% of all homes by this date.

The previous Labour government had a plan for incrementally more stringent requirements for new buildings, under the Code for Sustainable Homes – where all new homes were intended to be zero carbon beginning in 2016. Zero-carbon homes have very low, or close to zero, heating demand in line with EU near-zero-energy building standards.[38] Therefore, any new homes should be consistent with near zero standards, such that their additional energy demand is minimised.

As part of the Advancing Net Zero Programme, the UK Green Building Council (UKGBC) convened an industry task group in October 2018 to develop a definition for net zero carbon buildings in the UK. It is recommended that this framework definition be adopted. The EPC standard for all new buildings should be "A", from as early as possible, and a zero-carbon standard (similar to the Code for Sustainable Home's) implemented in the early 2020s, ideally by 2022. This will include a ban on fossil fuel use for heating in any new buildings.

Doing so will cover all "regulated" emissions (building heating and lighting).

This would give industry time to reactivate the capacity that was lost when the coalition government scrapped the scheme. It would also ensure all new buildings are very low demand and therefore for the sake of this study, assumed not to influence heat demand significantly.

To cover "non-regulated" energy use at, that at the "socket" for appliances, new buildings will need to be powered by onsite renewables or offsite through allowable solutions, which would likely be introduced slightly later, by the mid 2020s to allow the industry to build up to it (for instance 2024, with industry consultation required to identify the exact date).

Note, imbedded carbon in new buildings is an extremely high source of emissions, but since is not an on-site energy issue, has not been covered in this report. Labour's separate and ongoing work into the measures needed to implement this housing upgrade program, which will be launched in due course, will include detail on proposals for this.

[38] EU Commission - https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf

Recommendation 8: Reintroduce a zero-carbon buildings standard for all *new* buildings from 2020 and seek to ensure all new buildings are constructed full net zero-carbon as early as possible.

2.7 Summary of Recommendations

Energy savings must be maximized if the decarbonisation of energy is to be achievable. It will require the majority of buildings and processes in the UK to become as energy efficient as possible. It will also require approaching energy demand in buildings as an infrastructure challenge, with a well-organized and well-funded national programme to ensure all buildings make good use of electricity. This will be a significant national undertaking, but the benefits to business, families and communities around the UK will be enormous.

Recommendation 1: Reduce energy waste, and thus demand, to the maximum possible extent over the years to 2030, and so set a target to reduce the need for energy across the UK by a minimum of 20% for heat and a minimum of 11% for electricity, relative to current levels.

Recommendation 2: Retrofit almost all of the UK's 27 million homes by 2030 to the highest energy efficiency standards feasible for each building to reduce domestic heat demand by 23% relative to current levels.

- Retrofit the as many homes as possible to EPC level A or B by 2030, making EPC C level the targeted minimum. This is expected to result in 41% of UK buildings reaching EPC A or B, and 44% at EPC C.
- Proactively implement area-based retrofit programmes – including SME buildings at the same time as domestic houses.

Recommendation 3: Ensure this retrofit work targets those homes in most need first.

- Top priority: high fuel poverty and low-quality housing.
- Second priority: homes and buildings with lowest energy performance (those that "leak" the most energy due to poor building design)
- Home retrofits should peak at around 3m per year in 2027.

Recommendation 4: Conduct a root-and-branch review of the range of standards, measures, materials specification and practices of the UK construction industry to maximize the quality, impact and benefit of the retrofit and renovation programme, to add to the work carried out under the Each Home Counts review.

Recommendation 5: Ensure all existing public buildings reach EPC A or B by the mid 2020s, except in extenuating circumstances, with EPC C required as a minimum energy-efficiency standard.

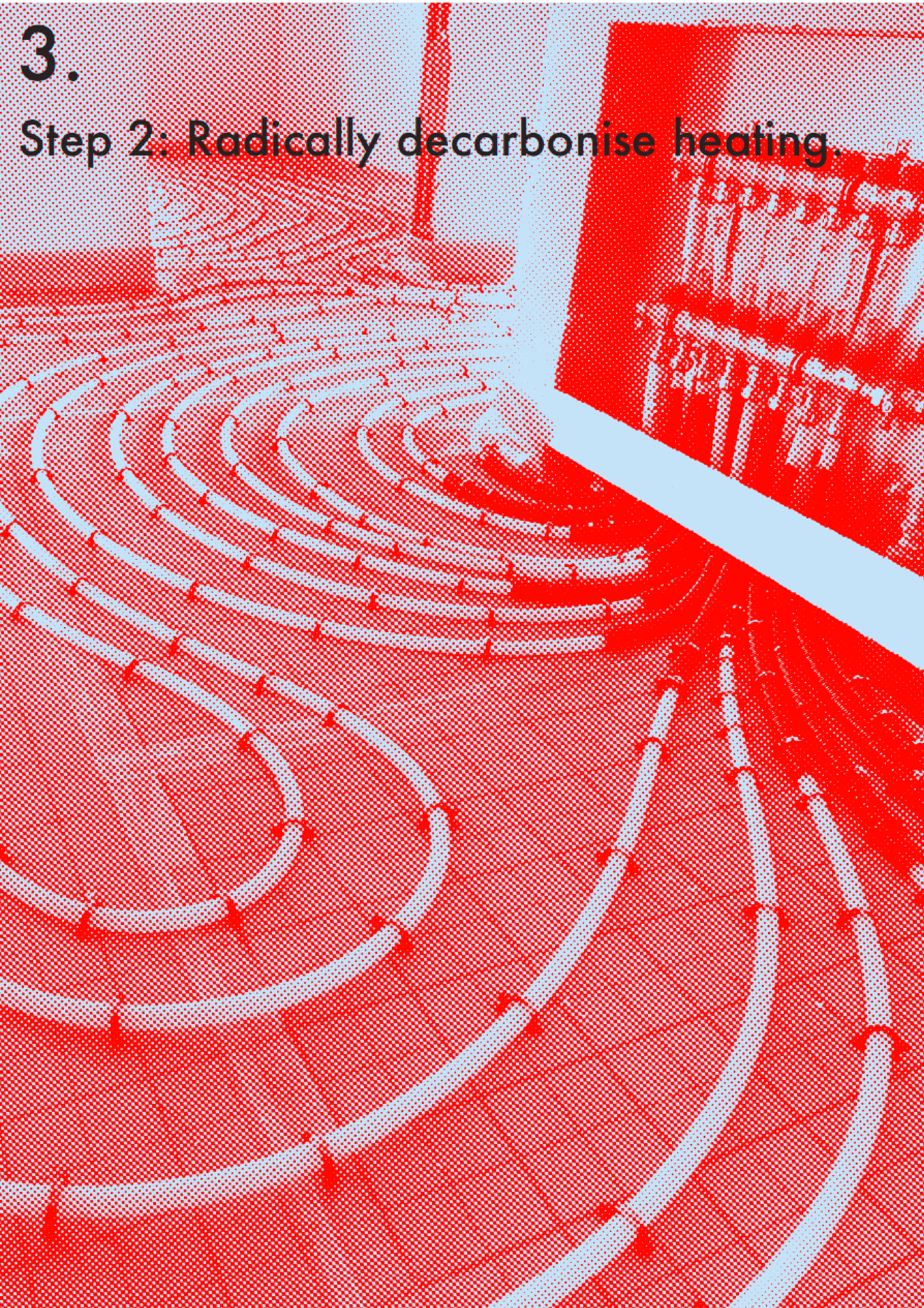
Recommendation 6: Ensure all existing commercial and industrial buildings reach EPC A or B by the mid 2020s, except in extenuating circumstances, with EPC C required as a minimum standard. Work with commercial and industrial sectors to achieve this.

Recommendation 7: Reduce energy use in industry by 11% by ensuring that process efficiency is maximised, waste heat is used on-site to the maximum viable extent and the remaining waste heat is made available to external users.

Recommendation 8: Reintroduce a zero-carbon buildings standard for all *new* buildings from 2020 and seek to ensure all new buildings are constructed full net zero-carbon as early as possible.

3.

Step 2: Radically decarbonise heating.



3.1 Chapter Summary

GOAL 2: RADICALLY DECARBONISE HEATING

CHAPTER BACKGROUND

The previous chapter outlined the huge potential for energy efficiency across the UK, which will reduce heat demand by 20%, and allow direct electricity use to drop by 11%, by 2030.[39] In this and the following chapters we consider how as much as possible of the remaining heat and electricity demand can be met from renewable and low-carbon sources.

We address heat first because the decisions made on heat supply will have a large impact on the electricity system. For instance, the more heat that is provided electrically (*heating electricity*), the higher the total electricity demand, and the more renewable and low-carbon electricity generation capacity would be required.

CHAPTER FINDINGS

Around 50% of energy for UK wide heating (covering domestic and non-domestic buildings) should come from renewable and low-carbon sources by 2030.[40]

A nearly twelve-fold increase in contribution of renewable and low-carbon heat will be needed, moving from from today's 4% (or 24TWh per year), to 50% (277TWh per year) in 2030.[41]

Achieving this will be an essential stepping stone towards almost completely decarbonising energy by the 2040s in order meet the UK's Paris Climate Agreement commitment.

It is entirely possible to achieve 50% renewable and low-carbon heating while minimising disruption for the majority of people through a combination of:

- 25% electrification of heat using heat pumps and hybrid heat pumps – a huge increase from today
- 10% from a combination of local sources, solar hot water, and waste heat supplied by district heat networks
- 3% from solid biomass heating, which is assumed to remain at current output levels
- 11% renewable and low-carbon heating supplied via the gas network, consisting of 5% biomethane injected into the gas grid, and 6% from renewable or low-carbon hydrogen used in buildings, supplied via new or upgraded gas networks.
- Biofuel for use in industrial processes could also displace 1% of UK heat demand
- The remaining 50% retains the use of natural gas.

Of UK heat customers currently using gas, 78%,will continue to use existing gas infrastructure and boiler technology by 2030, and so will not require new technology installed in their home before 2030.

The complete removal of oil from heating is a priority because oil is so polluting. All 3.3 million UK homes currently using oil will need to be supported to instead use either local sources such as solar hot water, or renewable and low-carbon grid electricity[42].

Decarbonising heating will create the need for more electricity generation (117TWh), which must all be from *additional* renewable or low-carbon sources.

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[39] See Section **Error! Reference source not found.** for explanation of the different types of electricity demand considered in this report.
[40] See Section **Error! Reference source not found.** for more detail.
[41] Calculated based on data from National Grid FES Data Sheet, see **Error! Reference source not found.**.
[42] The exception is the very small number of fully off-grid buildings for which delivered oil may be the only practical source for heat.

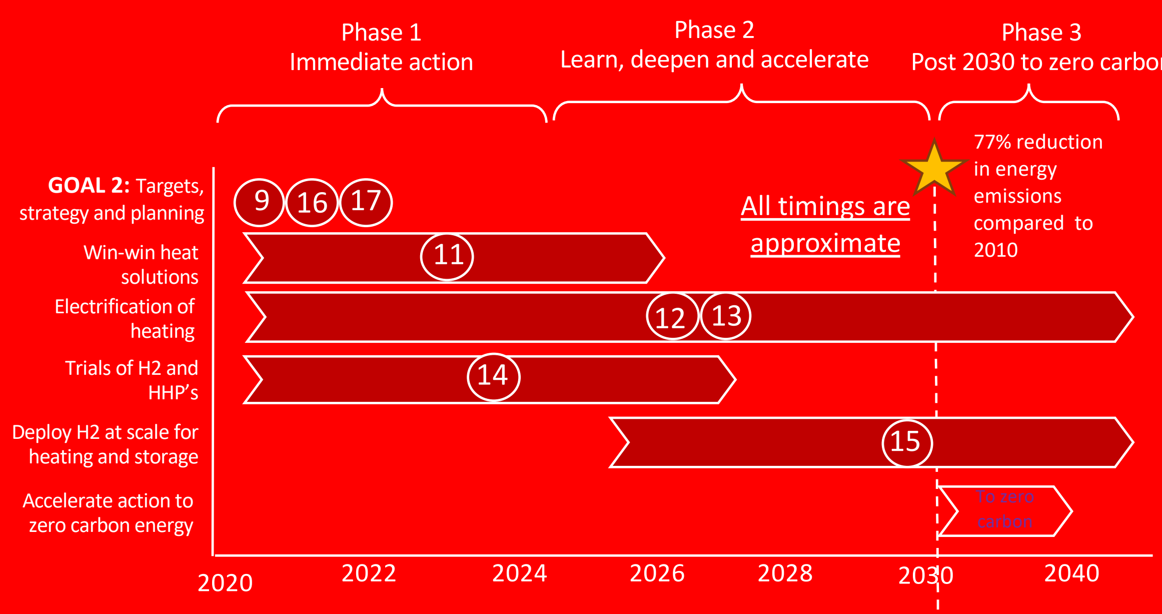
A future heat strategy must meet the unique nature of UK heat demand. The peak heat demand, several times larger than the current electricity grid capacity of the UK, can be managed through diversifying heat sources (using of a mixture of local heat sources and electrification), maintaining current heating infrastructure, where possible, and heat storage.

Large-scale deployment of renewable and low-carbon heat solutions can and must begin *immediately,* with significant deployment of existing tried and tested technologies by the mid-2020s.

Training and support for the energy sector will be crucial to enable an effective transition to renewable and low-carbon heating that meets people's needs and supports security and guarantees for any workers currently employed in high-carbon sectors. How this policy is managed will require discussion between a Labour government and trade unions representing workers in high-carbon energy jobs.

A three-phased approach will be needed to optimise the system shift over time – taking advantage of the best technologies and supporting people to meet their heating needs:

- **Phase 1 (up to mid/late 2020s):** rapid deployment of existing tried, tested and understood technologies and deployment approaches in suitable areas, combined with intensive research, development and testing of new and less established technologies and deployment approaches.
- **Phase 2 (from mid/late 2020s):** deployment of a wider range of successful technologies and deployment approaches. Existing well established solutions **(**including solar hot water, biogas, district heat networks, and the electrification of heating using heat pumps) make up 70% of the changes recommended in this document. A high level of confidence is possible that phase 1 research and development will enable an optimised choice of technologies (for instance the pace, scale and type of contribution to heating made by hydrogen by the late 2020s, or an optimal level of deployment is for hybrid heat pumps) and deployment in phase 2.
- **Phase 3 (beyond 2030 and outside the scope of this report):** successful technologies and deployment approaches should be rolled out to replace remaining gas heating.



CHAPTER EVIDENCE

The evidence base and analysis for this chapter has been drawn from a wide range of source, with some key works including:

- National Grid Future Energy Scenarios
- Imperial College London Research

- Government's own energy statistics
- UK Energy Research Centre
- Committee on Climate Change

CHAPTER CONTENT

- Background: the UK's current heat supply
- The importance of transitioning from dependence on natural gas heating
- Heating technology options: opportunities and challenges
- Coordination of heat decarbonisation and energy demand reduction
- Maximising renewable or low-carbon heat by 2030
- Appendix A, B and C: hydrogen, bioenergy and district heating strategy

3.2 Background: the UK's current heat supply

The UK currently uses conventional natural gas (which is mostly methane) for the majority of heating. According to the National Grid, 58% of total gas use is for domestic use, 34% for industrial processes and 9% for commercial (excluding gas use for power generation)[43].

As outlined in the Table 12, the large majority of domestic heating systems in the UK are fired by natural gas, at around 79%, with the remainder being fired mostly by oil boilers and electric storage heaters, at 12% and 7% respectively. Currently around 2% of homes are on district heating networks. All remaining technologies showed a marginal deployment by 2017.

Table 12. Current residential heating installations in the UK, by technology.[44]

Technology	Number of installations (2017)
Air Source Heat Pump	29,339
Electric storage heater	2,077,074
Gas boiler	21,933,029
Gas heat pump absorption	0
GSHP	8,658
Hybrid heat pump gas boiler	0
Micro-CHPs (including fuel Cells)	1,003
Oil boilers	3,328,873
Hydrogen	0
District Heat	450,000
Bio-LPG	0

The 'peakiness' of heat demand makes heat one of the UK's most important infrastructure challenges. It is the peak demand volume that determines the overall necessary generation and distribution *capacity* of the system. As demonstrated in Figure 16 below, demand currently fluctuates from zero to around 300 GW at peak heating times when it is cold out. As outlined in the previous chapter, this strategy proposes an annual heat demand reduction of 20% by 2030 across the UK, which will also significantly reduce the peak heat demand. However, peak heat demand will still likely be several times larger than the current electricity grid capacity of the UK. [45] So, any future low-carbon heating solution will need to be able to accommodate such peak demands to keep the UK warm on the coldest of days.

[43]Committee on Climate Change, *The infrastructure needs of a low-carbon economy prepared for climate change*, https://www.theccc.org.uk/publication/briefing-note-the-infrastructure-needs-of-a-low-carbon-economy-prepared-for-climate-change/

[44] http://fes.nationalgrid.com/fes-document/

[45] Due to the calculation complexity and lack of available external analysis, this study has not identified a figure for the likely peak heat demand reduction by 2030. This will be a key piece of work to be undertaken in the next steps.

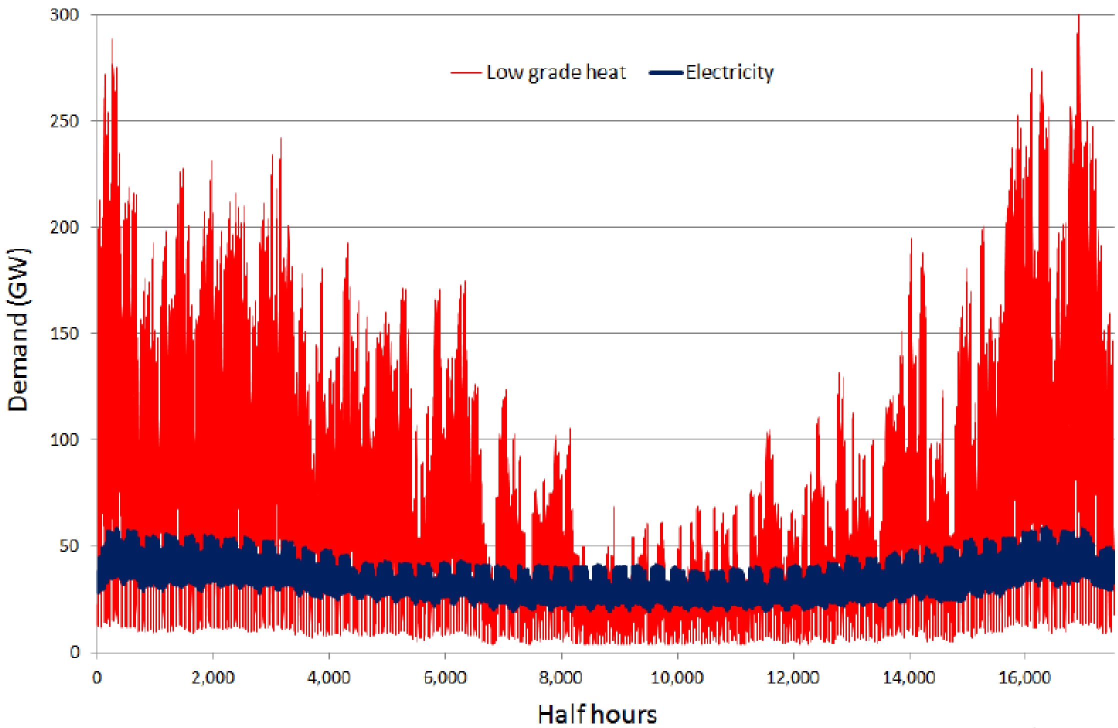


Figure 16. Comparison of UK half-hourly heat and electricity consumption over the course of one year, showing current gas demand fluctuation from zero to around 300GW peak.[46]

3.2.1 Renewable heat today

Today renewable and low-carbon heating contributes only a small proportion of the UK overall heat demand, at 4%, with 24.1TWh generated from renewable sources. The vast majority of this renewable supply comes from solid woody fuel biomass, used across a range of scales, with the majority at the small and medium commercial scale. Table 13 summarises the main contributions from renewables in 2017.

Table 13. Renewable Heat in 2017.[47]

Technology	Capacity (GW)	Annual output (TWh)
Biomass	3.4	17.0
Solar hot water	0.004	0.04
Heat pumps	0.091	1.43
Biogas	0.144	0.74
Bio-methane	n/a	5
Total	*3.7*	*24.1*

3.3 The importance of transitioning from dependence on natural gas heating

By most accounts heating is the largest source of UK GHG emissions (see Chapter 7 for more detail). Conventional natural gas currently provides the vast majority of UK heating, and hence GHG emissions. Therefore, it is crucial that conventional natural gas use for heating is over time displaced by other lower carbon alternatives. Heat is one of the areas that most urgently needs action if the UK is to deliver its carbon targets.

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[46] http://www.lolo.ac.uk/w2lp15-domestic-thermal-energy-storage-a-study-of-the-present-and-future-benefits-and-impacts/
[47] National Grid Future Energy Scenarios data sheet 2018, https://www.gov.uk/government/statistics/rhi-deployment-data-march-2018

By 2030, 50% of heating should be provided by renewable and low-carbon sources, a twelve-fold increase from today's 4%. To achieve this there will need to be a reduction in the use of natural gas for heating.

Recommendation 9: Set a target of 50% renewable and low-carbon heating by 2030, more than a 1,000% increase in output from today. Heating is responsible for over half of the UK's energy-related GHG emissions, and current renewable and low-carbon heating levels are extremely low. Therefore, the urgent expansion of renewable and low-carbon heating is one of the most important aspects of this strategy, as well as one of the most complex – due, for instance, to the scale and shape of heat demand.

3.4 Heating technology options: opportunities and challenges

There is a wide range of technology available for heat generation, heat storage and heat energy transmission. This section considers the options and some important issues when working toward a national UK heating solution.

3.4.1 Factors informing the choice of heat technologies

Technologies have suitability based on factors including:

Energy availability. The capacity and operating conditions required by heat users must match the supply capacity of the chosen system.

Delivery conditions. Certain solutions can be deployed only in specific conditions, for instance where there is available space in a home for larger plant items (such as air-source-heat-pumps or solar hot water).

Technical maturity. Some solutions have a long commercial operating history; others are newer and less well tested at scale, with limited data, particularly on costs at large scale.

Consumer preference. Consumers have difference preferences in relation to heating periods, temperatures, warm up times, and noise.

Regional specificity. Varying climate, prevailing building types, proximity to the coast or natural resources, or current infrastructure are important considerations. Some studies have concluded that some areas in northern UK would be better suited to the deployment of hydrogen infrastructure, and some areas in southern UK to electrification with heat pumps, and found that localized approaches like this could be more cost effective.[48] It is clear that there is no one size fits all solution.

3.4.2 Heat generation options

There are a range of heat generation options available for buildings or industry.

3.4.2.1 High-carbon technologies to be reduced or phased out

Gas boilers to be reduced by 2030. The UK currently meets 85% its heating needs by burning natural gas. Nearly 22 million homes mainly use conventional and condensing boilers. Condensing boilers capture the latent heat contained in water vapour to preheat combustion air, resulting in a higher overall efficiency, up from around 82% in conventional boilers to 90% or higher. Sections 3.6.4 and 3.6.6 outline the extent to which these boilers should be supplied with other low-carbon and renewable fuels in place of natural gas, as well as the number of gas boilers that should be removed and replaced with completely new systems such as heat pumps. It will be possible to meet the heat decarbonisation target with the majority

[48] Goran Strbac et al, *Analysis of alternative UK Heat De-carbonisation Pathways*, Imperial College London, 2018

of heating in 2030 still coming from gas boilers supplied with natural gas. There should be support for households to move from conventional gas boilers to renewable and low-carbon sources.

Oil boilers to be phased out almost entirely by 2030. Oil boilers are still used in over 3.3 million homes, are the most carbon intensive form of heating used in the UK, and also have a very negative impact on local air quality. They tend to be used in more isolated places, such as rural locations, and places where there is no local supply of natural gas. Due to their high emissions, these systems must all be replaced urgently with renewable and low-carbon sources (such heat pumps) as outlined in the rest of this chapter. Exceptions would include the very small number of cases where buildings are entirely off-grid and also have no mains electricity, for instance those on remote Islands. There should be support for households to move from oil to ensure their heating needs are met by renewable or low-carbon sources.

Resistive electrical heating to be phased out almost entirely. Conventional electrical heating converts electricity directly into heat with a resistive heating element or immersion heater – for example a night storage heater. Currently resistive heating is used in the majority of homes not using gas or oil, and many high-energy industries because they are easy to install, responsive and have cheap capital costs. There should be support for households to move from resistive electrical heating to ensure their heating needs are met by renewable or low-carbon sources.

3.4.2.2 Renewable and low-carbon heating technology options and considerations

Of the following options, 1-4 do not require large scale changes to national energy transmission infrastructure outside the building, options 5-7 do.

1. **Gas boilers using low-carbon gas such as biogas**. Conventional gas boilers can burn methane from any source, including forms of renewable or low-carbon methane such as biomethane. Biomethane can thus be injected into the gas grid without any change to the rest of the system. These boilers can also accommodate fuel mixes that contain a small portion of hydrogen, up to 20%; but their 20% limit prevents their large-scale hydrogen use.

2. **Solar hot water**. Solar power can generate hot water in daylight hours, even on cold, cloudy days (although output is highest when the sun shines). Solar hot water is mainly used to heat hot water tanks for use for domestic use and is only viable in properties with suitable roof space and space for a hot water tank. A very cost effective and well-proven solution.

3. **Biomass boilers**. Biomass boilers typically use automated fuel systems, and can be of any size. In some ways they can be a like-for-like replacement for a gas boiler, but they use solid biomass fuel, typically either wood pellets or wood chips, rather than gas. Aside from the fuel source, the main difference is that properties need space for biomass storage on site, and also need wood to be delivered. The main challenge for large-scale deployment is the need to source only sustainable biomass fuel, which is of limited supply globally. Another key challenge is the impact of burning biomass on local air quality and hence human health. See Appendix B for more detail on the use of biomass.

4. **Building heat storage at scale.** Most heating is used in buildings, and homes in particular, for space heating and hot water. It is this demand that is most variable on an annual basis, with very high peaks, calling for a large heat-supply infrastructure. To help mitigate this impact, the capacity to store heat on the customer side can be hugely helpful. The most straight-forward and low cost means of doing so is hot water storage, which many homes across the UK already have.

5. A heating system that combines some element of smart operation, such as a Home Energy Management System (HEMS), might combine smart meters, smart heat storage and a heat pump

to manage space heating throughout the day to avoid peak heat demand. Such systems will be crucial to maintaining a cost-effective and reliable shift to low-carbon heating in the UK.

6. **Hydrogen boilers**. These systems produce hot water using hydrogen fuel and operate in all other ways like a normal natural gas boiler. They can be easily installed as a replacement to a conventional boiler where renewable and low-carbon hydrogen is available.

   Currently these systems are expensive but prices are expected to drop, becoming similar to current gas boiler prices as deployment reaches scale. Fuel cell technology is another means of converting hydrogen into general electricity and power onsite. However given its cost and operational constraints, it is not considered a viable heating technology.

   Moving to 100% hydrogen heating for a building would also mean all other natural gas appliances, such as cookers, would need to be replaced with hydrogen-burning versions. Households may need support to achieve this transition.

   Although the technology currently exists for the production of renewable or low-carbon hydrogen, it is largely uneconomic, requiring either carbon capture and storage or electrolysis. So, further research and development is required to reduce these costs and ensure that hydrogen boilers are an economically viable and environmentally sustainable solution. Furthermore, the technology has not yet been applied at scale in the UK context, and so it would need to be rolled out in a measured manner, with lessons learnt over time as its use broadens.[49] See Appendix C for more detail on challenges and opportunities around the production of hydrogen.

   District heating: A district heat network is a set of insulated, usually underground water pipes transporting hot or warm water from one or more heat sources to many heat customers, domestic or nondomestic. This technology is used at large scale in many contexts around the world, from Denmark to China, as is well proven and understood.

   District heating allows the capture of large point sources of heat that would otherwise be wasted, for instance waste heat from:
   - power stations
   - low- or high-temperature industrial processes
   - sewage treatment works
   - water heat sources such as rivers or lakes

   See Appendix A for a more detailed exploration of district heating. Three related technologies that are important for the deployment of district heating are:

   a. **Conventional (high temperature) district heat networks** provide heat at the temperature required by modern central heating systems, around 90-100 centigrade. Most UK building heating systems operate at this temperature (requiring modification to radiators to reduce it). It is also hot enough to supply domestic hot water. Hence, heat can be directly transferred to those systems, greatly increasing the number of heat customers that can be supplied with a district heat network. This output temperature limits the number of usable heat sources, however, as typically only high-temperature process heat is a suitable waste heat source. The vast majority of heat networks in the UK and around the world are of this type.

[49] Committee on Climate Change, *The infrastructure needs of a low-carbon economy prepared for climate change*, https://www.theccc.org.uk/publication/briefing-note-the-infrastructure-needs-of-a-low-carbon-economy-prepared-for-climate-change/

b. **Low-temperature district heat networks**. A newer and in some cases promising technology, low-temperature district heat networks operate at a much lower temperature of around 30 centigrade – constant all year round – and on a different principle. Rather than providing heat directly to customers, they provide a steady temperature heat sink from which heat pumps can draw heat more efficiently than from the air or ground, which would be much colder during the winter.

   This system is also able to act as district cooling network in (our increasingly severe) summers. This has the benefit of being able to access much lower temperature heat sources, such as sewage pipes, and so potentially increases the nationally available resource. The solution is yet to be applied at scale in the UK but has been operating successfully for some time in various locations around Europe[50].

c. **Combined heat and power (CHP).** The generation of electricity always creates waste heat as a by-product, and a CHP plant is simply a system where this heat is captured and put to use, greatly improving overall efficiency. CHP can be deployed at various scales, from the household scale (micro-CHP) to community to commercial power scale. In the case of the latter two a district heat network would be required.

   It is the view of the project team that based on historical operational data micro-CHP is not considered a viable option at scale due to cost, complexity and low reliability. Additionally, CHP is only a viable option from a GHG point of view when the heat is genuinely "waste" heat, and that CHPs deliver marginal or even negative savings over the long term as a new installation.

   See Appendix A for a more detailed explanation CHP and waste heat.

7. **Heat pumps**. Like refrigerators, heat pumps use the refrigerant cycle to move heat from a cold place to a warmer place, against the direction heat would normally flow. For instance, from within a fridge to the surrounding room, or from the cold outside air to within a home.

   In this scenario it has been assumed that the electricity supplied to heat pumps must be renewable or low-carbon in order for all the heat supplied.

   Improved building efficiency is vital for heat pumps, which prefer to operate at lower heating temperatures. Heat pumps are not able to ramp up very quickly or to high temperature; they provide a slow trickle of lower temperature heat throughout the day, avoiding need for demand peaks – but also only working well where the building can accommodate these restrictions.

   A very important aspect of heat pumps is the regulation of coolants, which can have a very high CO_2e figure when lost as fugitive emissions. It will be vital therefore to ensure effective regulation to address this risk.

   The key considerations for a wider uptake of heat pumps include:

   - mechanical design (particularly supply temperatures and Domestic Hot Water (DHW) provision
   - architectural integration
   - installation quality
   - commissioning and maintenance

[50] https://www.researchgate.net/publication/318204212_Low_Temperature_District_Heating_for_Future_Energy_Systems

More work is required to ensure that they will not have unintended consequences, but none of these considerations are thought to be substantial barriers". [51]

Heat pumps can be deployed in a range of scales, small (0-20kW, typically for one flat/property/building), medium (20-170kW for communal use, such as a large building or several properties) and large scale (170kW+ for district level use). There are two main types of heat pump:

- **Full heat pump (HP).** Conventional HPs use only electricity as fuel energy. It is crucial that the building is well insulated so that at peak times the required temperatures do not exceed the capacity of the heat pump. Efficient heat pumps can be a cost-effective solution, although capital costs are higher than some other solutions.

- **Hybrid heat pump (HHP).** HHPs use a combination of an electric heat pump and a gas boiler, with the HP element providing most of the year-round baseload heating. At peak demand on the coldest days, the boiler will either support or take over. On a very cold day the HHP will typically operate on 55% electricity and 45% gas, but most days it runs on 100% electricity[52]. This reduces challenges around grid reinforcement due to reduced load at peak times and avoids some of the challenges of hugely accelerated decommissioning of the gas grid. This is an important benefit, particularly as a transition technology. An HHP can be installed alongside an existing boiler or as a whole system and is typically cheaper than a full HP.[53] The proportional mix between use of gas and electricity used by a HHP over the year depends on: rated output of the electrical and gas components of the HHP and how carefully the system is managed to avoid peaks and the variation in external temperate throughout the year. However the electricity (and hence zero carbon) element can be anything from 65-80% on an annual basis, and has shown to be reliable in trials[54] [55]. Since HHPs are only partially renewable and low-carbon, towards the late 2030s they will need to be shifted to full heat pumps so the UK can eliminate all gas use to meet its Paris Agreement targets. Figure 16 illustrates an HHP system.

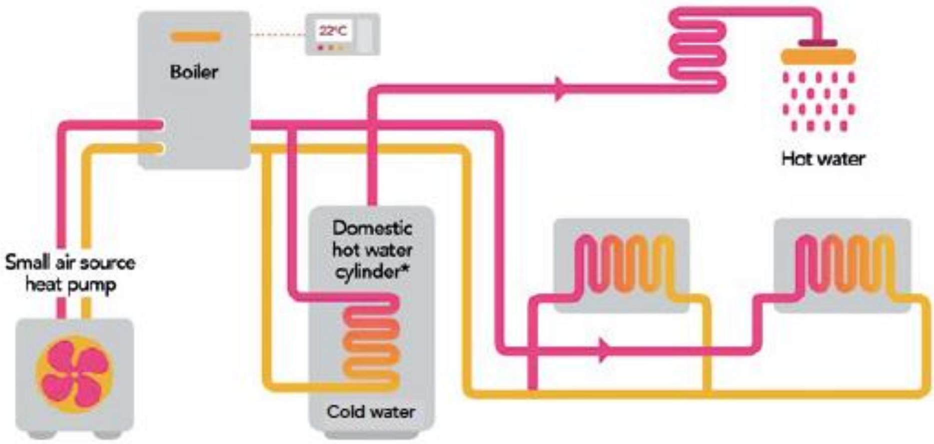

Figure 17. Hybrid heat pump system.

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[51] https://www.london.gov.uk/sites/default/files/low_carbon_heat_-_heat_pumps_in_london_.pdf
[52] https://www.westernpower.co.uk/docs/Innovation/Current-projects/FREEDOM/Freedom-Project-Interim-Report-Online.aspx
[53] BSRIA, UK Heat Pumps, Report 59122, https://www.bsria.co.uk/download/product/?file=TSPWGDxr%2Fhc%3D
[54] http://www.wwutilities.co.uk/media/2717/the-freedom-project-outline-april-2018.pdf
[55] Future Energy Scenarios 2019, National Grid, Page 70

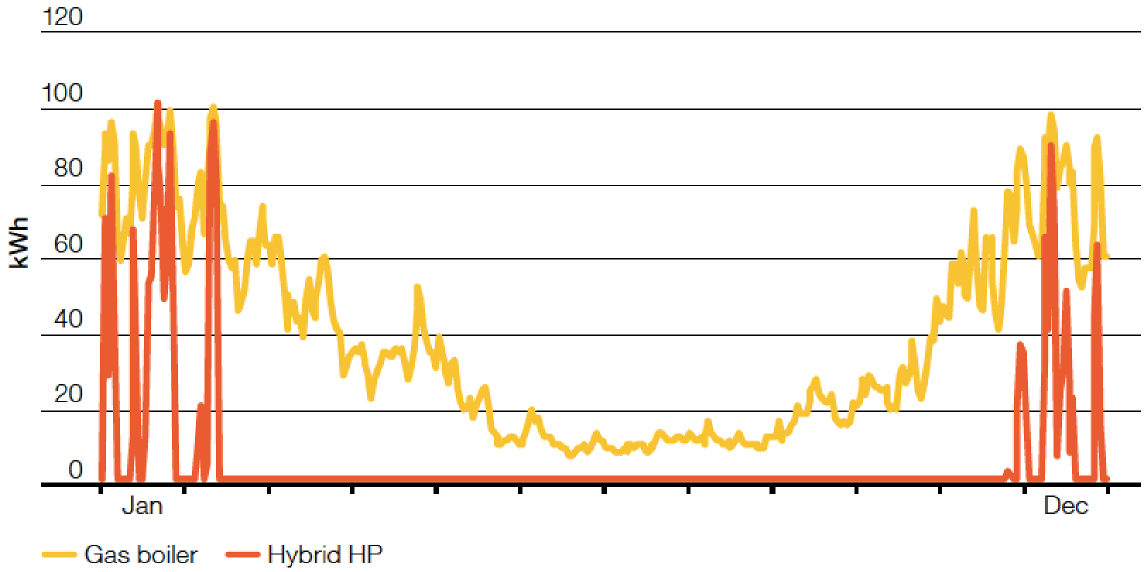

Figure 18 Modelled gas use with hybrid heat pumps. Source (NG Future Energy Scenarios 2019[56])

3.4.3 Energy transmission options

Some low-carbon heat technologies use on-site generation; sunlight is transformed to solar hot water, for instance, or electricity can be used to draw heat in from the outside air. But most heating technologies must be supplied with energy from external and usually rather remote sources. Below are the primary options for transmission of low-carbon heat or energy for heat:

1. **Piped renewable or low-carbon methane**: The existing heating infrastructure across much of the UK consists mainly of steel pipes, with some iron and PVC, for the transmission of methane. This gas network could be used to contribute to increasing renewable energy if a renewable methane source (such as biogas from anaerobic digestion of organic waste) is added to the conventional methane /natural gas mix. The higher the concentration of renewable and low-carbon methane, the higher the contribution of renewable and low-carbon energy. (Note that CCS cannot be used in this situation as that would require the transformation of natural gas to hydrogen, requiring entirely new infrastructure.) This shift is already happening to a small degree. It would also be possible to add a small amount of renewable hydrogen to the methane (such as syngas), but only up to a mixture of 20% hydrogen. For higher concentrations of hydrogen, specialist pipework is required.

2. **Piped hydrogen**: For higher volumes of hydrogen, plastic pipes would supply hydrogen directly into buildings or energy centres for use in boilers. If there were a large-scale shift to hydrogen, the existing gas network would need to be upgraded. This has already happened to various degrees around the country as part of the natural upkeep of the grid, and so would potentially be a greatly reduced undertaking once renewable and low-carbon hydrogen is widely available.

   As outlined in Appendix C, however, the scale of deployment of low-carbon hydrogen will not begin until the mid/late 2020s. Decisions on scale, type and pace of deployment will be made at that time.

3. **Electricity**: Heat pumps will be the main users of electricity for heating. As outlined below, heat pump use is expected to increase substantially and even be the single largest renewable heat

[56] National Grid, Future Energy Scenarios 2019, Page 71

source in the UK by 2030. The existing electricity grid can be used for much of this, but on colder days is likely to approach and potentially exceed the limits of the electricity grid's capacity, which was built in 1970s. To meet large amounts of heat demand this way would need a range of measures, which will include likely include significant upgrades and reinforcement to the grid.

See Section 5 below for more detail on grid balancing.

4. **Piped 'hot' or 'warm' water**, also known as district heating. District heating involves a network of pipes linking a heat source to heat customers. See Appendix A for discussion on the application of district heating as a complete long-term infrastructure solution.

3.5 Coordination of heat decarbonisation and energy demand reduction

This section considers two important cross-sector issues for heat decarbonisation: its integration with efforts to reduce building energy demand, and its integration with efforts to reduce industrial process energy demand.

3.5.1 Heat decarbonisation integrated with energy-efficiency programmes

The deployment of renewable and low-carbon heat across the UK can most efficiently be delivered through the building retrofit programme and new building regulations.

As each building is audited as part of the retrofit program, it will be assessed for suitability for renewable or low-carbon heating, ensuring that by 2030, 50% of buildings have heating provided by one of the options outlined above. Therefore, while all buildings will have efficiency measures installed, not all will need such heating systems. Those buildings that do not have renewable or low-carbon heating installed must use highly efficient condensing natural gas boilers.

3.5.2 Industrial process heat

There are two main areas where industrial heat interfaces with other elements of the heat strategy:

Biofuel. Industrial process heat is included within total heat consumption and is therefore accounted for alongside other heat demand. However, there are components of industrial *processes* that are quite unique – such as those requiring the use of petroleum products.
As outlined in Appendix B, this is the only non-transport application for bioenergy that this report recommends, because it is very difficult to deliver this heat in other ways. Based on our assessment of the CCC 5th Carbon Budget Central Scenario, we have estimated that around 6.4TWh of biofuel a year in 2030 would be the required volume of bioenergy. [57] This is around 1% of total UK heat use by 2030.

Waste Heat. There is potential to capture waste heat from industrial processes for use in heating local buildings. This has been captured in the figures below relating to district heat networks.

3.6 Maximising renewable or low-carbon heat by 2030

In this section:

- Summary 2030 Heat supply mix
- Four step approach to technology choices
- Step A: Nationwide quick-win solutions for renewable and low-carbon heat
- Step B: Solutions for new buildings
- Step C: Solutions for existing building on electric heating
- Step D: Solutions for existing building on gas heating

[57] Committee on Climate Change, The Fifth Carbon Bidget: The next step towards a low-carbon economy, (2015) 130.

3.6.1 Summary of 2030 Heat supply mix

As outlined in Figure 17, we propose a 2030 heat supply mix of:
Figure 20

It is entirely possible to achieve 50% renewable and low-carbon heating while minimising disruption for the majority of people through a combination of:

- 25 electrification of heat using heat pumps and hybrid heat pumps – a huge increase from today
- 10% from a combination of local sources, such as solar hot water and waste heat supplied by DHNs.
- 3% from solid biomass heating, which has been assumed to remain at current output levels
- 11% renewable and low-carbon heating supplied via the gas network (including 5% biomethane injected into the gas grid, and from 6% renewable or low-carbon hydrogen used in buildings, supplied via new or upgraded gas networks)
- The remaining 50% is natural gas
- Of UK heat customers currently using gas, 78% will continue to use existing gas infrastructure and boiler technology by 2030, and so will not require new technology installed in their home before 2030.

There is high confidence in this mix until at least the mid 2020s. Towards the late 2020s, flexibility in relation to the balance between heat pumps and hydrogen should be maintained to take advantage of advances in technology.

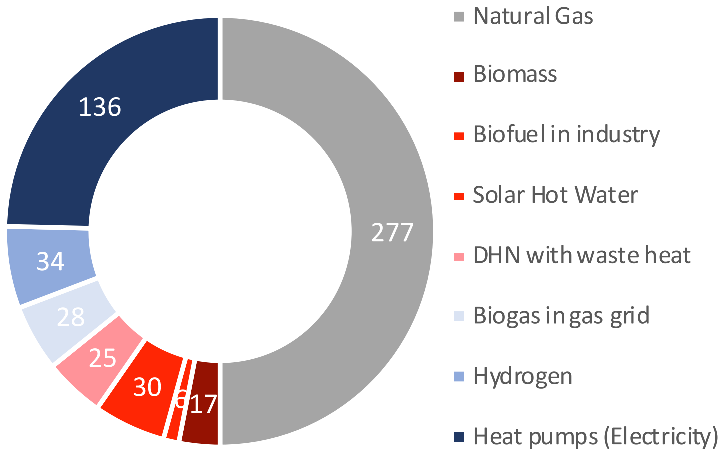

Figure 19. Modelled 2030 heat supply mix (TWh).

3.6.2 Four-step approach to technology choices

This balance of heating technologies is the result of considering all the technologies outlined in Section 3.4, using the strategic recommendation's in Section 3.7, and applying a detailed analysis by building type. As outlined in
Figure 20, conventional wisdom indicates there should be mix of supply solutions deployed according to the appropriate heat demand/building type.

This has resulted in four main heating steps.

Step A: Deploy quick-win solutions at the earliest possible time across the whole country. There are some solutions that should be maximized quickly in all suitable conditions as they involve local or readily available resources that can be accessed with minimal disruption. These quick-win soltuions include the almost complete removal of all coal and oil heating; biomethane injection into gas grid; solar hot water and the use of waste heat via district heating.

Step B: Heat all new buildings by renewable or low-carbon energy only (or as close as possible), taking advantage of the fact that new buildings have no existing heating systems to replace, and can be designed to make the best use of renewable and low-carbon heating.

Step C: Convert all existing buildings currently using electric heating to renewable or low-carbon electric heating at the earliest possible time, using heat pumps and solar hot water. Buildings already using electricity, rather than gas mains, for heating can be shifted to low-carbon electric heating without substantial further burden on the electricity grid, and in some cases the modifications are easier within the building.

Step D: Convert buildings currently using natural gas for heating to a mix of hybrid heat pumps, heat pumps, and increasing volumes of renewable or low-carbon hydrogen by the late 2020s. These buildings are the most complex group, requiring a complete shift in heating solutions, and are therefore approached last and only to the extent needed to make up the difference to 50% of heat, to minimise disruption.

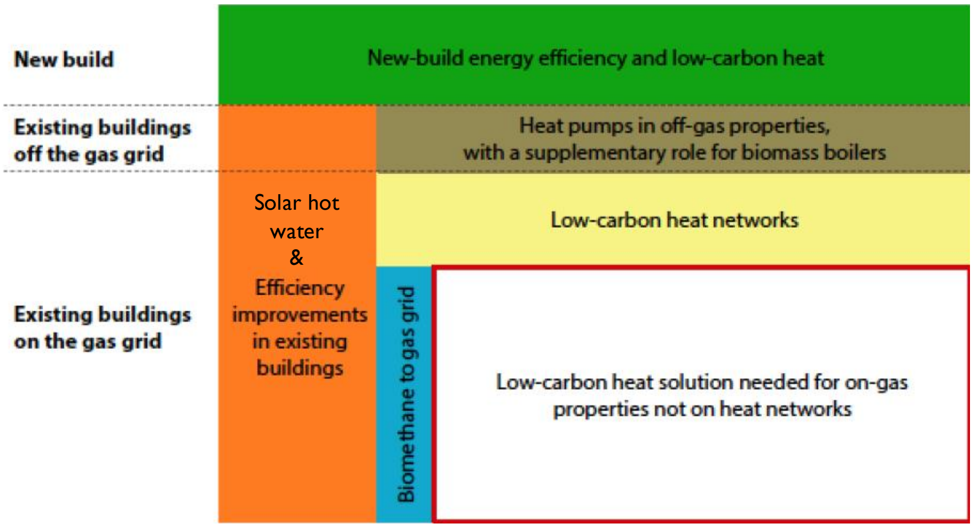

Figure 20. Renewable and zero-carbon heat supply options by key building type.[58]

The following section unpacks this approach and make recommendations for technology deployment in different building types to achieve the 50% goal by 3030.

3.6.3 Step A: Renewable and low-carbon heat for *new* buildings

Deployment recommendation:

- All new building should have renewable or low-carbon heat (or as close as possible).
- The large number of new affordable homes Labour is committed to building (the green slab at the top of Figure 20) need to either have heat pumps installed or be connected to district heating schemes, using waste heat from industry and other sources.

Renewable or low-carbon heat in new buildings would contribute only a small amount of energy to overall UK-wide heat demand because:

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[58] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf

- New should be designed to have a very low heat consumption due to stringent near zero energy building standards, with some minor variation depending on local conditions.[59]
- They are expected to be relatively few compared to the existing housing stock, an expected ratio of 9:1 (24m existing homes today compared to 3m expected to be built between 2019 and 2030).

Recommendation 10 (Heating Step A): Heat all new buildings by renewable or low-carbon energy only (or as close as possible), with no fossil-fuel heating of any kind (related to recommendation 8), from 2020.

3.6.4 Step B: Nationwide quick wins for renewable and low-carbon heat

There are renewable or low-carbon heat technologies that are highly viable and beneficial win-wins that should be maximised by 2030: solar hot water, heat networks and biomethane injection into the gas grid.

Together they would contribute:

- around 83TWh
- or 15% of total heat in 2030

3.6.4.1 Solar hot water

Deployment recommendation. Solar thermal technology should be deployed on the rooftops of all buildings (homes and business) where possible and appropriate.

In 2030, solar hot water would contribute:

- around 21.7TWh from domestic rooftops
- 8.3TWh from nondomestic buildings
- around 6% of UK heating[60]

This scenario assumes 1m^2 of solar thermal for each UK citizen (based on an EU target[61]), to be split between domestic, commercial and industrial (55,000,000 people, each with allocation of 550kWh, from 1m^2).

Domestic analysis. We assume that 71.76% of solar thermal is deployed to domestic buildings, reflecting their share of hot water demand.[62]

Non-domestic analysis. We assume that 28.24% of solar thermal is deployed to nondomestic buildings, reflecting its share of hot water demand. This produces 8.54TWh with 0.21TWh used for pumps, or 8.34TWh in total savings.

We did not look at the use of solar hot water for industrial processes, though it may have potential.

3.6.4.2 Waste heat district heating networks

Deployment recommendations:

[59] https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf
[60] Team's own calculation
[61] A. Ramos, I. Guarracino, A. Mellor, D. Alonso-álvarez, P. Childs, N.J. Ekins-daukes, C.N. Markides, *Solar-Thermal and Hybrid Photovoltaic-Thermal Systems for Renewable Heating*, Grantham Institute, Brief. Pap. No 22. Imp. Coll. London. (2017) 1–20. doi:10.13140/RG.2.2.10473.29280.
[62] BEIS, Energy Consumption In The UK, Department for Business, Energy and Industrial Strategy, 2017. https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

- Deploy high-temperature waste heat via district heat networks across urbanised areas of the country, where suitable and genuine waste heat exists – avoiding the need to install new networks with new *dedicated* supply sources, for reasons outlined in Appendix A.
- Deploy low-temperature waste heat via district heating networks located with buildings that have low-temperature heating systems, such as underfloor heating. Trials should be undertaken for low-temperature heat networks to demonstrate their most viable applications.
- Make use of all economically viable waste-heat *sources* (places where heat can be capture from using a heat pump, then transported for use in buildings using a heat network), such as rivers (using a river source heat pump), sewage works (capturing heat from heat given off by microbial action in the water cleaning proess), sustainable waste-to-energy plants and low-temperature waste heat and high-temperature waste heat (mainly from industry).
- Expand existing district heating networks where suitable.
- Until cost effectiveness is proven, large new district heating networks with new dedicated heat sources such as gas-fired CHP should *not* be a priority unless the majority source is waste heat.

In 2030, waste heat district networks would contribute:

- total capacity by 2030 around 25TWh
- or 5% of UK heat demand
- or roughly two million homes

Analysis. This value is based on the 41.9TWh outlined as possible by the 2015 Element Energy Study.[63] However, it removes the portion supplied by biomass and small-scale CHP for reasons outlined in Appendix A and Appendix B. It also removes the contribution from gas boiler back-up; though likely necessary to meet peak loads, gas boiler back-up will not contribute towards an increase in renewable and low-carbon energy. The availability of waste heat will provide the upper limit for deployment of district heat networks by 2030.

See Appendix A for further discussion.

3.6.4.3 Biomethane

Deployment recommendation. Maximise biomethane in the gas grid and deliver it independently of the retrofit programme, as a supply-side measure. Biomethane should be maximised because it makes use of a resource (waste organic matter) that would otherwise result in landfill methane emissions and can be inserted into the gas grid, and thus easily added to the national heat supply.

In 2030, biomethane would contribute:

- a maximum of around 28TWh of heat energy[64]
- 5% of UK heating

Analysis. This figure is based on a 5% of overall UK gas supplied by biomethane, as corroborated by the Committee on Climate Change. This would maximise the viable use of organic waste treatment in an anaerobic digester to produce zero-carbon methane for injection into the gas grid. Modelling assumed this option is only available for buildings connected to the gas grid, and also assumed an even spread across all gas use in 2030.

The following three sections outline recommendations for providing the remaining renewable and low-carbon heating needed. Recommendations are based on consideration of:

- building type

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[63] https://www.theccc.org.uk/wp-content/uploads/2015/11/Element-Energy-for-CCC-Research-on-district-heating-and-local-approaches-to-heat-decarbonisation.pdf
[64] https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/

- the most appropriate renewable and low-carbon heating source
- whether the building is new or existing
- whether the building is currently connected to the gas grid or not

3.6.4.4 Biomass

The use of solid biomass in biomass boilers is already the largest source of renewable heat in the UK today. Therefore, it is assumed that the current capacity is maintained, and continues to produce 17TWh of heat a year. However it is not anticipated that this would be expanded any further for reasons outlined in Appendix B. At the same time it is not anticipated that the value would drop, since many buildings now have biomass boilers and ancillary facilities installed (such as biomass stores) and so will likely maintain the same system type for the foreseeable future. As outlined above, the majority of this demand is used in small and medium-sized boilers by nondomestic users.

In 2030, biomass would contribute:

- 17TWh of heat
- around 3% of heat demand in 2030.

> **Recommendation 11 (Heating Step B): Deploy quick-win heating solutions at the earliest possible time across the whole country,** including: the complete removal of all coal and oil heating; biomethane injection into the gas grid; solar hot water; and the use of waste heat via district heating in dense areas.

3.6.5 Step C: Renewable and low-carbon heat for *existing* buildings that currently have *electric* heating

Deployment recommendation: All buildings connected to electricity mains only, with no gas for heating, should be transferred to renewable or low-carbon heating by 2030, which in almost all cases will be a heat pump.

In 2030, around 1.4m existing buildings not on the gas grid would use renewable and low-carbon heat sources. These buildings currently use 32TWh of electricity for heat, representing 5% of UK total heat demand today.[65] Every single such building, since already using electricity, can more easily be converted to use heat pumps, which will be the majority source of heating for these buildings because they are a more efficient technology, will decrease instantaneous electricity demand for heating for most of the year, and greatly decrease annual demand.

Analysis. In some cases, where an air-to-air heat pump is suitable, it will be more straight forward and less costly. In other cases, where a new wet central heating system must be installed, such as underfloor heat piping, the capital costs and disruption of installation will be higher. Because these buildings are not on the gas grid, there is no option to use hybrid heat pumps, which need a gas supply. So only a heat pump can be used. These buildings will also have solar hot water installed where suitable, which may require a new hot water tank to also be installed.

> **Recommendation 12 (Heating Step C): Convert all existing buildings currently using electric heating to renewable or low-carbon electric heating at the earliest possible time**, using heat pumps and solar hot water.

3.6.6 Step D: Renewable and low-carbon heat for *existing* buildings that currently have *gas* heating

Deployment recommendations. The final heating opportunity is shifting buildings on the gas grid to lower-carbon options through a combination of actions: deploying heat pumps and hybrid heat pumps; maximizing heat pumps to the extent the electricity network can sustain; and, once renewable-hydrogen becomes commercially viable towards the end of the 2030s, introducing renewable-hydrogen where viable. The balance between these actions will need to be determined through further testing and research, and in the case of hydrogen the results will take several years to determine. The maximum feasible level of deployment for these technologies is a complex question and one that is still hotly contested. This study has taken the approach of focusing on a 50% target for renewable and low-carbon heating. At this stage a plausible deployment assumption on how to deliver the remaining 170TWh needed to meet this 50% aim, by 2030 could be as follows:

- 32% hybrid to help manage peak loads (or 40% of total heat pumps installed by 2030), meaning that gas can still contribute in the coldest days
- 48% conventional electrical only heat pumps (or 60% of total heat pumps installed by 2030)
- 20% renewable and low-carbon hydrogen, as a mix of blended hydrogen with natural gas in existing gas infrastructure, and dedicated hydrogen transmission infrastructure and appliances.

By the late 2020s, a mix of mainly heat pumps and small volumes of hydrogen could shift a total 170TWh of energy demand currently on the gas grid to renewable and low-carbon heat when combined with the electrification of heating for buildings not on the gas grid (Step C). h The contribution would break down as: 34TWh from hydrogen, 54TWh from hybrid heat pumps and 82TWh from heat pumps.

Analysis. Steps A and B demonstrate how 106TWh/yr of renewable and low-carbon heat will be provided. This leaves a gap of 170TWh/yr to meet meet 50% renewable and low carbon heat by 2030. The solution to this gap must now be found from the remaining large majority of UK buildings that are currently heating with natural gas from the gas grid. These buildings are the most complex to provide renewable and low-carbon heat for reasons outlined in Section 3.4.1.

Given that all the other options have been exploited already, there are three main options for this heat in a renewable and low-carbon form (note that the contribution from biomethane has already been accounted for above):

- **Electrifying heat to replace gas** (renewable and low-carbon electricity suppling heat pumps, see Section 3.4.2.2 above).
- **Partial electrification of heat to replace gas** (using hybrid heat pumps, see Section 3.4.2.2 above).
- **Shifting to hydrogen to replace gas** (renewable and low-carbon hydrogen being blended with natural gas within the gas network, up to a maximum of 20%, allowing homes to continue using current heating system and cooking appliances without any need to change). 100% renewable and low-carbon hydrogen systems (large scale transmission and use of pure hydrogen) is not considered likely to be viable at significant scale in the early to mid 2020s, however some penetration is expected by late 2020s.

Recommendation 13 (Heating Step D): Begin converting buildings currently using natural gas for heating to use heat pumps and hybrid heat pumps, as well as introduce increasing levels of renewable or low-carbon hydrogen blended within natural gas supply. These buildings are the most complex group requiring a complete shift in heating systems over the long term (either to electric or 100% hydrogen) and so should be prioritised after Heating Steps A to C. *Renewable or low-carbon hydrogen* is hydrogen that has be produced without GHG *emissions*, through ether natural gas reformation combined with carbon capture and storage, or through the electrolysis of water using renewable electricity.

Hydrogen recommendations. Hydrogen production, transmission and combustion are in principle very well understood technologies that have been used for over half a century. However, the production of renewable and low-carbon hydrogen is very much an emerging area, as is the large scale transmission and use of hydrogen for conventional heating and operation in the domestic and commercial sectors. For the application in a domestic heating context, there are various opportunities and potential directions and scales for the future role of renewable and low-carbon hydrogen. As mentioned, decisions on the exact role of hydrogen will be best made in the mid 2020s. For this reason, a staged approach to its rollout is considered best. This approach should include:

- **The supply of small proportions of hydrogen as a blend with natural gas via the existing gas network**. This would allow the reduction of carbon content of gas used in the network, while ensuring no infrastructure or appliance changes are required (as long as hydrogen proportion of the gas mix stays below the maximum 20% level, this research assumes around 5% penetration by 2030). This is a core part of the recommendation made on the previous page.
- **Measured and controlled implementation of large-scale dedicated hydrogen use for heating**. Designs for such projects in the UK are already well outlined, such as the H21 North of England hydrogen project[66]. These projects will likely take until the mid-2020s before large scale implementation begins and so are expected to contribute only a small contribution by the late 2020s.
- **Research and development towards reducing the costs of renewable and low-carbon hydrogen production.** Research and development is vital. Currently renewable hydrogen production through the use of electrolysis is highly expensive, and low-carbon hydrogen production through gas-reformation and CCS has undemonstrated costs (even though the technology is well proven technically, see Appendix C).

It is beyond the resources of this study to accurately estimate the appropriate proportion of renewable hydrogen by the late 2020s. A a speculative assumption has been made that 5% of UK heat demand by 2030 is assumed to be from renewable and low-carbon hydrogen, or 34TWh, however this could indeed be significantly higher depending how tests and demonstration projects go in the early 2020s.

This is a high-level estimate at this stage and one that should be researched in much more detail. This split has been assumed to permit the gas grid to keep providing for a large portion of peak demand on the coldest days. This assumption is considered "safe" due to the fact that even if dedicated hydrogen infrastructure and appliances are not deployed at scale by 2030, this volume of hydrogen could simply be supplied via the existing gas grid as a hydrogen-methane blend.

Recommendation 14 (Heating Step D): **Research and development to demonstrate the long-term role of dedicated renewable and low-carbon hydrogen and hybrid heat-pumps**, with three key elements:

- Trials of hybrid heat pump use at scale, to support in peak demand periods.
- Trials of dedicated hydrogen distribution and use for heat at scale – exploring full 100% hydrogen transmission infrastructure and household use. Important to demonstrate long-term feasibility of hydrogen as a 100% low-carbon solution, rather than partial low-carbon when blending with natural gas in existing gas network.
- Research and development towards reducing the costs of renewable and low-carbon hydrogen production, and well as hydrogen storage solutions.

Recommendation 15 (Heating Step D): Significantly expand renewable and low carbon heat in the second half of the 2020s, based on experiences and lessons from Recommendation 14. In particular expand renewable and low-carbon hydrogen, heat pumps and hybrid heat-pumps to appropriate scale and in the appropriate locations.

[66] National Grid FES 2018 Data Work Book, http://fes.nationalgrid.com/fes-document/

3.6.7 The large majority of existing gas heating can remain in place by 2030

The above strategy ensures delivering the necessary 50% of renewable and low-carbon heat can be delivered while minimising disruption to homes and businesses. The total amount of gas used for heating drops to 301TWh (assuming all remaining boilers in 2030 are high efficiency condensing boilers). When combined with the use of biogas and 5% insertion of hydrogen, this means 338TWh of heating is supplied via the existing gas network, or 61% of total UK heat demand. Today the figure is around 80% of buildings heating using gas infrastructure. Therefore this is only a roughly 20% drop in use of the gas system, meaning 78% of those buildings currently connected to the gas grid will see no change in how their heat is supplied. This would mean 4.4 million homes would need to shift from natural gas to another solution, out of 27million nationally, minimising the amount of disruption to business and households as the UK transitions to low carbon heating, and meaning the existing skilled workforce of gas engineers will be able to remain employed in the sector. Households and businesses would need to be supported to make any changes needed.

This results in a 2030 supply mix as outlined in Figure 19, which forms the basis for the proposed scenario for delivering maximum renewable and low-carbon energy by 2030. Through the 2030s continued deployment of renewable and low-carbon heating will need to continue.

3.7 Strategic solutions for decarbonising heat

The solutions below address practical principles that are important when planning the decarbonisation of UK heating.

Create a zonal and locally specific approach. On the national level, we recommend introducing a regionally or zonally planned patchwork of heat technologies, with different solutions deployed around the UK depending on the local appropriate technology. However, at the local level, only one solution should be deployed in each area, rather than implanting duplicated or competing infrastructure solutions. A degree of central direction will be required from the national government to achieve a coordinated patchwork of technologies across the country that meets the needs of people and the environment.

Minimize the impacts of system shift. A shift towards a low-carbon heating system will need to ensure that all the successful characteristics of the existing system are maintained. For instance:

- The gas grid is a large piece of embedded infrastructure, that in heating terms is well designed for delivering the 'peaky' heat demand of the UK. A new system will need to also meet this demand by maintaining existing functionality.
- The existing infrastructure providing natural gas via National Grid piping, directly to buildings and then combusted on site, is very well understood, with a large, skilled supply chain in installation and maintenance of gas-distribution and associated equipment. Training and support to these sectors will be crucial to enable them to transition to working with alternative low-carbon solutions.

Recognize that electrification of heat will be a multi-decade process, and certain decisions will likely be made during the 2020s, such as the exact balance between heat pumps and *hybrid* heat pumps. Total electrification will not be viable by 2030, and some natural gas will need to be used well into the 2030s. As recognised above, moving to full electrification of heating very quickly has a number of challenges, largely due to the extra electricity demand to the UK total in times of high demand. It is therefore recommended that a portion of heat pumps are duel fuel, hybrid heat pumps. Allowing the heat pump to combust gas to improve operation when demand is at its rare highest allows the heat pump to be quite a lot smaller in capacity, while delivering only slightly less energy over the year. Other benefits of this approach include:

- **A reduced national system size**. The cost of meeting peak demand across all the remaining buildings needed, with heat pumps only, would be huge because air-source heat pumps' efficiency drops on coldest days. This amplifies the amount of electricity needed at the time when demand is already high, increasing the capacity of the electricity transition and generations systems. This will lead to substantially higher costs overall.

- **Similar costs.** Overall the cost for this approach is expected to be the same as or similar to the cost of a heat-pumps-only solution, as heat pumps and hybrid heat pumps are similarly priced when considering the whole macro system costs.
- **Seasonal storage.** This solution not only reduces the difficulty in meeting instantaneous peak heat demand, but also high-risk conditions like a 'Beast from the East', where we have a prolonged period of extremely low temperatures. Under these conditions it is vital to guarantee that all buildings, in particular homes, can be heated constantly throughout long cold periods. There is a very serious risk of death for large parts of the population if heating cannot be provided.
- **A more gentle phase-out of gas infrastructure while still driving decarbonisation.** This gentle phase-out also has the substantial benefit of allowing the gas grid to continue operating for a number of years, but with substantially lower gas use. The feasibility of low utilization of gas networks, has been demonstrated at in at least one case in the UK.[67] The exact proportion of gas used towards 2030 will depend on the level of deployment of hybrid heat pumps by the mid-2020s, which in turn is a question that we recommend is established precisely, through further research, as soon as possible .

Further investigation is needed to determine exact balance between standard heat pumps and hybrid heat pumps. As with the likely penetration of hydrogen heating in the late 2020s, the exact balance between standard heat pumps and hybrid heat pumps is beyond the resources of this study to determine, and further detailed modelling will be required. See discussion below on phasing of heat solutions. However, it can firmly be stated that both technologies are proven and available for use today.

Solid biomass for heating should not be a priority solution for direct heat supply because:

- Large scale *expansion* in the use of woody biomass for either heating or power is not recommended. However, there is already a substantial level of woody biomass use in the UK, and as long as all biomass full is sustainably sources, it is considered sensible to maintain the biomass heating capacity at similar levels to today.
- Biogas injection into the gas grid should be prioritized to 2030, although food-waste reduction policies should always take priority over waste valorisation.
- Biofuel resources should be prioritised for aviation, shipping and where necessary, industrial process heat.

See Appendix B for more detail.

Recommendation 16: Maintain but do not expand current levels of biomass *heating*; expanding solid biomass for heating should not be a priority solution for direct heat supply.

Recommendation 17: Ensure heat strategy adopts several key solutions to ensure successful delivery:

- Deploy a planned, coordinated and regionally and locally appropriate patchwork of renewable and low-carbon heating technologies across the UK – ensuring technology choices are suitable for each region, zone or location, and that duplication and competing infrastructure is avoided.
- Minimise impacts of system shift – by replicating the successful characteristics of the existing system and providing training and support to workers in sectors experiencing a transition, among other measures that it is understood Labour will develop with the trade unions.
- Build awareness across both the public and industry that electrification of heat will be a multi-decade process.

[67] http://www.wwutilities.co.uk/media/2717/the-freedom-project-outline-april-2018.pdf

3.8 Summary of Recommendations

Recommendation 9: Set a target of 50% renewable and low-carbon heating by 2030, more than a twelve-fold increase in output from today. Heating is responsible for over half of the UK's energy-related GHG emissions, and current renewable and low-carbon heating levels are extremely low. Therefore, the urgent expansion of renewable and low-carbon heating is one of the most important aspects of this strategy, as well as one of the most complex – due, for instance, to the scale and shape of heat demand.

Recommendation 10 (Heating Step A): Heat all new buildings by renewable or low-carbon energy only (or as close as possible), with no fossil-fuel heating of any kind (related to recommendation 8), from 2020.

Recommendation 11 (Heating Step B): Deploy quick-win heating solutions at the earliest possible time across the whole country, including: the complete removal of all coal and oil heating; biomethane injection into the gas grid; solar hot water; and the use of waste heat via district heating in dense areas.

Recommendation 12 (Heating Step C): Convert all existing buildings currently using electric heating to renewable or low-carbon electric heating at the earliest possible time, using heat pumps and solar hot water.

Recommendation 13 (Heating Step D): Begin converting buildings currently using natural gas for heating to use heat pumps and hybrid heat pumps, as well as introduce increasing levels of renewable or low-carbon hydrogen blended within natural gas supply. These buildings are the most complex group requiring a complete shift in heating systems over the long term (either to electric or 100% hydrogen) and so should be prioritised after Heating Steps A to C. *Renewable or low-carbon hydrogen* is hydrogen that has be produced without GHG *emissions*, through ether natural gas reformation combined with carbon capture and storage, or through the electrolysis of water using renewable electricity.

Recommendation 14 (Heating Step D): Research and development to demonstrate the long-term role of dedicated renewable and low-carbon hydrogen and hybrid heat-pumps, with three key elements:

- Trials of hybrid heat pump use at scale, to support in peak demand periods.
- Trials of dedicated hydrogen distribution and use for heat at scale – exploring full 100% hydrogen transmission infrastructure and household use. Important to demonstrate long-term feasibility of hydrogen as a 100% low-carbon solution, rather than partial low-carbon when blending with natural gas in existing gas network.
- Research and development towards reducing the costs of renewable and low-carbon hydrogen production, and well as hydrogen storage solutions.

Recommendation 15 (Heating Step D): Significantly expand renewable and low carbon heat in the second half of the 2020s, based on experiences and lessons from Recommendation 14. In particular expand renewable and low-carbon hydrogen, heat pumps and hybrid heat-pumps to appropriate scale and in the appropriate locations.

Recommendation 16: Maintain but do not expand current levels of biomass *heating*; expanding solid biomass for heating should not be a priority solution for direct heat supply.

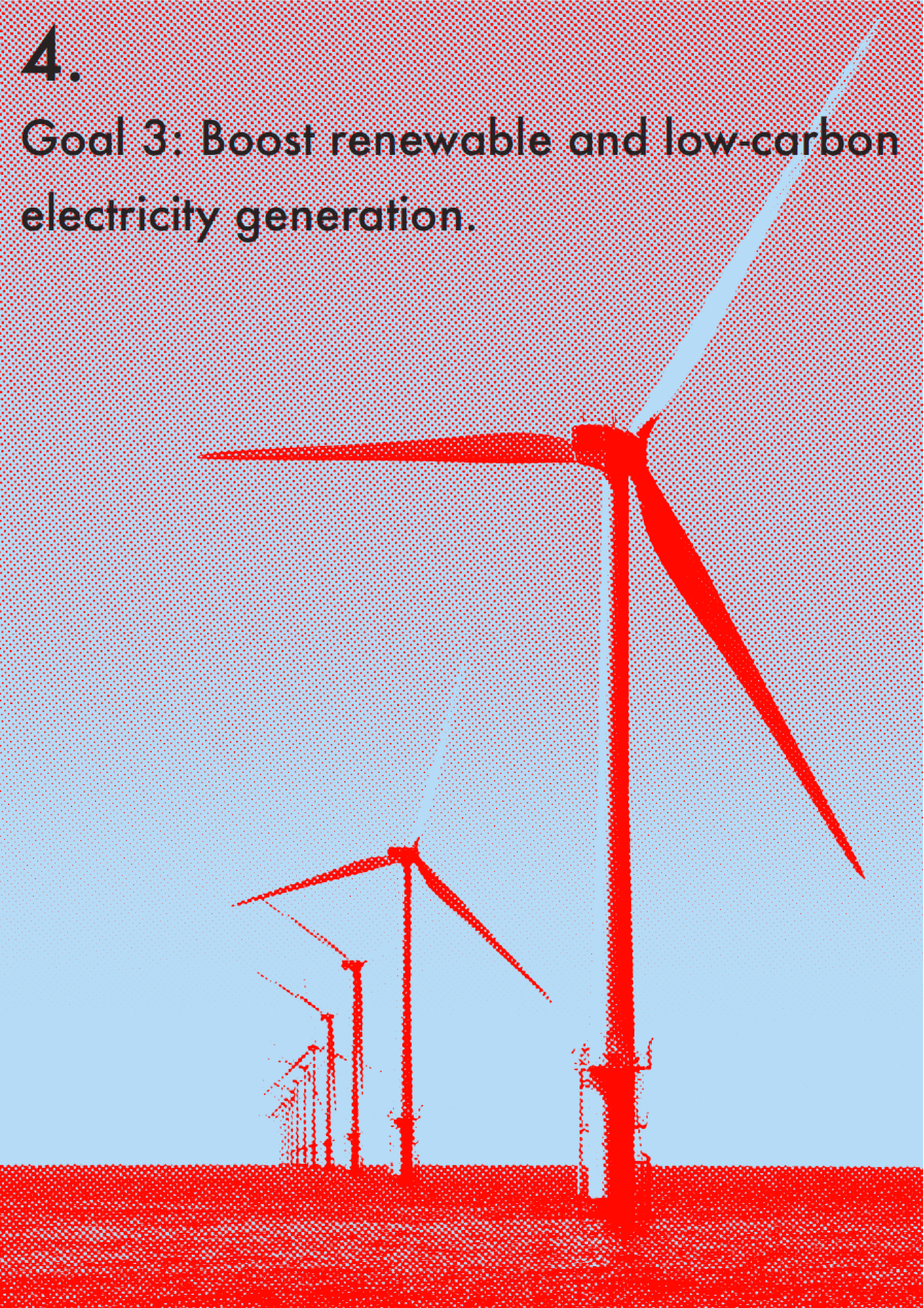
Recommendation 17: Ensure heat strategy adopts several key solutions to ensure successful delivery:

- Deploy a planned, coordinated and regionally and locally appropriate patchwork of renewable and low-carbon heating technologies across the UK – ensuring technology choices are suitable for each region, zone or location, and that duplication and competing infrastructure is avoided.

- Minimise impacts of system shift – by replicating the successful characteristics of the existing system and providing training and support to workers in sectors experiencing a transition, among other measures that it is understood Labour will develop with the trade unions.
- Build awareness across both the public and industry that electrification of heat will be a multi-decade process.

4.

Goal 3: Boost renewable and low-carbon electricity generation.



4.1 Chapter Summary

GOAL 3: BOOST RENEWABLE AND LOW-CARBON ELECTRICITY GENERATION

CHAPTER BACKGROUND

This chapter considers how to shift electricity generation towards renewable and low-carbon sources.

We outline how 90% percent of *direct electricity* demand, or 235Wh, can be met by renewable and low-carbon energy sources, up from 45% today, by 2030. These energy sources will combine with the 50% of renewable and low-carbon heat outlined in the previous chapter to maximise renewable and low-carbon energy overall.

The UK will then still need an additional 106TWh of renewable and low-carbon electricity to power the heat pumps and hydrogen production that will contribute to the renewable and low-carbon heating supply outlined in the previous chapter. This means there is a total demand for 382TWh of renewable and low carbon electricity, and a generation level of 392TWh once transmission and storage losses are taken into account. This is more than two and half times greater than the amount generated today.

CHAPTER FINDINGS

The UK has more than enough renewable and low-carbon energy resource to meet it's needs, and so it is recommended that these resources be harnessed to the maximum feasible level.

The UK has one of the largest offshore wind resources in the world and it can be harnessed to meet more than half the UK's electricity needs by 2030. This can be done without impacting the lives of UK residents, which is why more than a five-fold increase in offshore wind is recommended. Also, public support for offshore wind continues to stay high, with 79% of the public saying they are in favour. More than doubling onshore wind is also important.

This ambitious wind target can be set with confidence that there is sufficient resource, and that the UK offshore wind industry is in a good position to ramp up production sufficiently having not experienced the recent policy setbacks endured by the other sectors, and should benefit from cost saving innovations such as higher capacity turbines. That said, capturing the scale of this potential will require an unprecedented national focus on expanding and capturing the benefits of this industry in the UK.

Solar energy would contribute to 9% of total renewable electricity by 2030, after almost tripling the already impressive capacity developed before recent policy setbacks.

Various emerging energy technologies will be taking hold by 2030 that could put the UK out infront. Carbon capture and storage and tidal power – both key for long term GHG reductions – are technologies in which the UK is well placed to be a world leader, with UK companies already at the forefront, and a large existing offshore skills base. Both technologies should be supported to ensure they are reaching large scale deployment by 2030, to take advantage of growing gobal markets throughout the 2030s.

This scale and pace of change would put the UK on the fastest possible trajectory to a full phase out of fossil fuels in electricity.

This would build on the global success story of new renewable installations outstripping new fossil fuel capacity. It can also be achieved through relying on a large majority of existing proven technologies.

The strategy makes the assumption that nuclear capacity is maintained at current levels, by 2030 that the existing plants that are planned for decommissioning before 2030 are replaced with equivalent capacity. This could be possible in the time frame by developing two replicas of the Hinkley Point C in the mid to late 2020s. It is clear however that ensuring 90% renewable and low-carbon electricity is still *technically* feasible without any further development of nuclear energy beyond Hinckley Point C, with other renewable and low-carbon technologies expanded to make up supply.

Fossil-fuel electricity generation will be close to eliminated by 2030. Coal and oil will be aim to be completely phased out by 2022 at the latest. By 2030 some gas-fired fossil fuel generation will still be required for meeting peak demand – likely from a mix of existing and new plants. However the overall use of gas to generate electricity will be reduced by 71%.

This generation mix is entirely manageable with a more integrated and flexible system. Only 69% of the proposed annual power generation comes from generators classed as intermittent. This will require a UK energy system that transmits, uses and stores energy in a substantially more sophisticated manner than today. Chapter 5 demonstrates how this can be done.

CHAPTER EVIDENCE

- National Grid Future Energy Scenarios 2018
- Committee on Climate Change
- RenewableUK
- European Wind Energy Association
- Met Office, UK
- BEIS, UK
- Ofgem
- International Energy Agency
- Digest of UK Energy Statistics
- World Nuclear Association

CHAPTER CONTENT

- Background: Renewable energy generation today
- Approach for renewable and low-carbon electricity analysis
- Summary of renewable and low-carbon electricity mix in 2030
- Onshore wind
- Offshore Wind
- Solar photovoltaics
- Marine power
- Carbon capture and storage
- Hydropower
- Biomass power
- Nuclear power
- Deep geothermal
- Decentralised electricity and community electricity generation
- Summary of Recommendations

4.2 Background: Renewable energy generation today

Today renewable and low-carbon sources account for 46% of electricity generation, or 141TWh, with solar and wind generating 79TWh or 25% of total generation, according to the National Grid. Figure 21 shows the 2018 mix of generation technologies by capacity (GW), as reported by the National Grid in 2019.

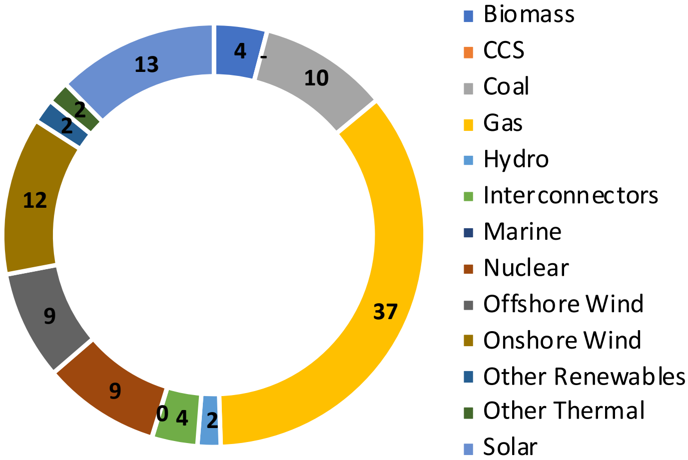


Figure 21. UK electricity generation mix in 2018 (GW).[68]

4.3 Approach for renewable and low-carbon electricity analysis

The maximum feasible level of renewable and low carbon electricity supply. When considering the maximum feasible level of renewable and low carbon supply, most of the leading research indicates a range of 75% - 90% as the upper limit for renewable and low carbon electricity contribution to overall supply. This is because the system will still require some form of modulating back up to provide the ability to quickly increase supply when demand increases unexpectedly. Currently gas fired power generation is the only viable option other than biomass, which as explained below, is not considered viable for large scale power generation. Therefore, a 90% has been taken as the maximum contribution of direct electricity from renewable and low-carbon sources by 2030. This is around the technical limit of what is likely to be feasible by 2030, as so is considered the right target.

The project team has considered the following to determine the mix of renewables required for electricity generation to meet 90% by 2030. Our approach is similar to the approach taken for the wider study and outlined above in Section 1.4.

Total electricity demand in 2030. As mentioned above in Sections 2 and 3, direct electricity demand in 2030 is expected to be 265TWh. An extra 117TWh of renewable and low-carbon electricity is needed to supply heat pumps and renewable hydrogen for heating[69], meaning a total of 392TWh of electricity must be supplied. As summarised in Figure 22**Error! Reference source not found.**, there will be 29TWh from transmission and distribution losses and 13TWh of storage losses due to the need to store electricity at times of high demand and low supply. (See Section 5.7 for more detail.) In total, 424TWh must be generated in 2030.

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[68] Graph drawn from data taken directly from National Grid *Future Energy Scenarios* 2019 datasheet: http://fes.nationalgrid.com/media/1432/fes-data-workbook-v30.xlsx

[69] it is important that this renewable and low-carbon component not be double counted, in the sense that the renewable electricity generated for use in a heat pump cannot be counted on its own towards the target, and then the heat provided by the what pump, since this electricity is in fact being used to generate renewable heat.

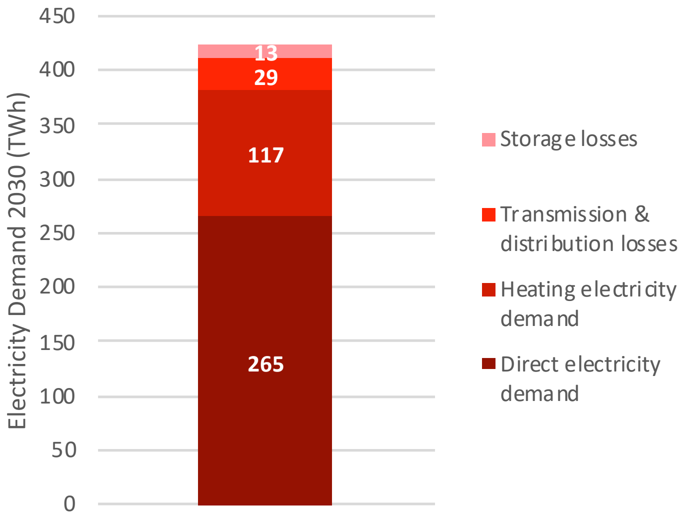

Figure 22. Total need for electricity generation in 2030.

The output that can be achieved for each suitable generation technology, based on the following steps:

- An analysis of today's capacity – determining how much of that capacity will still exist in 2030 and what the necessary extent of re-powering will be (analysing, for instance, the number of existing wind turbines that need replacing after reaching the end of their operational life).
- The extrapolation of historical development patterns into assumptions about development by 2030 – determining a lower bound for what is feasible given historical build rates, which have been moderate and could readily be reproduced and continued until the exhaustion of available resources.
- Research into what the potential capacity is for different technologies – giving an upper bound for what is possible.

The results of various scenarios. We have run various scenarios using the energy balance model within the constraints of the available resource to deliver the necessary capacity, and tested these with experts to assess the most viable and cost effective mix for reaching maximum renewable and low-carbon energy by 2030. Recommendations from the scenarios are based on maximising cost effectiveness, long-term job creation in the UK, minimum disruptive impact, and maximum system stability.

Based on this approach, the following sections provide a summary of the overall picture for 2030, followed by a look at each technology individually, outlining the generation potential and development trajectory for each of the large-scale generation technologies available.

4.4 Summary of renewable and low-carbon electricity mix in 2030

To demonstrate that the necessary expansion in renewable and low-carbon electricity capacity by 2030 is feasible (well over two and a half times today's output), a realistic scenario for 2030 has been developed considering every available technology and its likely output, as constrained by viable deployment rates and available energy resources. There is very high confidence in the type and scale of changes needed from the outset. As outlined below, there are some aspects of this proposed generation mix that require more research and development work to decide the exact contribution by 2030, but even these we can take a fairly estimate of what a suitable level of deployment would be.

In sum, an increase to 137GW in generation capacity, from today's 44GW, will be necessary. Figure 23. Modelled UK electricity generation capacity and output by technology in 2030. [Source: Team's own analysis]outlines the proposed electricity mix in the UK in 2030, accounting for a total of around 375TWh of renewable or zero-carbon electricity and a further 37TWh from natural gas generation. Figure 23. Modelled UK electricity generation capacity and output by technology in 2030. [Source: Team's own analysis]also shows the capacity of each technology in 2030.

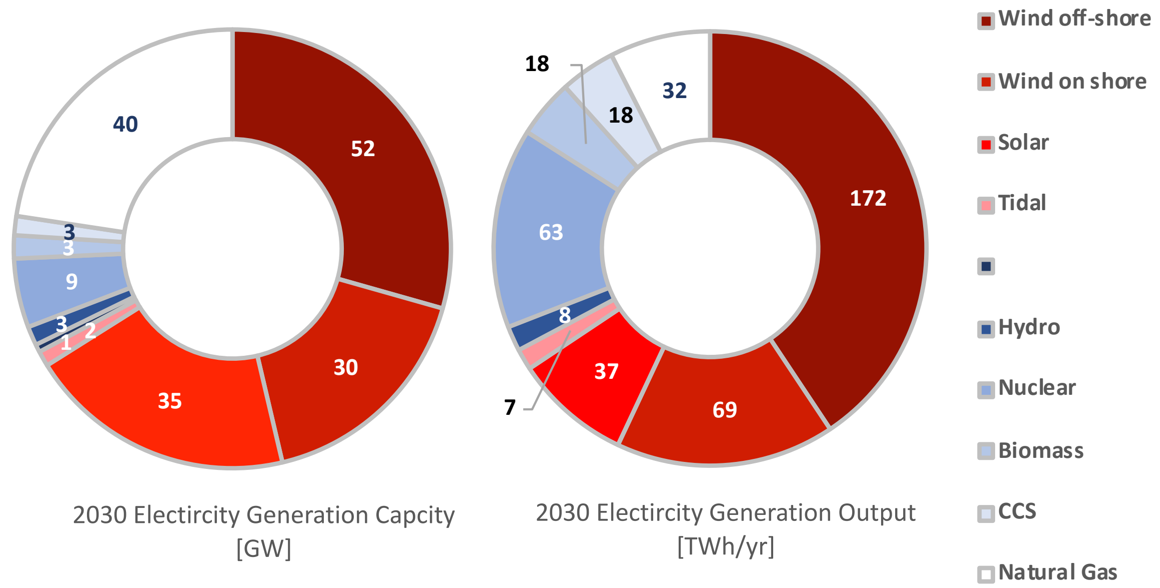

Figure 23. Modelled UK electricity generation capacity and output by technology in 2030. [Source: Team's own analysis]

Wind power is the UK's primary non-fossil fuel natural resource today, as the UK has one of the best wind resources of any industrialised country. Accordingly, in this proposal wind power accounts for more than half of all electricity generated in 2030, at 57%. Offshore wind alone accounts for 41%. This is a significant increase from today's total of 21GW of wind, to around 82GW in total in 2030 when considering both onshore and offshore.

The expansion of offshore wind is the most significant, however, based on the available resource, historical building out rates, this expansion is ambitious but viable. Substantial investment in the UK wind industry in terms of manufacturing capacity and skills will be vital to support this scale up in capacity.

Solar sees an increased role, supplying 9% of the UK's electricity, as does tidal energy. Biomass, nuclear and hydro see a similar level of output as today, and hence a reduced proportional contribution to electricity given the increased net demand. CCS also sees its contribution starting to emerge.

Other major differences between today and 2030 involve the use of fossil fuels. Coal is completely removed from the mix. Natural gas is maintained at its current capacity. However, the gas-plant output drops from 130TWh today to 32TWh in 2030, a 75% reduction, while the capacity remains the same to be able to manage intermittency.

Interconnectors have not been modelled directly as part of this 2030 analysis. Further modelling of a range of interconnector and low-carbon energy mix scenarios is needed. However it is extremely likely that they will be an important part of the UK energy solution, as outlined in Section 5.5.2.

The following sections outline one by one the expected deployment of each generation technology in 2030.

Finally, as outlined elsewhere, given 2030 is still over a decade away, this is not a fixed and rigid set of sub-targets to be held to for ten years. Rather a demonstration of what level of renewable and low-carbon energy is viable, and a best estimate today of the most appropriate balance of generation technologies to ensure it is delivered. While working with exact numbers is important to determine feasibility, any sound strategy allows for shifts in future implementations. In that respect, we suggest that it is the general thrust of the approach that is most important. Technology developments in the meantime may well mean that the final energy mix is marginally different in one way or another.

Recommendation 18: **Set a target of at least 90% of direct (non-transport) electricity demand being met from renewable and low-carbon sources by 2030**, almost a tripling in output compared to 2019 levels of generation.

4.5 Fossil fuel power generation

As will be explored in more detail in Section 5, to ensure stable supply of electricity at all times of the year, the need for some fossil fuel power generation will remain out to 2030. This study currently assumes around 40GW of energy from gas-fired plants, likely a mix of open-cycle gas turbine plants and combined-cycle gas turbine plants, based on research outlined in Section 5. The exact figure will need to be determined going forward, as it may vary depending on various factors. The strategy assumes all oil- and coal-fired power generation is completely discontinued sometime before 2030. As outlined above, only 37TWh of operation would be expected, a huge drop from today's 130TWh, representing a 72% reduction in the use of natural gas for power generation.

Because fossil fuel use for heating and electricity will have dropped significantly so will, the UK dependency on fossil fuels and the associated energy risk will have dropped as well. This means the rationale for fracking in the UK has evaporated. It is high energy, highly disruptive, and, in light of reduced fossil fuel dependence, entirely unnecessary.

See Section 4.10 below for a discussion of use of fossil fuels with carbon capture and storage technology.

Recommendation 19: **Rapidly phase out fossil-fuel extraction and use for electricity generation.** Immediately end new coal extraction and phase out coal electricity generation as soon as possible; immediately end fracking for gas; end electricity generation from oil anywhere in the UK by 2022; and reduce the annual operation of gas-fired electricity generation from 130TWh today to 32TWh in 2030 – a 75% reduction. The only form of fossil fuel use permitted, whether for power generation or production of hydrogen, should be that coupled with 100% carbon capture and storage, meaning no GHG's are emitted to the atmosphere at any point (See Recommendation 24)

4.6 Onshore wind

Understanding the technology, background, current deployment and capacity for onshore wind is critical to understanding the report's recommendations.

4.6.1 Technology

Modern wind turbines rely on the movement of air to drive rotor blades, which drive a shaft, which in turn a gear box, which translates the relatively slow motion of the blades into a faster rotating generator creating electricity. The first commercial wind farm in the UK was built in Delabole, Cornwall in 1991.[70] This wind farm had a total capacity of 4MW with a rotor diameter of 31m. Since then the UK has seen a slow rise in the number of wind farms throughout the country, with the capacity of a single onshore turbine increasing from 0.4MW to 3.4MW.

[70] For more information on the UK's first wind farm, see http://www.delabole.com/windfarm.html.

Taller wind turbines benefit from higher wind speeds as they are further from the ground, decreasing the impacts of surface friction. It also allows the use of larger blades, which increase the power generated. Although larger blades require turbines to have larger foundations, they can significantly reduce the number of turbines needed, decreasing the required infrastructure that comes with them.

The UK is an island surrounded by windy oceans, this has resulted in the largest combined onshore and offshore available wind resources in Europe.[71] Wind power is developing significantly in the rest of Europe as well, making it the centre of the world's wind industry. There are a number of benefits of wind power beyond the fact that is does not produce GHG emissions, as well as some drawbacks.

Benefits:	**Drawbacks:**
• Increases the UK's energy security, as it is an indigenous resource • Wind reserves will never run out • Turbines are low cost once constructed as there are no fuel costs • Wind has a very low footprint compared to other technologies, with minimal disturbance of ground wildlife • Creates thousands of skilled jobs	• Wind is intermittent and difficult to predict over the long term (but very predictable over the course of a day) • Suffers from NIMBY (Not in My Back Yard) as turbines can be aesthetically displeasing for some people • Can have a minor impact on wildlife such as birds and, if inappropriately sited, will disturb marine habitats

4.6.2 Deployment today

The current UK capacity of onshore wind is 12.1GW.[72] Historically it has been more prominent than offshore wind due to the ease of installation. The UK saw steady growth in onshore up until 2015, when the acting government removed financial support through subsidies and implemented new planning conditions that amount to a near ban, making it incredibly difficult for projects to receive planning consent. The result is that planning applications have dropped by 94% since 2015.[73] 2017 saw an onshore capacity of 2.6GW installed, breaking the UK record. This was the result of a rush to get projects consent granted before these polices came into effect. Since 2015 there has been minimal progression in new projects, which has had a huge impact for onshore wind in the UK, effectively stalling the industry. In the next several years the number of developments coming online will continue to remain very low due to current government policy, as seen in Figure 24, which will be during the first years of the 2020s.

4.6.3 Delivery by 2030

Potential deployment based on historical build rate. Between 2013 and 2016 the UK's onshore wind capacity rose from 7.6GW to 10.9GW. If onshore wind rollout were to continue at this rate, the total capacity would be 25.6GW by 2030.

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[71] *Europe's onshore and offshore wind energy potential*, European Environment Agency, Technical report No 6/2009, 2009.

[72] https://www.renewableuk.com/page/UKWEDhome

[73] https://1010uk.org/articles/investigation-has-the-governments-onshore-wind-ban-worked

Available resource. Table 14shows UK onshore wind maximum capacities as estimated in the reviewed literature. The 2018 *Future Energy Scenarios* (FES) report produced by the National Grid estimates 23.4GW in its greenest scenario.

Table 14. Literature 2030 wind power generation predictions.

Reference	Poyry 2011 – Max scenario	Poyry 2011 – Very high 2030	WEA 2030 – High Scenario[74]	FES 2018 Community Renewables 2030[75]
Potential Capacity (GW)	33	21	20	23.4

Table 15 shows a number of predicted energy scenarios by 2030 from CCC. All these scenarios achieve an emissions intensity under 110 gCO_2/kWh by 2030. This emissions intensity is of particular importance, as it indicates weather or not the UK is on track to reaching the legally binding Fifth Carbon Budget.[76] See Chapter 7 for more information on emissions.

Table 15. CCC annual progress energy scenarios.

Scenario	Central Renewables	Central CCS	Central Nuclear	High Low-Carbon	High Renewables
Potential Capacity GW (TWh)	25 (60)	24 (56)	22 (53)	26 (62)	29 (70)

Targeted 2030 wind build out. The trajectory we set out in this strategy delivers just over 30GW by **2030**. This is considered feasible for a number of reasons. The increase in delivery rates is relativity small compared to before the 2015 policies were introduced. Since then turbine technology has improved and costs are continuing to reduce. These targets are in line with the multiple scenarios outlined by the CCC in Table 15. Figure 24 shows the preferred trajectory for onshore wind up to 2030 based on historical build-out rates. By the early 2020s the first new developments reach completion after a project completion flatline. Growth will continue at a rate of 1.7GW per year throughout the 2020s, reaching a total capacity of 30GW. This net annual increase is a 40% uplift on the average historical deployment rate from 2013 to 2017.

[74] *Wind energy scenarios for 2030*, European Wind Energy Association, August 2015.
[75] *Future Energy Scenarios*, National Grid, 2018.
[76] *Reducing UK Emissions*, 2018 Progress Report to Parliament, Committee on Climate Change, June 2018.

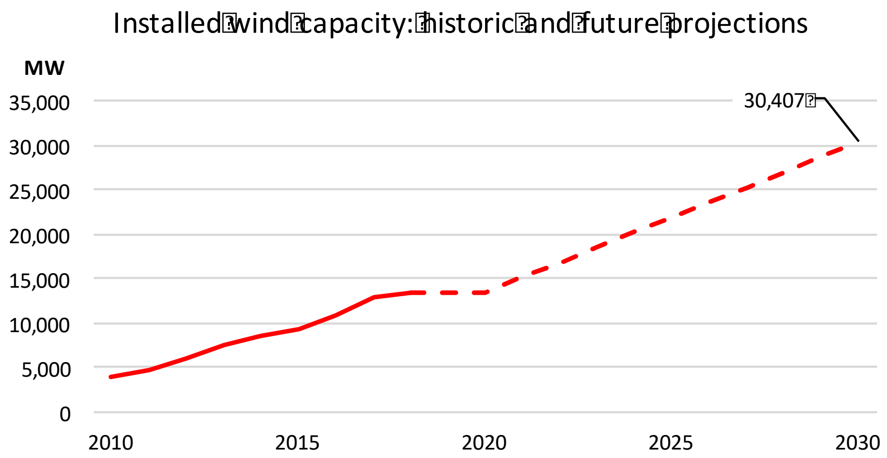

Figure 24. Onshore wind capacity projections.

There are 7,104 wind turbines currently in operation across 1,564 projects, with an average capacity for each wind turbine at 1.7MW. Modern turbines have much higher capacities, with the world's largest onshore turbine achieving 4.8MW. Using an average value of 3MW for today's turbines, 4,500 new turbines would be needed to reach the 30GW target (around a third less than already exist today, so would need less than double the current number overall). Figure 25 shows the distribution of wind farms as of 2016. Most of the UK's onshore wind resource is located in Scotland, Northern Ireland and Wales, with 60% of the total located in Scotland.[77] Wind turbines have an average life span of 20 years, this means by 2030 4GW of onshore wind will need replacing or decommissioning.[78]

[77] http://www.lse.ac.uk/GranthamInstitute/faqs/where-are-onshore-wind-farms-located-in-the-uk-and-where-are-the-proposed-future-sites/

[78] Lisa Ziegler, Elena Gonzalez, Tim Rubert, Ursula Smolka, and Julio Melero, 'Lifetime extension of onshore wind turbines: A review covering Germany, Spain, Denmark, and the UK', *Renewable and Sustainable Energy Reviews*, 82 (Part 1). 1261–1271. ISSN 1364-0321, 2018, http://dx.doi.org/10.1016/j.rser.2017.09.100.

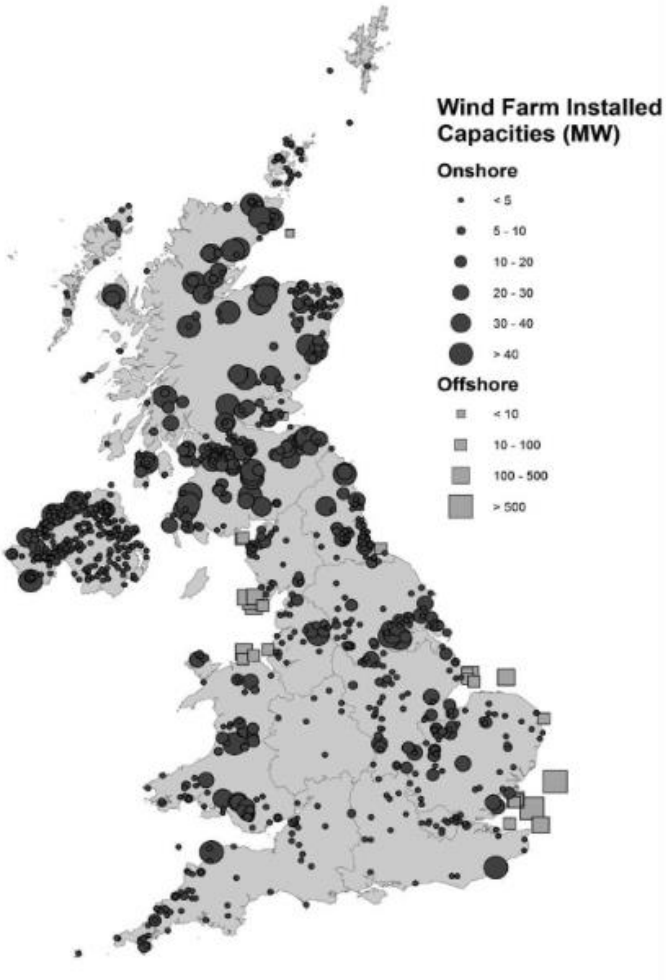

Figure 25. Map showing locations of UK windfarms as of 2016.[79]

4.6.4 First steps for onshore wind

During the first years in parliament it will be important to 'unlock' the onshore wind industry as quick as possible. Current policy barriers preventing the development of onshore wind should be removed as a priority prevent delays in development. Projects that have been side-lined can then be reinstated and sent through the planning process again. It will take several years before any new projects come online due to this policy gap.

Reactivating stalled projects. The removal of the planning barriers is also important to prevent older wind farms reaching the end of their terms going offline. A study has shown that renewing these projects will likely be cheaper than building new wind farms and will add a net 1.3GW.[80] They will also likely be implemented quicker as the planning process will not take as long.

Priority areas for onshore wind development. Figure 26 shows where the highest windspeeds are achieved in the UK, which correlates with the locations of wind farms shown in Figure 25. This visual aid allows us to see where in the UK is best suited to develop future onshore wind farms. It should be noted

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[79] http://www.lse.ac.uk/GranthamInstitute/faqs/where-are-onshore-wind-farms-located-in-the-uk-and-where-are-the-proposed-future-sites/

[80] *Repower to the People*, Energy and Climate Intelligence Unit, 2018.

that a there are many factors in addition to wind speed that determine the suitability of wind farm locations, including land and building obstruction, public exposure and existing transmission and distribution infrastructure.

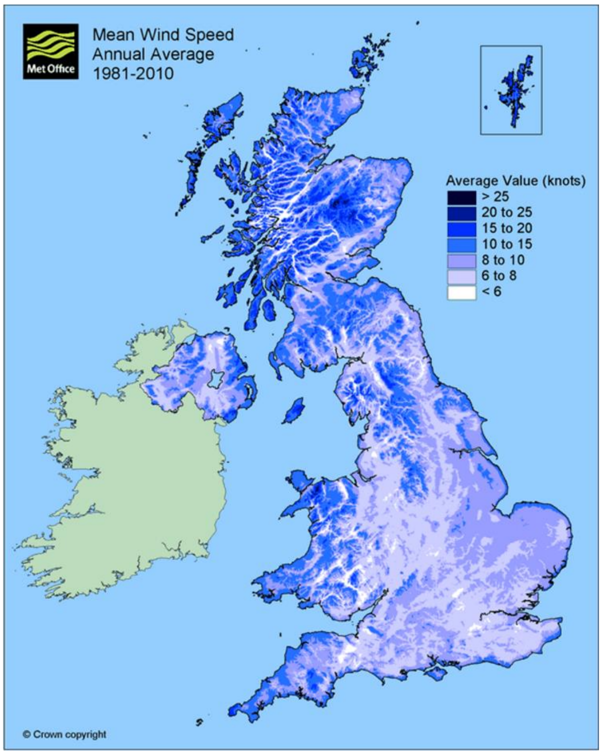

Figure 26. UK average wind speeds. [81]

By the end of 2022 it is estimated that a further 2.4GW of onshore wind should be installed to guarantee meeting the 90% target by 2030. There will also be a substantial number of projects in development with planning permission to ensure the continued rollout after the early 2020s, and then expand at a rage of 1.7GW per year until 2030.

Recommendation 20: **Two and a half times today's onshore wind capacity by 2030**, or 30 GW. Ensuring that together onshore and offshore wind would provide 55% of electricity generated in the UK.

4.7 Offshore Wind

This section sets out an ambitious plan to very significantly expand the offshore wind capacity of the UK to become the main electricity source by 2030. This large-scale expansion is possible due to offshore wind's dropping costs, low impact, availability as a resource, and high level of public support, as well as constraints on the scale of other technologies.

4.7.1 Background

Offshore wind benefits from higher and more consistent wind speeds compared to onshore wind. It also does not suffer from 'not-in-my-back-yard' issues as long as the turbines are not too close to the shoreline. Offshore wind farms can also be located near densely populated coastal areas.

[81] https://www.metoffice.gov.uk/learning/wind/windiest-place-in-uk

A number of other low-carbon and renewable energy sectors such as onshore wind, CCS and marine energy have seen considerable project and initiative setbacks from the acting government. These setbacks have caused investors and industry to lose confidence in government decisions and have impacted supply chains, manufacturing and technological developments in the UK. The offshore wind industry, on the other hand, is in a healthy position with investors confident in the technology. This has resulted in a more grounded platform for Labour to increase investment, helping to create more secure and efficient supply chains pushing the technology forward to maximum renewable and low-carbon energy by 2030.

Technology. The increased size of wind turbines is helping to drive down the Levelized Cost of Energy (LCOE) and increase efficiency, harvesting more wind more cost effectively.[82] This is because larger turbines reduce the overall number of turbines required to produce the same output, which results in less maintenance, manufacturing, power cables and connections. Turbine technology is developing faster than expected. The world's largest wind turbine, the Haliade-X, will be capable of delivering 12MW and is set to be deployed in 2021. This turbine achieves a capacity factor (see Appendix E for definition) of 63%, which is nearly double the average value used in this paper's modelling. The higher capacity factor and larger blades of the Haliade-X means that this turbine can produce around 45% more energy than today's largest turbines.[83]

Recent breakthroughs in floating wind farm technology are also significantly increasing the potential capacity of offshore wind. The world's first floating wind farm, the 30MW Hywind project in Scotland, has been performing better than anticipated, reaching a capacity factor of 65% compared to the typical seabed fixed range of 40-60%.[84] Floating foundations can operate in sea depths far greater than grounded methods that are limited to a water depth of 60 metres, increasing the available sea area and flexibility in location. Wind farms can be located in areas with stronger and more consistent winds, avoiding sensitive areas and reducing variability issues. Flexibly allows wind farms to be located nearer to load centres, reducing the length of power line needed and simplifying infrastructure and logistics.

Plummeting costs of off-shore wind. The government had originally set a price target for UK offshore wind at £85/MWh by the year 2026. But Contract for Difference (CfD) auctions in 2018 have revealed the LCOE has dropped as low as £57.50/MWhr for the Hornsea 2 and Moray windfarms. For reference, the new Hinkley point C nuclear power station has a guaranteed CfD of £92.50/MWh. Both projects are set to be completed by 2023, which sets a promising precedent for other projects developed throughout the 2020s. Figure 27 shows the extent to which LCOE has reduced relative to expectations, and based on the Hornsea 2 and Moray scheme, could represent a 60% drop in costs by 2022 from 2015 (note that it remains to be seen whether this low price is representative across the sector).

Offshore wind is therefore highly cost competitive with other generation technologies, and will likely become even more so. This cost effectiveness is a core contributor to confidence that the UK can significantly expand its offshore wind capacity.

[82] The average cost of generating energy using technology per unit of energy generated.
[83] https://cleantechnica.com/2018/03/02/ge-announces-worlds-powerful-offshore-wind-turbine-haliade-x/
[84] Wind energy scenarios for 2030, European Wind Energy Association [2015]

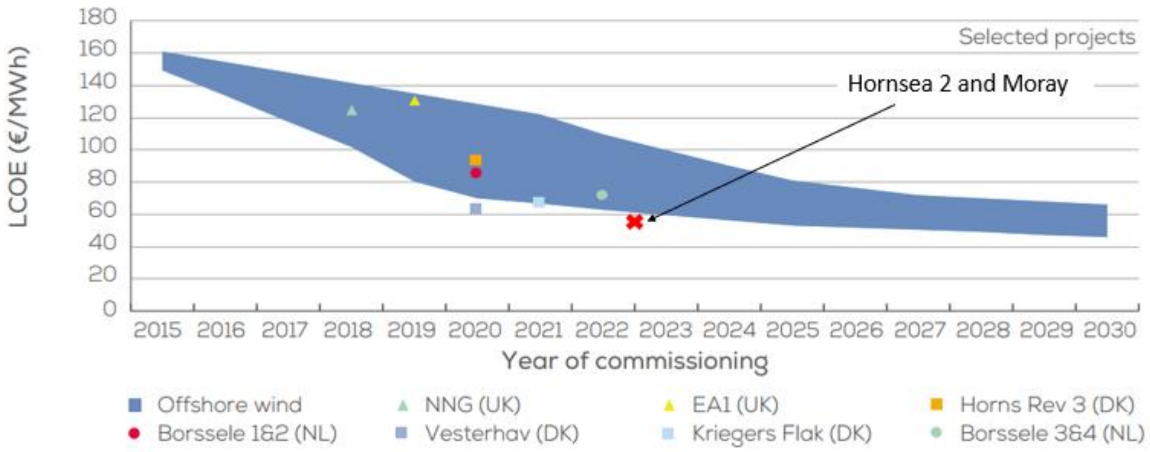

Figure 27. Offshore wind LCOE trajectory from 2015 to 2030. [85]

Deployment today. In the UK, offshore wind currently has a lower overall capacity than onshore wind, however it has a much larger potential. The installed capacity at the time of writing is 8.5GW. The reason for the lack of development historically is due to the cost and difficulty of installing the turbines out at sea. This has changed over recent years with the cost of offshore reducing dramatically below what has been predicted. (Figure 32 shows the location of existing offshore windfarms in various stages of development and those fully commissioned.)

4.7.2 Deployment by 2030

Potential deployment based on historical build rate. The installed wind capacity from 2010 to the present day has grown steadily from 1.3GW to 7.1GW as taken from Figure 28. If development were to proceed on this trajectory, only an additional 9MW would be installed by 2030. The combined capacity of projects under construction and those that have consent granted is already 13.6GW. This additional capacity will bring the total number to 20.7GW by 2030 if all of these projects are followed through to commissioning. Offshore wind has not received the same policy barriers that other renewables in the UK have, meaning that projects are under construction and there is substantial infrastructure and a growing supply chain in place for delivering projects.

Already planned and proposed off-shore wind farm capacity

According to the National Grid Future Energy Scenarios, although only 8.5GW is currently installed, the off shore wind farm sites currently being developed or considered for development reach up to around 40GW. As outlined in Figure 28 below, this made up of 8.3GW built, 1.5GW under construction, 4.2GW with CfD's allocated, 5.4GW with consents approved, 5.6 awaiting consent, and those in scoping or early development more than 20GW. This demonstrates at around a 40GW capacity already considered of interest to wind farm developers. This would therefore represent an absolute lower bound on potential capacity for 2030.

[85] *Europe's onshore and offshore wind energy potential*, BVG Associates, WindEurope, Geospatal Enterprises, 2009, https://windeurope.org/wp-content/uploads/files/about-wind/reports/Unleashing-Europes-offshore-wind-potential.pdf.

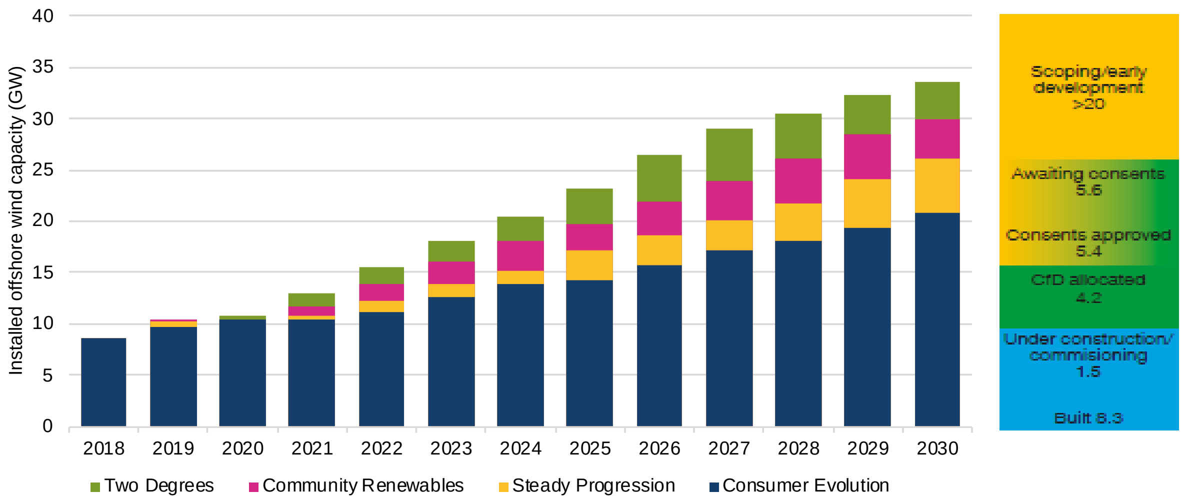

Figure 28 Offshore wind capacity current under construction, planned or proposed (Source: FES 2019)[86]

Available resource. The UK has the largest offshore wind resource in Europe with a potential annual generation estimated at 1,100TWh/yr by 2030, and reaching higher than 2,500TWh/yr if technical, political and economic factors allow, as shown in Figure 29. This generation far outweighs any of the European counterparts. UK has a unique opportunity to become the world leader in the technology.

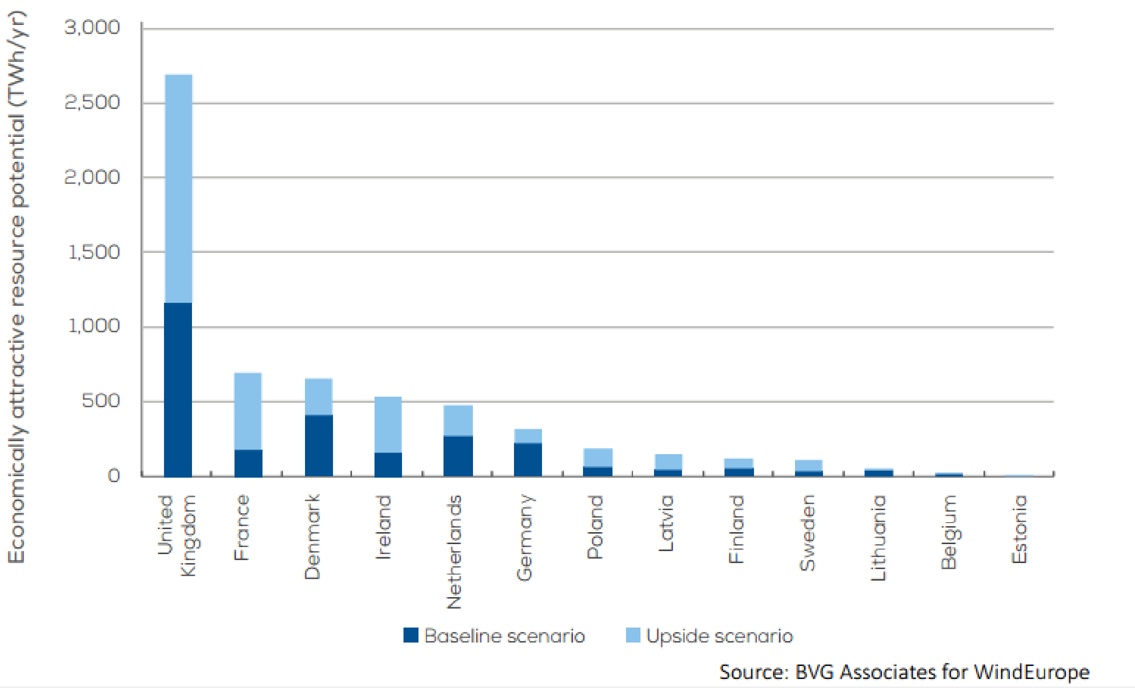

Figure 29. Potential offshore wind generation capability by 2030.[87]

From literature described in Table 16, a number of studies view 30GW as a common target for 2030. The CCC have outlined that the carbon intensity of each unit of energy needs to be 110 gCO_2/kWh by 2030, to ensure that the fifth legally binding carbon budget is on track to be met. In the report produced they

[86] http://fes.nationalgrid.com/fes-document/
[87] BVG Associates for WindEurope

outlined a number of energy scenarios, each of them achieving a carbon intensity of 110 gCO_2/kWh by 2030. Offshore wind capacity varied from 28GW to 34GW in these scenarios.

Table 16. Literature 2030 power generation predictions.

Reference	Poyry 2011 – Max scenario	Poyry 2011 – Very high 2030	FES 2018 Two Degrees 2030	Wind energy scenarios for 2030 – High Scenario	UK OWIC Government deal 2030	Wind Europe 'Unleashing…' 2030	CCC Zero Carbon UK, Further Action Scenario[88]
Potential Capacity (GW)	156	47	29.9	35	30	29	75

4.7.3 Targeted 2030 buildout

For the reasons set out above, there is a substantial case for significantly expanding the capacity of offshore wind. A very important driver for expanding off-shore wind is the constraints on the scale of other technologies. These constraints, as outlined in the other aspects of this chapter, have been instrumental in setting the scale of offshore wind. The energy balance model (described in Section 1.4.2.2) used in this study to calculate how the 90% target can be met, has been used to estimate the necessary deployment of offshore wind based on the expected UK electricity demand between now and 2030 and the availability of other electricity sources.

Based on this approach, around 52GW of offshore will be needed in 2030 to achieve the 90% target. Assuming a capacity factor of 38%, which is common with today's large turbines off-shore, this would represent 156TWh of renewable electricity in 2030, or 38% of the total needed.

4.7.4 Delivering targeted build out

Since off-shore wind is the largest contributor in 2030 and sees the largest growth in capacity between now and then, it is important to demonstrate that this capacity can be achieved. To do so, we explain the rollout in two approximate phases (in reality, though, we will see a much smoother, more continuous increase in the development), explained below and shown in Figure 30.

Phase 1. Delivery of the currently consented 13.6GW of offshore wind, completed in the first five 5 years, putting offshore wind capacity at 23.8GW by 2024 and calling for an average installation of 2.7GW/yr out to 2024. During this time, UK capacity and skills will be significantly expanded in a huge upward growth of the wind industry, which will allow the sector to increase its output beginning in the mid 2020s. The cost of wind is falling and with increased investment it will continue to fall as supply chain, project management, and operations and maintenance strategies become more developed, technology evolves, and efficiency increases. The industry ramp-up will also create a large number of jobs throughout the UK.

Phase 2. From 2025 the rate of deployment will need to increase to 4.7GW per year to ensure 52GW is installed by 2030. While ambitious, this goal is entirely feasible as long as the industry has had clear and steady signals and support from government in the years leading up to the mid 2020s.

[88] https://www.theccc.org.uk/publication/net-zero-technical-report/

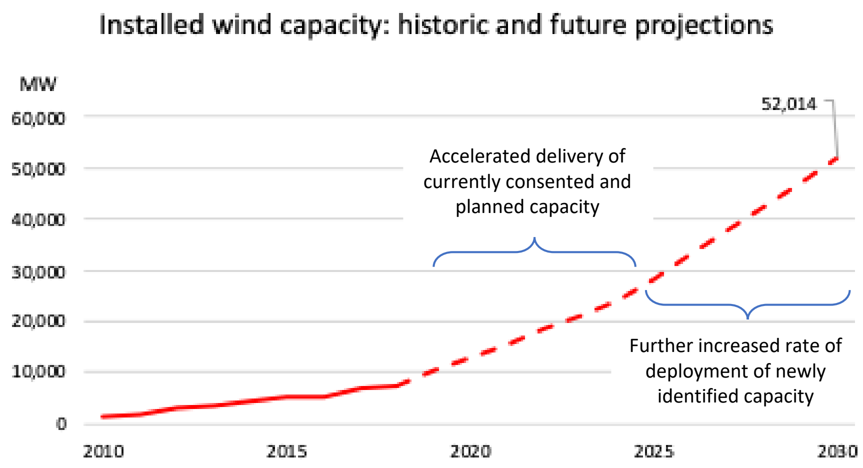

Figure 30. Offshore wind capacity projection. [Source: Team's own analysis.]

The proposed target is very ambitious, and higher than some modelled by previous studies, but lower than others. If technological, economic and grid-balancing constraints permitted, the UK would have enough wind energy to supply the whole of the UK and excess to export. Offshore wind gives the UK a unique opportunity to become an energy exporter as well as producer. As turbines become larger and capacity factors (see glossary for explanation) continue to rise, the regularity of wind output will increase.

Aurora Energy conducted study scenarios in which 40GW capacity was reached in the UK by 2030s.[89] This same research implies that to reach higher levels of installed capacity the further incentives may need to be offered to support greater levels of rollout.[90]

There are various examples of research considering scenarios beyond 2030 showing higher offshore wind capacities, demonstrating technical potential, even if it will require an accelerated trajectory to delivery by 2030. For instance, the British Pugwash report *Pathways to 2050*: *Three possible UK energy strategies*, includes 76GW of offshore wind by 2050.[91]

In particular recent analysis by the Committee on Climate Change, and separately by the National Grid, both on what it will take to deliver net-zero carbon UK. The recent CCC report on reaching net zero carbon in the UK highlights the deployment of 75GW in its 'Further action' scenario, giving further confidence the 47GW outlined in this study is technically achievable.[92]

It is a clear recommendation of this study that further research is undertaken to determine how best UK offshore wind capacity can be urgently and significantly expanded in line with this strategy, and indeed whether capacity could be expanded even further.

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[89] *The new economics of offshore wind*, Aurora Energy Research, January 2018, https://www.auroraer.com/wp-content/uploads/2018/01/The-new-economics-of-offshore-wind.-Aurora-Energy-Research-Report..pdf

[90] Exame options include provision of zero subsidy CfDs are vital as well as allowing for revenue stacking
[91] *Pathways to 2050: Three Possible UK Strategies*, British Pugwash, 2013, https://britishpugwash.org/wp/wp-content/uploads/2013/02/British-Pugwash-Pathways-to-2050-small.pdf
[92] https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Finally, public support for offshore wind continues to stay high with 79% of the public saying they are in favour. This shows a clear commitment from the public to invest in offshore wind, which should result in low public resistance to the proposals.[93]

4.7.5 First steps for offshore wind

Priority areas for wind development. Figure 31 shows the economically viable areas for offshore wind in the UK by 2030. Although it depicts projected availability in 2030, it gives a relative indication of where costs are lower in the present.

By comparing Figure 31 and Figure 32 it can be seen that many of existing wind farms have been developed in these low cost areas. Figure 32 shows that in the North Sea around Scotland there are many large areas which are being investigated for offshore windfarms. This indicates that this area will be a strong focus for the wind industry through the 2020s.

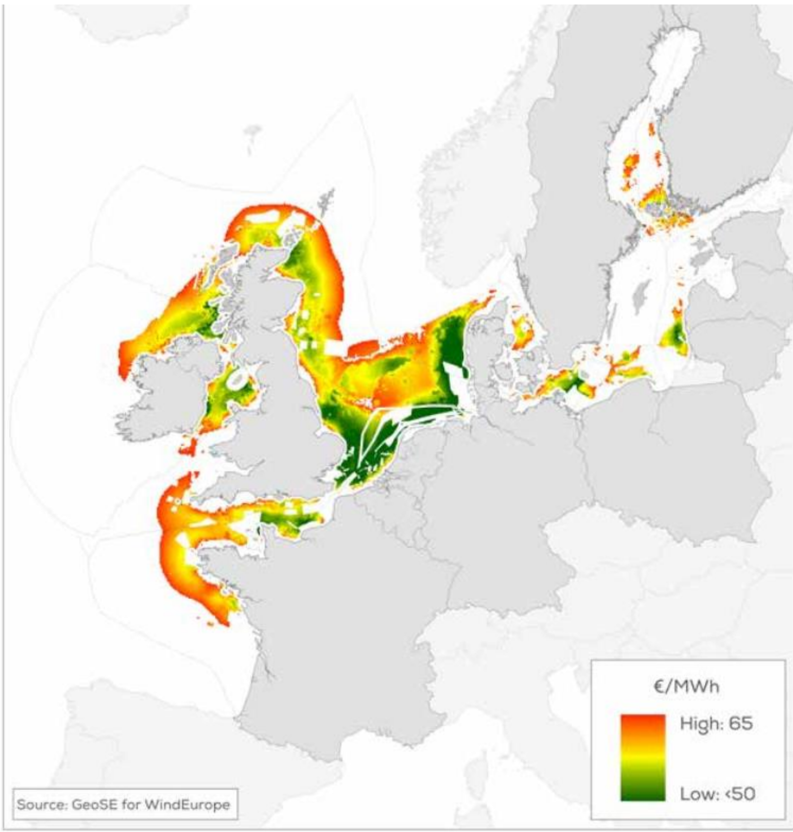

Figure 31. Economically attractive resource potential by end of 2030. [Source: GeoSE for WindEurope.][94]

[93] *BEIS Public Attitudes Tracker,* Department for Business, Energy & Industrial Strategy, September 2018 (Wave 27] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/754515/W27_Summary_Report.pdf

[94] Unleashing *Europe's onshore and offshore wind energy potential*, BVG Associates, WindEurope, Geospatal Enterprises, 2009, https://windeurope.org/wp-content/uploads/files/about-wind/reports/Unleashing-Europes-offshore-wind-potential.pdf

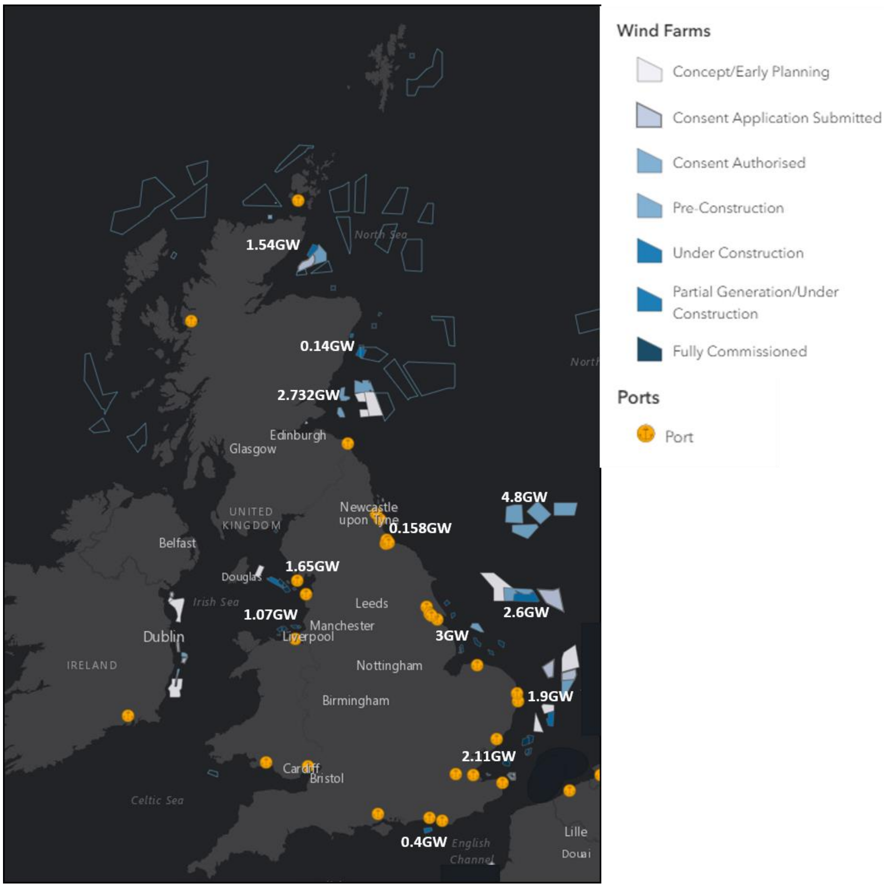

Figure 32. Map showing all offshore wind projects existing and in development. [95]

Investing in new technologies

Floating wind turbines are still a relatively new technology and therefore more expensive. As such, they will require government support and subsidies to hasten progressions in the technology. Initiatives and policies that directly support floating turbines should be instigated. If actions are not taken, then deployment will be delayed, increasing risks of not reaching emissions targets. Such activity represents a significant opportunity for UK jobs and industry as these solutions would have a significant global market. Even though their present cost is high, floating turbines will be helpful in unlocking the full potential of offshore wind in the UK, which in turn will bring long-term cost reductions.

Recommendation 21: **Nearly a seven-fold increase in the offshore wind capacity by 2030**, or 52GW. This would make it the UK's largest source of electricity and be around 7,000 new large-scale turbines (depending on average future turbine size). To maximise the UK's potential, undertake further detailed research to determine the maximum large-scale capacity and ideal distribution of off-shore wind; and the expansion of UK manufacturing capacity and skills.

[95] https://www.4coffshore.com/offshorewind/

4.8 Solar photovoltaics

This section presents an assessment of solar photovoltaic (PV) generation potential in the UK.

4.8.1 Background

Technology. PV is a mature renewable energy technology, which generates electricity from solar cells made of photoconductive material. The PV market is highly competitive with several different types available and ongoing research and development to improve efficiency and reduce costs of manufacture. Currently, the two dominant PV technologies are those based on silicone, representing 95% of global market share[96] (monocrystalline or polycrystalline panels); and thin films that are manufactured using a number of different materials (such as cadmium telluride) characterised by flexible membranes and improved performance in diffuse light.

The PV industry has seen significant cost reductions in manufacture, consistently showing near 24% reduction in the cost of PV modules for each doubling of production since 1980, as shown in Figure 33. These cost reductions can be expected to continue as global production continues to grow rapidly.

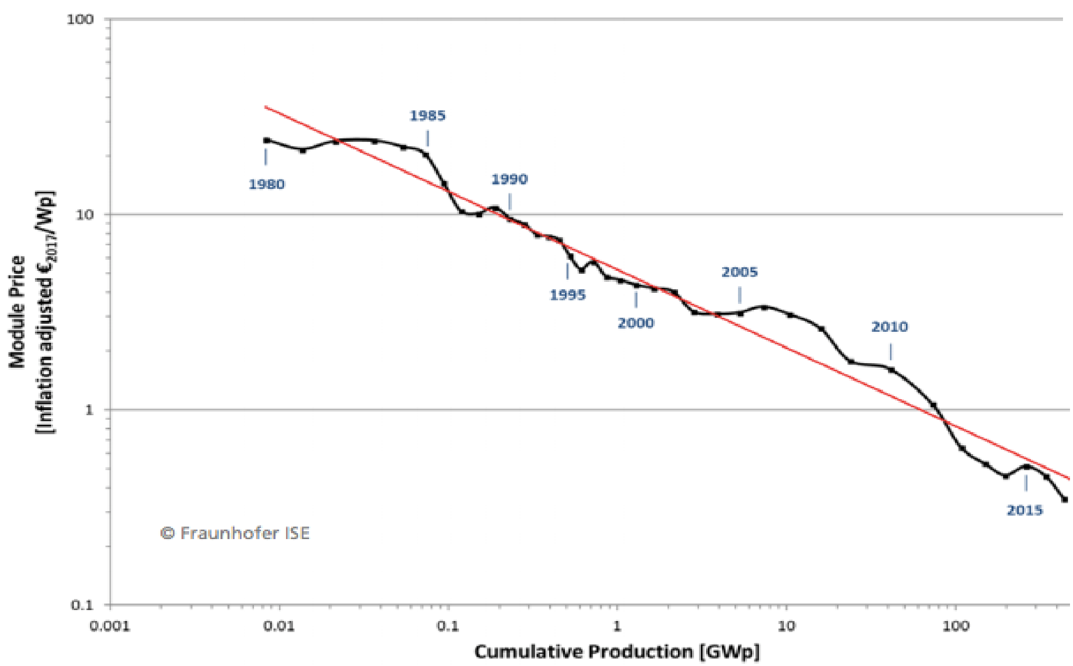

Figure 33. PV module price reduction against cumulative production.

Solar PV panels can be installed on roofs or ground mounted. This technology lends itself to both utility-scale generation (such as PV farms) or distributed generation (e.g. rooftop of a house). At the domestic level, solar PV installations have benefitted from the learning rate shown above with a 4kW household installation dropping from £20,000 in 2010 down to £6,668 in 2017.[97] As Figure 34 indicates, the cost reduction has decreased since 2014.

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[96] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf
[97] https://greenbusinesswatch.co.uk/uk-domestic-solar-panel-costs-and-returns-2010-2017

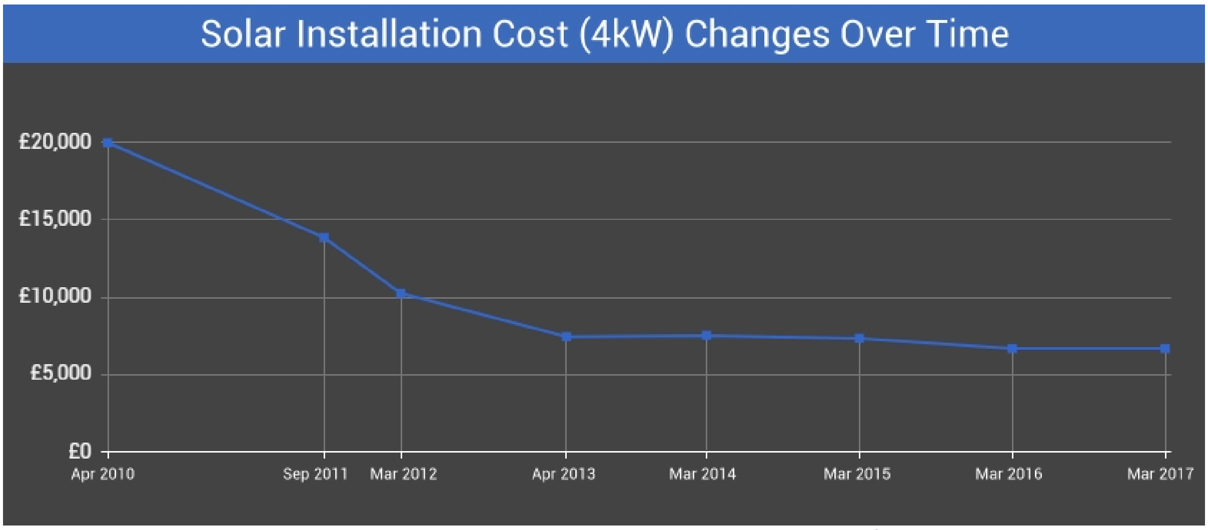

Figure 34. Solar PV installed cost reductions in the UK. [Source: Green Business Watch.[98]]

Current Deployment in UK. Solar PV has been an incredibly successful renewable energy technology in the UK, with generation capacity increasing from just 32MW in 2010 to 12.8GW in 2018, as shown in Figure 35.[99] The growth in solar PV capacity in the UK was driven by a combination of lowering costs of PV panels and provision of UK government subsidies – the Feed in Tariff (FIT) and the Renewables Obligation (RO) schemes.[100]

The highest annual increase in solar capacity was between 2015 and 2016, with new installations reaching 4.3 GW in one year. On average, between 2012 and 2017, 2 GW of additional solar PV capacity was installed per year. 2018 showed a marked decline at just 200 MW following the government's decision to cut subsidies for solar PV generation.[101] The FIT scheme reduced support for solar PV installations from 41.4p/kWh in 2010 to 4p/kWh in 2017 and the government is currently proposing to end the FIT scheme in March 2019[102]. With regard to large-scale installations, the RO was closed down to make way for the CfD scheme, however soon after its launch, auctions for so called 'established technologies' of solar power and onshore wind were halted, despite support being given to nuclear.[103] This stop-start approach to support for solar power eroded predictability and confidence, and has led to a greater reduction in the size of the solar industry and number of solar jobs than would have been the case had there been a managed decrease in support as costs fell, as had been initially intended.

The upsurge in solar capacity was initially driven by small-scale installations, defined as installations below 4 kW, typically installed on rooftops.[104] However, small-scale installations dropped from representing 70% of total installed solar PV capacity in 2011 to 24% by 2016, steadily decreasing down to 20% by 2018, as shown in Figure 35.

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[98] *UK Domestic Solar Panel Costs and Returns: 2010-2017*, Green Business Watch, https://greenbusinesswatch.co.uk/uk-domestic-solar-panel-costs-and-returns-2010-2017.
[99] Based on UK government statistics. 2010 figure is reported capacity in January 2010 while the 2018 figures is the reported capacity as of April 2018.
[100] For more information on FIT, see https://www.ofgem.gov.uk/environmental-programmes/fit. For more information on RO, see https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro.
[101] https://www.theguardian.com/environment/2016/apr/08/solar-installation-in-british-homes-falls-by-three-quarters-after-subsidy-cuts
[102] https://www.gov.uk/government/consultations/feed-in-tariffs-scheme
[103] https://www.pv-magazine.com/2016/11/09/uk-solar-still-being-blocked-in-next-cfd-auction_100026847/

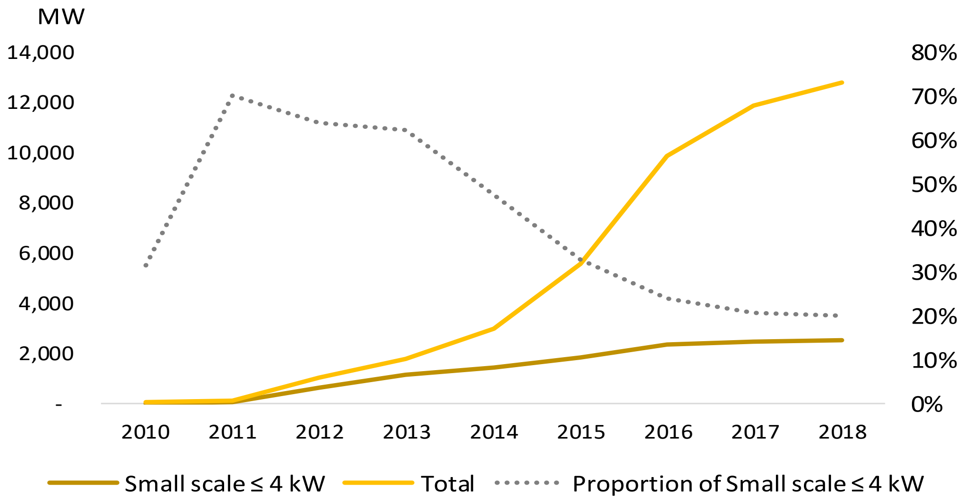

Figure 35. Historic UK cumulative installations of solar PV split by small scale (below 4 kW) and larger. The secondary axis shows the percentage that the household scale solar capacity represented of total capacity. [Source: DUKES[105]]

4.8.2 Delivery by 2030

Available resource. Total solar potential is only limited by the availability of land. Thus, it is in theory possible to generate all of the UK's electricity from solar power. Up to 160 GW of solar power could be installed on south-facing roofs and facades as there is a total 4,000km of available roof and I area on UK buildings.[2] Solar PV installations on these south-facing roofs and facades could generate up to 140 TWh/yr.[106] This estimate assumes an average rooftop solar installation produces 850kWh/kWp per year.[107] It is corroborated by other sources. David Mackay, the late scientific advisor to the Department of Energy and Climate Change), estimated that south-facing roofs alone could generate 111 TWh/yr.[108] The International Energy Agency, also considering just south-facing roofs, estimated 105 TWh/yr. [109]

Targeted 2030 build out. There is significant potential for growth of solar PV capacity in the UK given that solar PV is a cost-effective technology and there is the opportunity to 96prioritize on the availability of roofs. To realise the 90% target, it is proposed the total installed capacity is almost tripled from 13 GW to 35 GW by 2030. This is driven by the necessary capacity required to meet the 90% target rather than the available capacity across the UK, and is based on maintaining the average historic growth rate of 2.2 GW per year, as shown in Figure 36 below, which presents cumulative installations since 2012 and the projected increase to deliver 35 GW by 2030. The UK's additional capacity, however, means that it's possible to expand solar capacities even further in the future, with some research projects showing higher potential than 30GW.

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[105] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[106] UK-PV (2009) 2020 A vision for UK PV
[107] *Design of Feed-in Tariffs for Sub-5MW Electricity in Great Britain*, Element Energy, PÖYRY, Final Report July, 2009.
[108] MacKay, David JC (2009) Sustainable Energy – Without the hot air, UIT, Cambridge
[109] IEA (2002) PVPS Annual Report

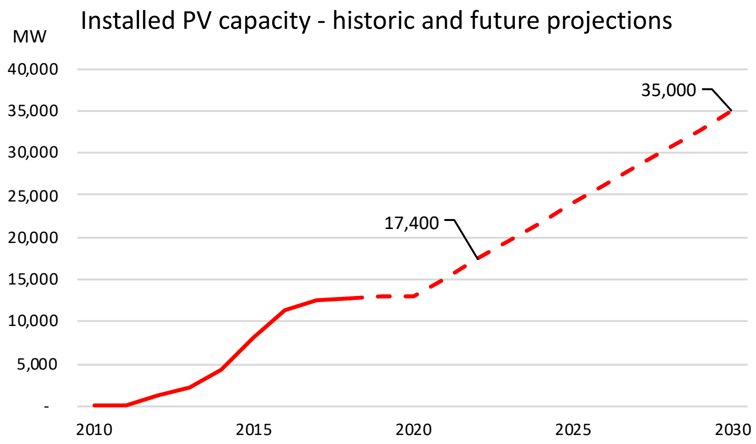

Figure 36. Historic and projected growth of solar PV capacity in UK to deliver 30 GW by 2030 [Source: Team's own analysis.]

Although solar PV capacity can be scaled readily and is limited only by availability of land and rooftops, this report 97recognises that the UK is not the ideal location for solar capacity given that its irradiance, or sunshine level, is lower than that of European countries such as Spain, while its wind resources mean it is better placed to develop wind power.

The report also recognizes that dramatic reductions in subsidies have nearly stalled the PV industry. According to the Solar Trade Association, increasing solar PV installation will continue to rely on financial support. Therefore, the report assumes that even though 2017 represented a seminal moment for the PV industry (as the first PV farm without subsidies was brought online, resulting in 10MW of solar PV and 6MW of energy storage) new installations will be limited over the next couple of years – until government support is revived and the industry 97prioritised.[110]

System scale and distribution. Solar PV is a technology that lends itself particularly well to investment at a small scale, for instance by individual households or energy cooperatives. Figure 35 indicates that the proportion of small-scale schemes of 4kW or less have stabilized at around 15% of total capacity. This would imply that in 2030 around 4.5GW capacity is small scale, translating to around 2.25 million homes with PV on the rooftop assuming an average domestic system size of 2kW. The remaining 25.5GW would come from large-scale PV.

It is recommended that some research be undertaken to determine whether this distribution is ideal, or if there should be a greater preference on building-scale schemes, which for instance have been shown to have greater community benefit by reducing energy bills.

4.8.3 First steps for solar PV

Deployment by the mid 2020s. According to this growth rate, the installed capacity by 2022 should reach approximately 16.5GW. The regional distribution of PV capacity shows greater deployment in the south of the country, corresponding to parts of the UK with higher irradiance, as shown by Figure 37 for large-scale installations. At 622 MW, Wiltshire is the leader of PV capacity by a significant margin, followed by Cornwall, Cambridgeshire, and Devon—all ranging between 480 and 407 MW of total installed large-scale solar PV capacity.

[110] https://oilandenergyinvestor.com/2017/11/the-surprising-secret-behind-the-first-subsidy-free-solar-farm/

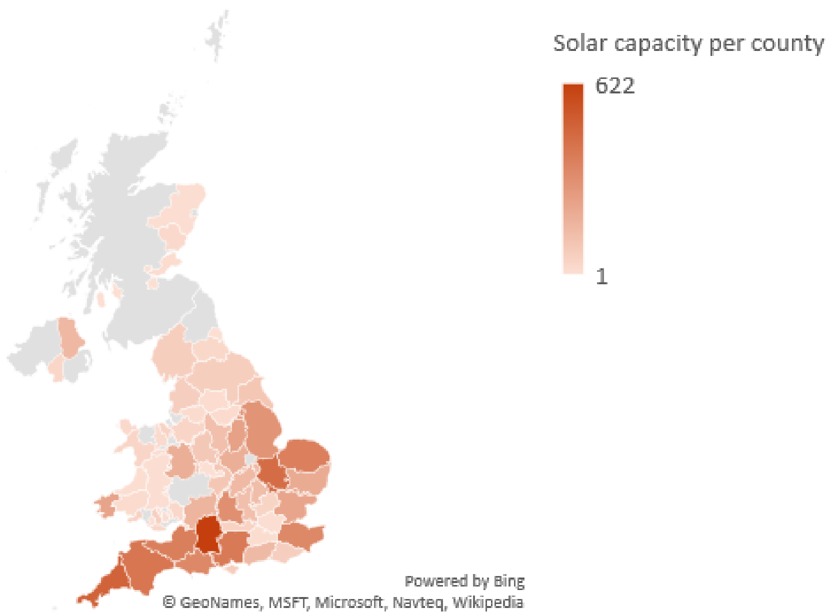

Figure 37. Regional distribution of solar PV capacity in UK based on large-scale installations recorded in BEIS Renewable Energy Planning Database.

Recent research on areas suitable for large-scale installations indicate that it is possible to accommodate up to 13 GW within areas with higher irradiance (southern UK) while excluding national parks, urban regions, woodland, moorland, mountainous areas, flood areas and areas of high-quality agricultural land (grade 1 and 2), as well as grid constraints for solar farms above 50MW. One important factor would be granting permissions for solar installations on land with a slope of up to 18˚.[111] Currently planning permission is more likely to be approved on flat land to reduce visibility of solar farms. However, there are other ways to potentially deal with this issue, such as integration of solar farms into other purposes (such as roofs providing shade, or joint solar farms / pasture land).[112]

Priority areas for development. To deliver this pathway, financial incentives and removal of outstanding barriers to development are needed. For instance, in the context of utility-scale PV installations, a recent report by the Solar Trade Association indicated a number of specific practicable changes a Labour government could introduce to kickstart the industry:

- Revising CfD rules to allow solar PV to participate, for instance through a technology-neutral floor price.
- Reducing barriers to the use of power storage at solar PV facilities –such as prohibitively high cost and/or the inability to connect to distribution networks, a result of the fact that under the current regulatory framework PV plus storage is not 98prioritized as a solution to grid congestion.
- Following the US precedent of corporations contracting directly with renewable energy providers in Power Purchase Agreements (PPAs) for price stability. The solar industry sees this as an interesting market that be unlocked through removal of the Climate Change Levy (CCL) on corporate PPAs. Currently, only direct-wire renewable energy PPAs are exempt from the CCL.

[111] https://www.sciencedirect.com/science/article/pii/S0960148118310590
[112] https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/NSC_-Guid_Agricultural-good-practice-for-SFs_0914.pdf

- Reinstating of the Feed in Tariff, essential for the purposes of supporting residential PV installations and community-scale projects. This change could be rapidly introduced and according to a recent survey would be widely supported by the UK public.[113]

Recommendation 22: **Almost triple solar PV capacity**, to 35GW, including a mix of building integrated small-scale systems and larger solar farms where appropriate.

4.9 Marine power

This section presents an assessment of marine power generation potential in the UK by 2030.

4.9.1 Background

Marine power encompasses a number of technologies that harness the energy of oceans. Typically these technologies target wave energy or tidal energy. Marine power presents an exciting opportunity technically. Based purely on the resources of the UK, marine power – including wave power, tidal stream and tidal range technologies – could deliver between 55 to 80 GW.[114] However, the technologies have lagged behind in becoming commercially viable.

There are many different designs for harnessing wave power. Similar to wind power, wave turbines can be located on the shoreline, nearshore, and offshore. To date, wave power has not demonstrated itself to be a commercially deployable technology, with most projects installed as part of pilot research projects. In the UK, despite £200m in public funding towards wave power, the technology has yet to reach widescale commercialization. According to a report produced by Imperial College and Strathclyde University, ongoing challenges include 'a policy landscape that failed to keep pace, lack of sharing between technology developers and lack of appropriate testing'.[115] Therefore wave energy has not been considered in depth as a large scale 2030 source of energy.

Systems designed to harness tidal energy include **tidal stream** and **tidal range** systems, the latter of which can be either a **barrage** or **lagoon** design. Tidal stream is a technology comparable to wave or wind power systems in that a turbine is used to harness the kinetic energy of moving water as the tide moves in and out. Figure 38 shows an example turbine developed by Atlantis Resources that can be installed at a depth of 30 m and can generate up to 1.5 MW of power.

[113] *A survey of UK attitudes towards climate change and its impacts*, ClientEarth's Climate Snapshot, August 20, 2018. https://www.documents.clientearth.org/library/download-info/clientearths-climate-snapshot/
[114] https://www.gov.uk/guidance/wave-and-tidal-energy-part-of-the-uks-energy-mix
[115] https://www.imperial.ac.uk/news/182832/wave-energy-needs-eu-funds-innovation/

Figure 38. Image of Atlantis Resource' tidal stream turbine[116]

Tidal range systems on the other hand use the tidal range – the height between high and low tide – by holding the water once it has reached maximum height and releasing it to run turbines and generate electricity. Tidal barrages harness this energy by way of a barrage of turbines installed across the mouth of an estuary. Tidal lagoons on the other hand require a manmade structure to create the enclosed area on the coastline to enclose the high tide and allow its gradual release. Figure 39 below illustrates a tidal range system with the sluice gates that previously held the body of water in the tidal basin opened to allow the water to flow out to return to the low tide level.

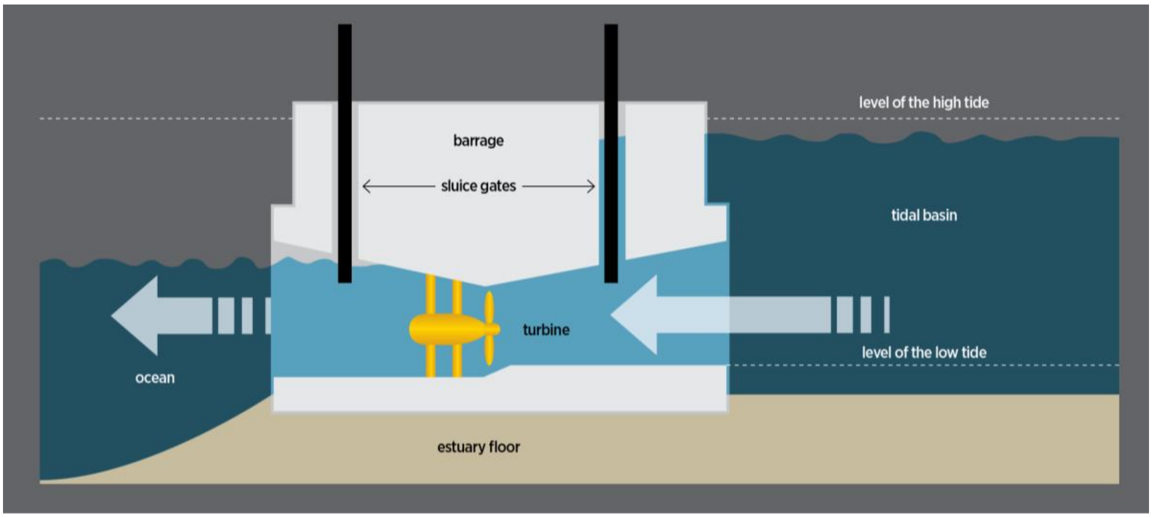

Figure 39. Diagram showing how tidal range systems function.[117]

As indicated above, the UK is recognized for its abundance of resources. For instance, the tidal range in the Severn estuary can reach over 15 m, the second largest in the world.[118] As it stands, the only commercial tidal range project constructed and in operation today is the 240MW La Rance Tidal Power Station tidal power station located on the estuary of the Rance River in Brittany, France.

Deployment today.

Tidal Stream – Current capacity of marine power is estimated at 18 MW, resulting from shoreline wave power pilot projects.[119] This has grown from 4 MW in 2010 to 18 MW by 2018. An important tidal stream

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[116] https://simecatlantis.com/wp/wp-content/uploads/2016/08/AR1500-Brochure-Final-1.pdf
[117] https://www.britannica.com/science/tidal-power
[118] http://www.tidallagoonpower.com/tidal-technology/
[119] 1st Quarter of 2018, DUKES.

commercial project was that led by Atlantis Resources, described as the MeyGen project off the North East coast of Scotland. To date 6MW capacity has been installed at the site with planned capacity to reach over 200 MW based on a phased approach.[120] Atlantis received public funds via the RO and European funding pots to deploy the turbines, however their deployment plan has been put on hold following the rejection of their CfD contract in 2017.[121]

Tidal Range – No tidal range projects have yet been delivered, albeit detailed feasibility studies (including those assessed in the Hendry Review) have demonstrated various highly viable locations around the UK. The most notable are the following:

- **Severn Estuary Barrage**, with an estimated capacity of 17TWh/yr. The development of a tidal barrage across the Severn Estuary has been considered since the early 20th century. In 2010, the government led a two-year to study to assess the feasibility of several options for a tidal range scheme across the Severn Estuary. Based on this study, it rejected all proposals. A few years later, in 2012, the government opted to reconsider, this time reviewing one proposal developed by Hafren Power. However, again, the proposal was rejected on the basis that it failed 'to demonstrate economic, environmental and public acceptability'.[122]
- **The Swansea tidal lagoon** project, with an estimated capacity of 320MW, promoted by Tidal Lagoon Power, was awarded planning permissions. However in early 2018 the Conservative government rejected a proposal to provide a guaranteed strike price (a minimum price agreed to be paid to different renewable generators under the government's CfD scheme) of £89.90 per MWh for 90 years, citing low value for money.[123] This is lower than the £93 per MWh agreed for Hinckley C nuclear station. This was disappointing for Wales, which had touted the project as a means of regeneration and was willing to provide £200m in funding.

4.9.2 Delivery by 2030

Viable assumptions have been made for roll out of both solutions by 2030.

4.9.2.1 Tidal Stream

There had been some question about the financial viability, but costs have come down very significantly. This partly due to being able to piggy back on the off shore wind industry, as well as solutions like multiple turbines sharing the same cable.

Figure 40below indicates the significant drop in cost of energy expected as we move to utility scale deployment. This indicates that indeed tidal stream energy, with the right support, could well become a commercially competitive solution, and so should be supported energetically.

[120] https://simecatlantis.com/projects/meygen/
[121] https://www.4coffshore.com/windfarms/tidal-energy-misses-out-in-latest-cfd-auction-nid6381.html
[122] https://hendryreview.files.wordpress.com/2016/08/hendry-review-final-report-english-version.pdf
[123] https://www.bbc.co.uk/news/uk-wales-south-west-wales-44589083

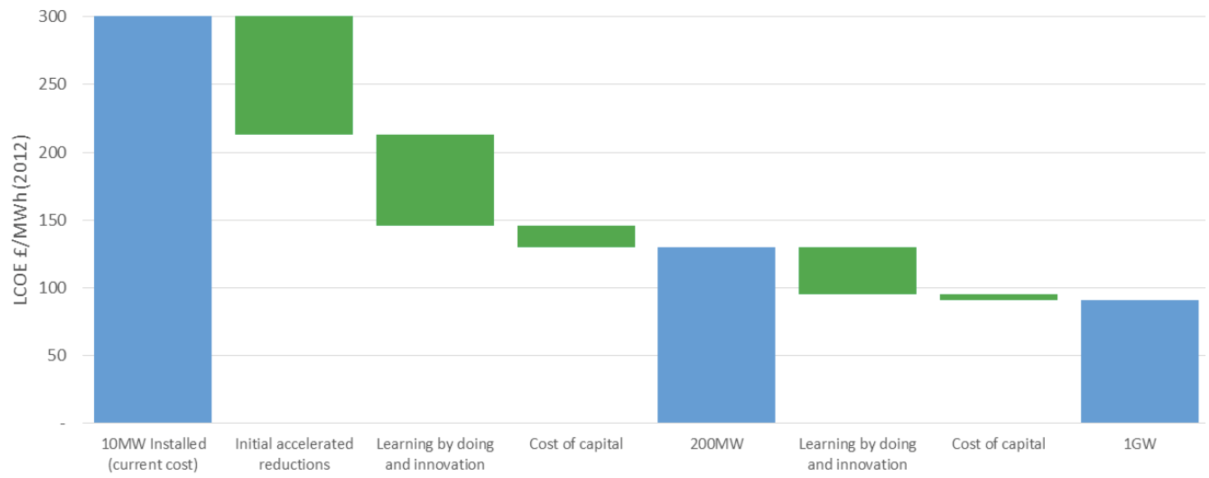

Figure 40 Tidal stream LCOE reduction (Source: Gavin and Smart et al)

This also has the huge benefit if being a "home grown" UK industry. Unlike with off-shore wind and other renewables, where much of the equipment is manufactured aboard, this will be British technology made in Britain. There is also a very significant opportunity for export, as research shows over 100GW of international potential by 2050[124], and 2GW of viable tidal stream potential in France alone by 2030, according to Atlantis Energy. This gives further motivation to support an accelerated expansion of tidal stream energy to the higher end of what is feasible by 2030.

The MayGen site itself, which is in development, is has lease permits for around 400MW, and so this would be a minimum target for tidal stream expansion by 2030[125].

However, the UK currently has an excess of 1GW of leased tidal stream sites across various locations.[126] Many of these sit within Crown Estate, and a large proportion are in Scotland. The same research indicates that this level of deployment (around 100MW per year) would be feasible by 2030. Consultation with industry leaders indicates that with the right support this capacity would be more that realizable by 2030. Therefore, this is the target level that has been set for this strategy.

Based on discussions with Atlantis Energy a 1GW farm is estimated to produce around 3TWh of electricity per year.

It is also noted in the same research however that the UK's practical resource for tidal stream is around 15GW, and so if there is greater progress in the sector than expected, it may be viable to deliver more than the 1GW proposed here.

4.9.2.2 Tidal Range

Available resource. Although it has been suggested the total resource is over 85GW, though full exploitation of this resource is unlikely given that all technologies are acknowledged to have potential detrimental impacts on marine life and human activities (at ports, for example) and because of affordability concerns.

The Hendry Review, a government-commissioned paper on tidal lagoons, proposed that seven tidal lagoon projects in high resource areas are currently deemed technically feasible and could deliver up to 18 GW.[127]

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[124] TIDAL STREAM AND WAVE ENERGY COST REDUCTION AND INDUSTRIAL BENEFIT, Gavin Smart & Miriam Noonan, April 2018
[125] https://simecatlantis.com/projects/meygen/
[126] TIDAL STREAM AND WAVE ENERGY COST REDUCTION AND INDUSTRIAL BENEFIT, Gavin Smart & Miriam Noonan, April 2018
[127] https://hendryreview.files.wordpress.com/2016/08/hendry-review-final-report-english-version.pdf

Figure 41 below highlights the main areas of high potential for tidal range. The Bristol Channel and Severn Estuary represent the largest single area of tidal range resources. The Solway Firth has the second highest tidal range and other potential sites include Liverpool Bay, North Wales, and the North West of England.

Given the scale and reliability of output available from these potential lagoon projects, it is considered important that they be considered further and ideally developed to form a sizeable contribution to UK renewable electricity generation.

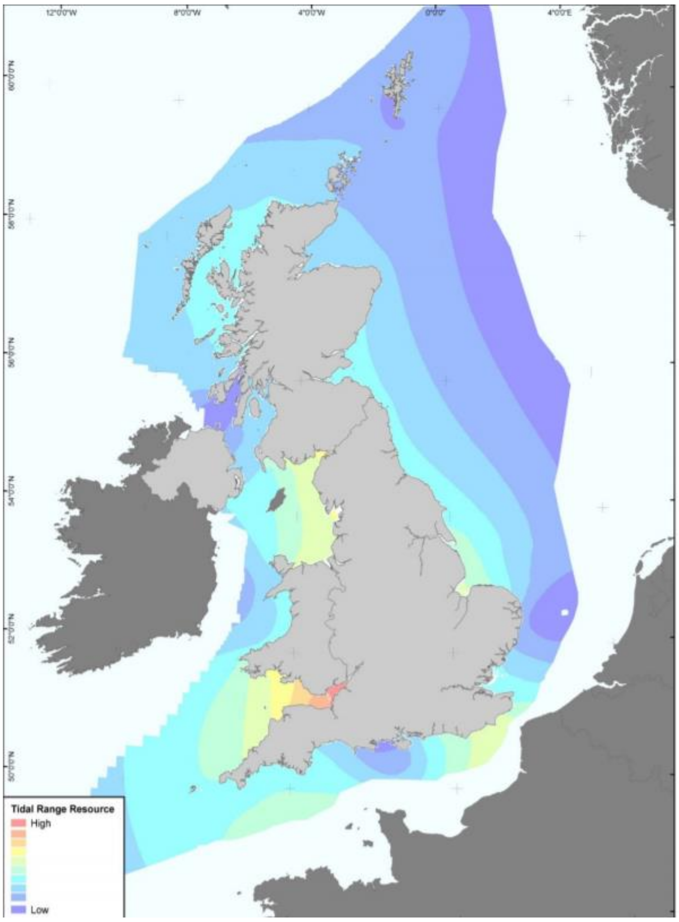

Figure 41. Tidal Range Resource in UK.

Potential deployment based on historical build rate. The historical buildout as been negligible, increasing by 14 MW over the past 8 years. At this rate, by 2030, the estimated capacity would reach 35MW. This is clearly too low a number, and so we call for a very significantly increased rate of development for tidal energy.

Targeted 2030 build out. Despite the fact that tidal power has the greatest potential of the marine power technologies to contribute to renewable energy generation in the UK, the targeted capacity by 2030 has been estimate at 2 GW because the technology is unproven at scale and there remain lessons to be learnt regarding the cost of generation, particularly in comparison to other renewable energy technologies. It is entirely possible that this number will be exceeded, but this has been set as a minimum objective. This capacity target is based on delivery of at least two of the promising tidal projects identified within the Hendry Review report, namely:

- Phase 1: A preliminary pilot project developed immediately in the early 2020s. Likely to be the Swansea tidal lagoon (320MW of annual electricity generation)
- Phase 2: One large scale project, which could be one of a number of site identified in the Hendry Review, for instance Newport tidal lagoon (1.4 to 1.8GW and 2 to 3TWh of annual electricity generation)

These figures indicate a capacity factor of around 20% (in the case of Cardiff Tidal), which if matched across the entire 2GW, would result in 3.7TWh of electricity generated in 2030.

Currently Tidal Lagoon Power is developing these projects, as well as few others it has identified as having high potential. Other players in the market include North Wales Tidal Energy and Coastal Protection Ltd as well as Natural Energy Wyre. These sites were selected on the basis of representing projects in high resource areas that are at a more advanced stage of development. Notably, the Swansea tidal lagoon project is currently ready for construction.

4.9.3 First steps for marine power

This strategy recommends the delivery of one project by the end of the mid-2020s —and proposes the delivery of the Swansea tidal lagoon project as a financially supported pilot project. The exact mechanisms for funding and delivery would need to be agreed by government. This is the recommendation of the Hendry Review (an independent review of the UK's tidal lagoon options[128]) which describes using Swansea tidal lagoon as a 'pathfinder'.

Recommendation 23: **Trial and expand tidal energy** to around 3GW of capacity, for instance with:

- at least one medium scale tidal-lagoon demonstration scheme operating by the early 2020s – then, if successful, at least one larger scale tidal lagoon installation by 2030; and
- an expansion of tidal stream to at least 1GW of capacity by 2030.

4.10 Carbon capture and storage

While carbon capture and storage (CCS) is not in itself a source of low-carbon or renewable electricity, this section addresses it as an important aspect of reducing emissions from fossil-fuel plants currently generating electricity.

4.10.1 Background

CCS is commonly used in various industrial processes that produce unwanted carbon dioxide as a by-product. The overall principle is to capture CO_2 before it is released into the atmosphere. The CO_2 can then be transported to a safer location and stored indefinitely underground, in depleted oil and gas fields or deep saline aquifer formations, or in other locations. CCS has the capability to reduce carbon emissions by up to 90%. For a number of decades, carbon has been transported and injected into the ground. However, large-scale storage is a relatively new concept, with the Weyburn-Midale Carbon Dioxide Project, commencing in 2000, being the first commercial-sized storage scheme.

[128] https://hendryreview.wordpress.com/#content

CARBON TARGETS, CARBON CAPTURE & STORAGE, AND CARBON REMOVAL

CSS will likely play an important role in limiting the further release of GHG emissions. There will also very likely be a firm need to deploy a related solution, carbon dioxide removal (CDR). CDR encompasses the many solutions for removing CO_2 directly from the atmosphere, while CCS prevents it from being emitted in the first place. A whole range of innovative trials and solutions are emerging to encourage and enable CDR, from agricultural practices, to costal management, to forest management, to bioenergy with carbon capture and storage (BECCS).[129] BECCS could provide a carbon-negative energy source as the trees planted remove carbon from the atmosphere and then the emissions produced in burning are buried. This technology is already being investigated; DRAX has announced it will be piloting Europe's first BECCS project.[130] While some have hailed BECCS as a long-term solution to climate change, large-scale deployment is not feasible due to limiting factors of biomass as discussed in Appendix B.

One of the often-raised criticisms about CCS or CDR is that the technologies let policy makers and industry 'off the hook' by providing a long-term technical fix, and hence discourage ambitious and often disruptive action today. This is a genuine concern, and one that must be mitigated through clear communication and policy-making, ensuring that reducing the production of CO_2 remains the first and primary priority.

However even in ambitious climate action scenarios, it is very challenging to see how carbon budgets can be met without CCS and/or CDR. The recent IPCC special report *Global Warming of 1.5°C* outlines illustrative pathways to delivering the 1.5 degree target set out in Paris under the COP21 agreement.[131] (See Figure 51 for more detail). In three of these four examples, due to the quantity of CO_2 that will be produced in the coming decades in addition to what has already been released, the world will have to remove some CO_2 to prevent going significantly beyond the 1.5 degree budget. This CDR will need to reach staggeringly large scales (up to 20GtCO_2 removed per year) unless very ambitious emissions-reduction policies are enacted across the world.

It is therefore the conclusion of this work that if the UK and wider world is going to stay within 1.5-degree carbon budgets, alongside rapid reduction in emissions, CCS will play an important role. CDR is not a panacea, but avoiding the worst of climate change likely without it. It will play an important role alongside rapid emissions reduction.

Another concern, for CCS at least, is that it is a short-term fix; in due course, the captured CO_2 may indeed escape. Should that occur, the impacts would be catastrophic. Therefore, there must be absolute confidence in the integrity of storage mediums and sites before they are used.

Box 4 Carbon targets, carbon capture and storage and carbon removal

General inhibitors to the deployment of CCS:

- **A lack of public acceptance,** due to poorly executed public engagement and successful opposition campaigns.
- **Poor system integration**, due to difficulty in coordinating and 105rioritize the different kinds of expertise needed for making a CCS system work.

[129] https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda
[130] https://utilityweek.co.uk/gas-with-ccs-could-be-cheaper-than-hinkley-study-claims/
[131] http://www.ipcc.ch/pdf/special-reports/sr15/sr15_spm_final.pdf

- **An inability of the technology to scale and accelerate,** due to continued uncertainty about the market, in the UK and beyond, which limits the ability of domestic industry to build and maintain capabilities.
- **Inadequate policy and regulation,** due to faltering political will, which leads to policy capture by reluctant operators of unabated fossil-fuel power plants and nuclear developers, and contributes to delays.

Deployment today. A strategy for CCS is urgently needed, and the UK has lacked one for years. CCS is still a relatively unproven technology and while the discrete components of CCS have been demonstrated, a fully integrated commercial power plant with CCS is still yet to be delivered. This makes the potential development and deployment trajectory difficult to predict. A number of CCS plants are successfully running around the world, with applications that include power generation and industrial processes. In the UK, however, there is still yet to be a single commercial CCS plant built.

In 2015 the coalition government pulled out of its £1bn investment project to see the first commercial-sized demonstration plant built in the UK. This has stalled the development in the UK, and to kickstart start the process again the current government has announced in the Clean Growth Strategy that it will pledge £100m for the development and research of CCS. They have also commissioned a CCS task force with the intention of pushing technology forward and reducing the economic costs.

Globally there are 18 large-scale CCS plants in operation, 5 in construction another 15 in development. A plant is considered large-scale if it sequesters:
- at least 800,000 tonnes of CO_2 annually for a coal-based power plant; or
- at least 400,000 tonnes of CO_2 annually for other emissions–intensive industrial facilities (including natural gas–based power generation).

Of the 17 CCS plants only 2 are for power generation. The others are 106rioriti in various industrial processes. Another 7 plants focused on power generation, one of which is the Caledonia Clean Energy Project in Grangemouth, UK.[132] Summit Power produced a feasibility study in early 2018, confirming that the Caledonia Clean Energy Project could generate up to 1.3GW of low carbon power using natural gas as a feedstock with over 90% CO_2 capture for geological sequestration in the North Sea.[133] The project could be delivered by the early mid 2020s. The energy produced would also be financially feasible with competitive prices lower than Hinckley C's nuclear power.[134]

Example projects:
- **Boundary Dam Carbon Capture Project**. Completed in 2014, the project became the first CCS coal power plant in the world. The retrofitted power station produces 115MW of power and is capable of reducing the SO_2 emissions from the coal process by up to 100% and the CO_2 by up to 90% (on paper). The plant has captured 1.75 million tonnes since start up instead of the 3 million tonnes expected. On average from 2015 to 2017 it has been capturing 46% of its emissions.[135]
- **Petra Nova Carbon Capture**. Petra Nova's post-combustion CO_2 capture system began operations in January 2017 with a capacity of 240 MW in Texas. The CO_2 captured from Petra Nova is used for enhanced oil recovery at the West Ranch Oil Field to increase oil production.

These CCS demonstrations have been limited to regions where:
- CO_2 has a value for enhanced oil recovery
- a low-cost coal supply is available

[132] https://www.globalccsinstitute.com/projects/large-scale-ccs-projects
[133] https://summitpower.com/projects/carbon-capture/
[134] https://utilityweek.co.uk/gas-with-ccs-could-be-cheaper-than-hinkley-study-claims/
[135] https://www.cbc.ca/news/canada/saskatchewan/saskpower-carbon-capture-future-1.4414985

- effective CO_2 emissions caps or pricing are in place

For CCS to be competitive in a broader context there is a need for dramatic reductions in the cost of capture, primarily through a reduction in the process energy consumption.[136]

4.10.2 CCS by 2030

The UK Energy Research Centre's 2012 report on CCS presents four pathways for CCS by 2030. [137] The report's Pathway 2B has been identified as a feasible development trajectory, outlined in Figure 42. In this pathway initially there is policy support, and experimentation across a wide range of technology variants in the initial plants. The key technical features include the identification of a range of potential storage sites. Some CO_2 pipeline routes are successfully built and operated. The first plants are outlined as demonstration plants in the order of 10s to 100s of MW, followed by larger commercial scale, until reaching around 2GW electrical output some ten years into the program, and 7GW 15 years into the program.

This trajectory was outlined in 2012, before the UK coalition government withdrew funding support for CCS. Little or no progress has been made, and so the 7GW of capacity outlined in the Pathway 2B scenario is considered very unlikely. However, if support were reinstated, a total of 2.5GW output from several UK CCS electricity-generating plant, almost certainly natural gas fired, is feasible in time for 2030.

It is also assumed this plant will be operated as a baseload plant to maximise output and returns, and so a capacity factor of 80% is assumed, resulting in 18TWh of low-carbon electricity.

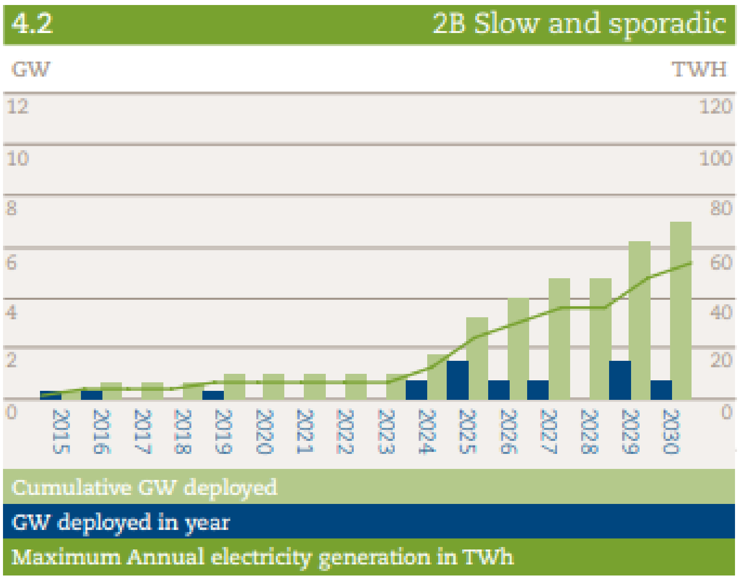

Figure 42. 2015 UK Energy Research Centre slow and sporadic CCS energy pathway to 2030, adapted to estimate potential development path from 2019 and hence revised capacity for 2030.

[136] https://ac.els-cdn.com/S1876610217320520/1-s2.0-S1876610217320520-main.pdf?_tid=b7025083-8e65-49cf-be02-e79c27d6aab8&acdnat=1531588602_198ba547306bb1d2f28b2dcd452d2e93
[137] *Carbon Capture and Storage: Realising the potential*?, UK Energy Research Centre, April 2012, http://www.ukerc.ac.uk/publications/carbon-capture-and-storage-realising-the-potential-.html

Recommendation 24: **Trial carbon capture and storage in the early 2020s and expand it to become a significant if still emerging component of the energy mix by the late 2020s.** This is for both power production and hydrogen production. One large plant is expected in the early 2020s and at least two large installations are expected by 2030, with a total capacity target of around 2.5GW. Research-and-development support will be necessary to ensure this. It should be noted that CCS will likely remain a minority contributor to the energy supply, and its inclusion is *not* a loophole for continuation of large-scale dependence on fossil fuels.

4.11 Hydropower

Hydropower is the generation of electricity by extracting kinetic energy from water as it falls from a higher altitude source to sea level. There are a wide range of types and scale of hydro power. Pico hydro schemes are small, typically 'run-of-stream' operations, meaning they do not create a reservoir to build up a steady water supply and drop. They generate up to 5kW of electricity and are able to provide lighting for a small number of homes. Micro hydro typically has an output of 5-100kW powering more intensive equipment and a greater number of buildings. Small hydro, from 100kW-5MW is typically a 'run-of-river' system and can be used to power, for instance, a manufacturing facility. Large-scale hydro, can have up to several gigawatts of capacity and makes up the majority of UK hydro capacity.[138]

The UK has a limited resource compared to some other EU countries, and much of that resource has already been harnessed. The current hydropower capacity of the UK is 1.47GW, with a total annual output of 6.51 TWh.[139]

There are substantial environmental risks associated with a poorly designed hydro scheme, for instance flooding of wetland habitats due to damming or inhibiting fish movement up and down stream. However, the UK Environment Agency (EA) has identified 526MW of environmentally safe potential new capacity, made up mainly of schemes in the 100-500kW (152MW available capacity) and 0.5-1.5MW (180MW available capacity) scales, and then around 90MW available at the >1.5MW scale.[140]

In fact, the EA describes these as 'win-win' sites because they actually deliver environmental benefit, enabling fish passage previously constrained by prior development or human obstruction. However, the EA study considered only viable resource, not commercially viable connection, and therefore this scenario assumes that only 70% of resource identified by EA is economically recoverable and also recommends that research be undertaken to determine the true recoverable amount. Hence, the total hydro capacity in 2030 is anticipated to be 2.5GW, generating 7.9TWh.

Recommendation 25: **Support hydro energy expansion across the UK**, from pico scale up to medium scale by 2030, adding a further 500 MW to UK capacity.

4.12 Biomass power

Solid woody biomass is a commonly used fuel source in the UK today, at around 3GW of capacity, generating about 16TWh. As outlined in Appendix B however, there are wide ranging concerns to the expansion of biomass use that limit the scope to increase capacity further. Therefore the 2030 scenario will adopt the following deployment of biofuels.

Woody biomass power generation capacity is not expanded for reasons similar to those for not expanding the use of woody biomass for heating buildings. Those reasons are set out in Appendix X. It is acknowledged

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[138] http://www.british-hydsro.org/large-hydro/
[139] *Future Energy Scenarios 2018*, National Grid, http://fes.nationalgrid.com/media/1366/2018-fes-charts-v2_as-published.xlsx.
[140] http://www.climate-em.org.uk/images/uploads/GEHO0310BRZH-E-E_technical_report.pdf

that there is an ongoing debate around the wider costs and benefits of biofuels, in particular in relation to burning solid biomass for power generation. Given that biomass use is partly a political question, this 2030 scenario and the modelling that underpins it assume that a certain amount of increased capacity balances out reductions in wood biomass combustion as coal co-firing plants are decommissioned over the coming years.

Industrial process energy. There are certain industrial processes that depend on the use of liquid hydrocarbon fuels. Currently there are no clear alternatives to such fuel, and so the only renewable and low-carbon substitute is biofuel. Based on its interpretation of the CCC's trajectory for the delivery of the fifth carbon budget, the project team estimates that around 8.8TWh of the energy used to provide industrial process heat is suitable for transition to biofuel, which is 3% of total industrial heat energy in 2030.[141]

Shipping and aviation. Bioenergy is 109prioritised for aviation and shipping in this scenario since there is no credible alternative for these sectors due to their fundamental reliance on liquid hydrocarbon fuel, which currently consists mostly of fossil fuel. Given that this strategy is focused only on stationary energy, we will not explore this any further, but 109recognises it as a constraint to using biofuel for stationary energy generation purposes.

In conclusion, the model assumes the UK's biomass electricity generation capacity remains similar to its current capacity, contributing around 3GW and 18TWh to renewable and low-carbon supply.

> **Recommendation 26**: **Do not expand solid biomass use for large-scale *electricity* generation**, though it has been assumed that current generation levels are maintained.

4.13 Nuclear power

For the purposes of this analysis, we have considered nuclear power as a contributing towards renewable and low-carbon energy supply.

4.13.1 Nuclear power and GHG emissions

The production of electricity by harnessing nuclear fission was pioneered by the UK and a small number of other nations almost 70 years ago. It is now one of the main electricity generation technologies deployed globally. The fission of uranium atoms produces large volumes of heat without any direct reliance on combustion of carbon-based fuels, and so creates low operational GHG emissions. However, as with all large scale civils work and plant manufacture and installation, there are significant imbedded GHG emissions associated with them. This is true for most energy generation technologies. It is also true for nuclear, in the case of the construction of the plant, uranium mining, milling, fuel processing, fuel enrichment, refuelling (plants are offline for months at a time), backup power, waste storage, and decommissioning have significant imbedded GHG emissions associated with them. For this reason, nuclear power is considered a low-carbon energy source, but not a zero-carbon energy source.

4.13.2 Current UK nuclear capacity

The UK has 15 reactors with a total capacity of 8.9GW generating about 21% of total electrical output. However almost half of this capacity is planned to be retired by 2025. The capacity factor of a typical nuclear power station is far greater than all other renewable and low-carbon sources, because a station provides output 24/7 when online – a core reason behind arguments that nuclear power should be a key part of any low-carbon energy mix. As outlined in Table 17, five of the current nuclear power sites in the

141 https://www.theccc.org.uk/publication/fifth-carbon-budget-dataset/

UK, representing 10 reactors, are expected to reach the end of their operational life before 2030, and most of these by 2025. EDF has a programme of work aiming to extend the life of these plants, but details for this are not currently publicly available.[142] Therefore, this work has assumed that the plants will come offline at the planned time, meaning around 5GW of the current fleet will potentially be offline by 2030, and all but Sizewell B from 2031.

Table 17. Current UK nuclear fleet (as of 2018).

Plant	Type	Present capacity (Mwe net)	First power	Expected shutdown
Dungeness B 1&2	AGR	2 x 520	1983 & 1985	2028
Hartlepool 1&2	AGR	595, 585	1983 & 1984	2024
Heysham I 1&2	AGR	580, 575	1983 & 1984	2024
Heysham II 1&2	AGR	2 x 610	1988	2030
Hinkley Point B 1&2	AGR	475, 470	1976	2023
Hunterston B 1&2	AGR	475, 485	1976 & 1977	2023
Torness 1&2	AGR	590, 595	1988 & 1989	2030
Sizewell B	PWR	1198	1995	2035
Total (15 units)		*8,883*		

4.13.3 Options for maintaining capacity to 2030

There are certainly sufficient proposed nuclear power sites within the UK to replace decommissioned plants between now and 2030. The UK government currently aims to deliver 12GW of new nuclear capacity by 2030, and has proposed a further 2.3GW, from a range of new sites (Hinkley C1/C2, Sizewell C1/C2, Wylfa Newydd ½, Oldbury B1/B2, Moreside ½/3 etc).[143] Of these only Hinckley C is under construction.

The nuclear power capacity contributing to supply in 2030 is therefore 8.9GW, resulting in around 63TWh of output in 2030, contributing 15% of the renewable and low-carbon electricity needed. Given the large number of nuclear plants being decommissioned over the coming 7 years, it may be possible that in the mid 2020s the nuclear capacity drops below that of today, but this strategy assumes that this number then increases back to 8.9GW by 2030.

However, at the time of writing there remains uncertainty around much of the planned and proposed new capacity in the UK. For instance, Toshiba has recently pulled out of the planned Mooreside plant in Cumbria for financial reasons. That plant was intended to account for 3.4GW of nuclear power, and was originally planned for 2024.[144] Hitachi have also recently pulled out of the planned Wylfa nuclear plant in Angelsey, also for financial reasons.

The assumption for this strategy, as per Labour Party policy, is to maintain nuclear generation capacity in the UK at its current level out to 2030, and so we assume these new reactors will be developed only to the extent required to replace the 8GW of existing plant capacity that is expected to come offline.

This could still certainly be achieved, however. Hinkley Point C is under construction and due for completion in 2025. Nearing the completion date there would be much more certainty around the cost of construction,

[142] http://www.world-nuclear-news.org/C-EDF-Energy-extends-lives-of-UK-AGR-plants-1602164.html
[143] http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx
[144] http://www.toshiba.co.jp/about/ir/en/news/20181108_4.pdf

and the design for the EDF EPR would now be familiar to UK regulators. This lengthy process involves two stages:

- Stage 1 – GDA (General Design Assessment), checking basic principles of operation of a new plant design
- Stage 2 – Site specific safety case, requiring many thousands of hours of staff time, demonstrating that the plant is safe in the context of a specific site.

This process would be much quicker post Hinckley Point C, significantly speeding up the process. Costs would look lower, potentially around the 65 GBP/MWh mark. Also the government is currently considering different funding model proposed next time for the following rounds. This all points to an easier and quicker development and implementation of new plant sites.

There are also multiple viable sites for doing so. The Sizewell C site could house very similar plant to Hinckley Point C, at 3.2GW, meaning total of 6.4GW, meaning only 3GW needs to be found. Again there are multiple sites where a third 3.2GW plant could be housed. Sizewell on the east coast could be anther option, or Bradwell in Kent. These are all in the south east, so from the point of view of supporting local industry, other sites in the north could be considered, such as Wylfa.

This analysis serves to give confidence that with the right government support, nuclear capacity in 2030 could be returned to today's output levels.

4.13.4 The Impact of not developing any further nuclear plants

This document takes a neutral position on the technology, assuming capacity remains level. Without substantial changes to the landscape, for instance through a change in government approach to financing, the collapse of such schemes highlights the risks of the UK maintaining current capacity out to 2030.

As of 2019, Hinckley Point C is the only new plant funded and confirmed as going ahead. If no further plant is commissioned, then by 2030 the UK would only have 4.4GW of operational nuclear capacity (1.2GW from the existing Sizewell B and 3.2GW from the new Hinckley C). This would mean a further 32TWh of power would need to be found from other renewable and low-carbon sources to plug the gap and meet 90% renewable and low-carbon electricity.

These levels are well within the available resources around the UK, and it is still entirely possible to meet the 90% target without any new nuclear capacity. It will however be more challenging for a number of reasons, including the loss of large volumes of low-carbon baseload power that nuclear provides and the increasing the proportion of generation capacity that is intermittent. This will necessitate greater capacity for grid balancing, either through power storage, interconnection, demand-side management, or fossil fuel back up. It may for instance necessitate greater volumes of fossil fuel to be put back on stand-by, resulting in higher system balancing costs. However, the system will also benefit from cheaper generation technology such as wind and solar. These issues will be explored in more detail in Section 5.

4.13.5 Technological developments in nuclear power

A nuclear power technology receiving a lot of attention currently is the small modular reactor (SMR). There are significant potential benefits reported for this technology. It is suitable for modular mass construction (reducing price and complexity and improving reliability and 111standardisation of processes) and it can be produced largely by UK supply chains (Rolls Royce, for example). However there are no operational commercial SMRs – just military ones – and so it is not considered likely that the technology would be cleared for civil operation before the 2030 target year. It has therefore not been considered any further.

This report assumes nuclear output will be maintained at current levels based on Labour's policy that nuclear will continue to form part of the energy mix. This assumes the existing plants that are planned for decommissioning before 2030 are replaced with equivalent capacity, which this report finds could be possible in the time frame.

4.14 Deep geothermal

Deep geothermal energy production relies on drilled deep wells, to depths where the earth's crust is hot enough to raise steam, to drive a turbine and produce electricity. The depth of drilling required depends on local geological conditions, and the best locations in the UK are around Cornwall[145]. The better the conditions, the closer the "hot rock", meaning the costs of drilling are lower, and viability higher.

There is currently a very limited industry in the UK, however the first such plant has recently completed drilling in Cornwall. This is 3MW, and 27 further sites have been identified as potentials. A commonly discussed solution is the use of existing mine shafts, many of which exist around the UK. This is not a "hot rock" technology however, and so is not used for power generation, but combination of warm water with a heat pump to provide water for heating[146]. This is called ground source heat pump, and is covered in the heating solutions outlined in the previous chapter.

It is recommended that "hot rock" geothermal technology be explored for use where possible around the UK. However, given how young the industry is, and the small size of plant expected in the coming decade, the UK wide contribution is expected to be very low relative to other technologies, at least by 2030. It is firmly recommended however that investment continue and R&D expand to make sure this opportunity is maximised.

4.15 Decentralised electricity and community electricity generation

Electricity generation is typically classified as being one of three scales or types, differentiated by the point at which they connect to electricity infrastructure:

- **Centralised energy generation** – connected to the power transmission network, and usually at utility scale. *Currently 71% of UK generation capacity.*
- **Decentralised energy (DE) generation** – of which there's two types:
    - **Distribution level** – connected to the power distribution network. *Currently 24% of UK generation capacity.*
    - **Micro generation** – connected "behind the meter", or on a specific site such as a school or factory. Typically less than 1MW. *Currently 5% of UK generation capacity.*

There are tremendous benefits to an increased level of decentralised energy, such as reducing overall system costs, democratising energy use, a community revenue source, and encouraging a shift to lower carbon technologies. With developments in battery technology and vehicle to grid charging of EV's, large amounts of decentralised energy become more and more viable.

Based on examples set by other countries such as Germany where community energy is a large contributor to national supply, and planning work done by National Grid, it is considered likely that DE and community energy will be a big part of future mix. National Grid estimates DE could represent as much as 45% of total generation by 2030, based on their "community renewables" scenario.
Most of the generation capacities included below are assumed to include some level of DE. However The level of likely DE depends on legislation, and is addressed is another labour strategy, and so the expected DE deployment per technology is not considered in this report.

Recommendation 27: Encourage the adoption of distributed and community energy to accelerate deliver of targets

[145] https://www.bgs.ac.uk/research/energy/geothermal/
[146] https://www.gshp.org.uk/London/7_BanksGeothermalMinewater.pdf

4.16 Summary of Recommendations

This report assumes nuclear output will be maintained at current levels based on Labour's policy that nuclear will continue to form part of the energy mix. This assumes the existing plants that are planned for decommissioning before 2030 are replaced with equivalent capacity, which this report finds could be possible in the time frame.

Recommendation 18: **Set a target of at least 90% of direct (non-transport) electricity demand being met from renewable and low-carbon sources by 2030**, almost a tripling in output compared to 2019 levels of generation.

Recommendation 19: **Rapidly phase out fossil-fuel extraction and use for electricity generation.** Immediately end new coal extraction and phase out coal electricity generation as soon as possible; immediately end fracking for gas; end electricity generation from oil anywhere in the UK by 2022; and reduce the annual operation of gas-fired electricity generation from 130 TWh today to 36 TWh in 2030 – a 72% reduction. The only form of fossil fuel use permitted, whether for power generation or production of hydrogen, should be that coupled with 100% carbon capture and storage, meaning no GHG's are emitted to the atmosphere at any point (See Recommendation 24)

Recommendation 20: **Two and a half times today's onshore wind capacity by 2030**, or 30 GW. Ensuring that together onshore and offshore wind would provide 55% of electricity generated in the UK.

Recommendation 21: **Nearly a seven-fold increase in the offshore wind capacity by 2030**, or 52GW. This would make it the UK's largest source of electricity and be around 7,000 new large-scale turbines (depending on average future turbine size). To maximise the UK's potential, undertake further detailed research to determine the maximum large-scale capacity and ideal distribution of off-shore wind; and the expansion of UK manufacturing capacity and skills.

Recommendation 22: **Almost triple solar PV capacity**, to 35GW, including a mix of building integrated small-scale systems and larger solar farms where appropriate.

Recommendation 23: **Trial and expand tidal energy** to around 3GW of capacity, for instance with:

- at least one medium scale tidal-lagoon demonstration scheme operating by the early 2020s – then, if successful, at least one larger scale tidal lagoon installation by 2030; and
- an expansion of tidal stream to at least 1GW of capacity by 2030.

Recommendation 24: **Trial carbon capture and storage in the early 2020s and expand it to become a significant if still emerging component of the energy mix by the late 2020s.** This is for both power production and hydrogen production. One large plant is expected in the early 2020s and at least two large installations are expected by 2030, with a total capacity target of around 2.5GW. Research-and-development support will be necessary to ensure this. It should be noted that CCS will likely remain a minority contributor to the energy supply, and its inclusion is *not* a loophole for continuation of large-scale dependence on fossil fuels.

Recommendation 25: **Support hydro energy expansion across the UK**, from pico-scale up to medium scale by 2030, adding a further 500 MW to UK capacity.

Recommendation 26: **Do not expand solid biomass use for large-scale *electricity* generation**, though it has been assumed that current generation levels are maintained.

Recommendation 27: **Encourage the adoption of distributed and community energy to accelerate delivery of energy decarbonisation**

5.

Goal 4: System balancing.

5.1 Chapter Summary
GOAL 4 – SYSTEM BALANCING

CHAPTER BACKGROUND

It is increasingly clear how the UK could maximise electrical and heat energy from renewable and low-carbon sources by 2030, based on the findings presented in Chapters 2, 3, and 4. If enacted, this plan wold result in 69% of the electricity generation capacity in the UK in 2030 depending on the weather in one way or another. Given that 25% of heating will be electrified by 2030, it is vital to demonstrate that the UK's lights and heating will stay on when the wind isn't blowing and the sun isn't shining.[147] This would be a challenge based on current electricity transmission and distribution systems.

Advancements will be needed to balance energy generation, storage and use. Over recent decades, this topic has been the focus of much research and development, which this chapter builds upon to demonstrate the steps necessary to balance the energy system along the way to 2030.

CHAPTER FINDINGS

- **The lights and heating will stay on.** The growing evidence from the research and industrial communities implies that for the system described in this document, it will be entirely viable and cost effective to keep the lights and heaters on all year around, as long as the right measures are put in place.
- **There are multiple viable solutions for achieving this**, from power storage to interconnectors to demand-side response. There are also many viable balancing scenarios (combinations of solutions). However, it is beyond the scope of this work to specify the exact preferred 2030 scenario.
- **This is new territory.** There is no working example of this system in an exactly comparable country, and so to an extent there will need to be experimentation and learning as we go. That said other countries are already generating much more renewable energy than ever before without any insurmountable challenges.
- **A UK-wide infrastructure approach is critical.** It is also vitally important that the UK strategy for buildings/housing, heating, electricity generation, balancing and transport are co-developed, and form a united plan. This will hugely reduce cost, improve efficiency and operation.
- **Detailed further work is needed soon.** Due to the partial electrification of heating described in Section **Error! Reference source not found.**, the biggest challenge will be meeting peak heat d emand. This is why nonelectric heat sources were prioritized first, and why a portion of heat pumps were hybrid, reducing the peak electricity demand for heating. However, the peak heat demand will still change the UK electricity demand profile significantly, and hourly system balance modelling is beyond the scope of this work, so the project team has relied on research encompassing similar conditions. Detailed hourly modelling should be a top priority once Labour is in government, and will need to involve regulators, generators, academics, system operators and other experts.

[147] Due to heat pump use either at the building scale or district scale via use of district heat networks.

CHAPTER EVIDENCE

This chapter is built on evidence drawn from multiple sources, in particular:

- UK Energy Research Centre
- National Grid Future Energy Scenarios 2018
- Ofgem
- Imperial College London
- UK Government (DECC / BEIS)
- Universtiy College London (UCL)

CHAPTER CONTENT

The chapter includes the following content:

- Background
- The importance of a “whole energy system approach”
- Demonstrating that the lights and heaters will stay on in 2030
- Further solutions for balancing supply and demand
- Ensuring long-term energy security and the Beast from the East
- Impact of storage on overall demand: losses
- Summary of recommendations

5.2 Background

5.2.1 How the Proposed 2030 energy system differs from that of today

The energy system described in the previous chapters, will be more complex to balance than today's, and yet the proposals in this scenario have been tailored to ensure that it is technically feasible to manage. The following points outline these complexities and the steps this report has proposed in prior chapters to mitigate them:

- **Electrification of heating means overall electricity demand will be larger and more variable.** The UK's single biggest energy use is for heating, on an annual basis, but in particular on a peak basis, with today's peak heat demand up to six times higher than electricity use. Therefore, the electrification of heat has the potential to vastly increase the required electrical supply capacity in the UK. Given the obvious importance of ensuring all buildings across the UK are sufficiently heated on the coldest days, it is vital for the system to be able to meet these peaks all year around, even when there is no wind or sun. While it is beyond the scope of this work to estimate that peak heat demand directly (for instance estimating the leftover peak after the energy efficiency measures outlined earlier have been implemented) it is important that we can demonstrate that it is plausible to that this peak demand will be met.

- **More electricity generation that depends on the weather means electricity generation will be more variable, or intermittent.** Today around 18% of electricity generation comes from either wind, solar or marine power, and so can be classed as intermittent. By 2030, 69% of overall electricity generated will come from these sources, as summarised in Table 18 below. Wind power in particular, when considering both onshore and offshore, accounts for more than half the the UK's total annual electricity generation. A portion of this power generation will need to be stored at times when it is not needed, reserving it for times when there is high demand for electricity. The remaining generation output is from dispatchable (not intermittent) renewable and low-carbon generation made up of nuclear, biomass, and CCS, and supplemented by a small amount of gas-fired generation to help manage loads.

- **Electrification of transport provides greater demand but also opportunities to balance**. The electrification of transport hasn't been directly considered in the fours step so far outlined in this scenario. However, it will only serve to significantly improve the capacity of the system to manage demand, by offering vehicle-to-grid balancing (V2G) services. Section **Error! Reference source not found.** considers some of the potential impacts of including electrification of transport within this strategy.

Table 18 below shows how the total figures for electricity use and supply, including the level of intermittent generation expected in the mix in 2030.

Table 18. Intermittency of electricity generation in 2030 for proposed generation mix.

Value in 2030	Figure	Unit
Total electricity generated	424	TWh
Total renewable and low carbon electricity	392	TWh
Total intermittent renewable and low-carbon sources output[148]	293	TWh
Total contribution from intermittent source across year	***69%***	
Total renewable and low-carbon non-intermittent[149]	99	TWh
Total generation capacity	177	GW
Total intermittent generation capacity	120	GW

5.2.2 The challenge of intermittency

Many renewable energy technologies are *intermittent* generators, meaning that they will only generate at certain times, such as when the wind is blowing or sun shining. However, electricity or heat usage does not necessarily follow the same weather patterns, leading to periods when there is not enough or too much renewable generation to meet demand. Managing intermittency involves taking steps such as increasing storage or reducing demand, to be able to provide electricity when renewable generation is not meeting demand.

In fact, all generating plants are intermittent in some way. Power systems have traditionally been optimised to integrate a range of generator characteristics –hydro power with output partly dictated by rainfall, coal plants requiring a 24-hour start up, inflexible nuclear, the periodic breakdown or malfunction of generators, and so on. However, high penetrations of intermittent renewables require a highly flexible system. System flexibility is the ability of a system to adjust generation or consumption in the presence of network constraints (such as intermittent generation) to maintain secure system operation for reliable service to customers. It will be the key enabler of the transformation to a cost-effective, low-carbon electricity system.

Introducing flexibility into an energy system allows for larger volumes of renewable generation to be integrated. At the same time, it allows more of the fossil backup capacity, slated for extended periods with little wind or solar generation, to be displaced.

High penetrations of renewables would cause a number of problems for our current inflexible system. These impacts are highlighted in the following points:

- **Intermittent generation cannot contribute to short-run system balancing.** Short-run system balancing ensures that electricity demand in the short term (seconds to hours) will be adequately met by supply. A system with a high penetration of renewables will require additional short-term reserves to balance electricity supply and demand over the timescales of seconds to hours. The amount of energy renewables produce cannot in most cases be increased when required: This poses an issue to system balancing as the required flexibility has to be found elsewhere. Some modern turbines can offer an increase in output for a short period to help with system balancing, and there are a number of other ways to balance a system. It is likely the market should be able to adjust to facilitate this.

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[148] Wind, solar, hydro and marine energy. Note that each of these has some level of controllability, for instance large hydro can be operated when needed., and tidal stream energy is highly predictable However the conservative assumption has been made here that all this capacity is intermittent.

[149] Biomass, nuclear and CCS.

- **Intermittent generation can contribute less to meeting peak demand**. There will be times of the day when electricity demand peaks, for example between 17:00 and 20:00.[150] Having enough energy to meet this peak demand is crucial for an energy system. Traditional fossil generation can be increased or decreased as required to meet demand, whereas the peak output from renewables is not so flexible and therefore might not coincide with peak demand. This is one of the bigger challenges with regards to managing intermittency: High penetrations of renewables with low wind and cloud cover during peak times could lead to serious problems without adequate flexibility in a system.
- **The transmission and distribution network capacity is insufficient**. The physical location of renewable generation is driven in large part by the location of the available resource. This location may not coincide with the electricity transmission infrastructure required to connect the generation to the grid, which has been designed around existing fossil generation.[151] The resulting bottlenecks in the current power transmission network, if not addressed, will constrain investment in renewable generation. There is particular need for investment in the Scottish grid.[152] Scotland has large potential wind resources but lacks adequate infrastructure to transfer this energy to demand centres and so it currently cannot be fully exploited. Equally, the distribution system will require significant investment and sophistication as more distributed generation and demand flexibility comes online. This is mostly a logistical issue; some solutions have already been identified. So it could be addressed with sufficient modelling and planning. However, this will also require a new and more active role for system and distribution network operators.
- **Renewable generators can at times produce more than the grid can accept.** Renewable energy cannot be accepted onto the grid when production outstrips demand, or when the transmission and distribution network has insufficient capacity. Renewables' dependence on the weather means there are often periods when they are producing more than is required, for example during heavy winds in the middle of the night. There are ways of dealing with this excess energy without curtailing the generation. For example, the excess generation could be used to cycle battery storage, exported over interconnectors or used to respond to increased usage from demand-side customers. While there are many possible solutions, this is again primarily a logistical issue of determining the most cost-effective way of dealing with production when it outstrips demand. Sufficient modelling should be able to determine when it is more cost effective to implement a flexibility solution rather than curtail the excess.
- **Thermal plant efficiency is reduced by keeping it on standby.** The intermittent nature of renewables means a certain degree of conventional generation is still required for when the renewables are not producing. It can take a number of days to get a coal plant running after a total shutdown and so this means in most cases they must be kept on standby, running them at a low level. However, conventional thermal plants are most efficient when they are running at their optimal capacity. Operating them at a reduced capacity significantly reduces their efficiency and introduces various potential consequences. First, certain types of plants actually produce more greenhouse gases when running at suboptimal capacity, meaning that the carbon intensity of the energy system can actually increase during periods of high renewable production. Second, thermal plants experience much lower revenues for these low load factors. This could result in very high prices being demanded in the balancing market, creating both very high and negative prices at different points. Although important to consider, these issues are not a large concern: They would likely be alleviated with proper planning of thermal generation, and by switching from coal plants to more flexible technologies such as OCGTs and CCGTs.
- **Renewables have lower system inertia compared to fossil fuel plants.** There is a need to ensure that a system has sufficient mechanical inertia to maintain frequency and stability. Thermal plants are generally made up of a large mass that generates electricity by being forced to rotate by the

[150] Claire Gavin, *Seasonal variations in electricity demand*, Department of Energy and Climate Change, March 2014.
[151] Philip Heptonstall, Robert Gross, Florian Steiner, *The costs and impacts of intermittency – 2016 update,* UKERC, February 2017.
[152] *Our Electricity Transmission Network: A Vision for 2020*, ENSG, February 2012.

production of steam. This large mass will continue to rotate due to inertia even if something goes wrong at the plant, ensuring electricity production does not suddenly stop and the 55Hz frequency can initially be maintained then gradually ramped down as other plants are brought on to maintain this frequency. This sudden loss of generation can cause problems for an inflexible energy system. There is considerable inertia in the rotating mass of wind turbines, with some studies suggesting that the theoretically available inertia is as much as conventional synchronous generators of the same rated power.[153] Harnessing this inertia would require additional features on wind turbine power conversion but is within the realm of possibility. In fact, some modern wind turbines already have this ability. Research into the potential impacts of loss of inertia on an energy system are ongoing, and it is not thought of as one of the big issues surrounding renewables.[154]

- **Energy markets are not designed for flexibility.** Energy markets are not currently set up to promote and facilitate the flexibility that intermittent generation requires. Renewable generation has a high capital cost and a very low marginal (operational) cost. The current energy market operates on a pay-as-clear model, based on marginal cost bids. This means the last unit to clear an auction will set the price for all the other units within the auction. Conventional generation with high marginal costs drives up the price renewables receive for their energy, which allows them to make up for their high capital expenditure. With increasing renewables in the market, the amount of conventional generation winning agreements in the auction will decrease, thus driving down the price renewables receive for their energy and affecting their business models. This is a significant issue but an economic rather than technical one.

5.2.3 The available solutions

The above issues highlight the impact a high penetration of renewables could have on our current inflexible energy transmission system. An energy system designed to be highly flexible, on the other hand, would be able to integrate large volumes of renewables. There are many available sources of flexibility that can be integrated into a system to address the challenges posed by a large amounts of intermittent generation. These include the following technologies:

- **Energy storage.** Various technologies store energy in times of excess production for times of excess demand, for both electricity and heating.
- **Grid upgrades.** Transmission network enhancements ensure the network is able to transfer power from regions of high production to those of high demand.
- **Digitalisation and data sharing.** Availability of real time data of demand, supply and storage options will allow much more precise system management and decision making. Includes smart meters and other smart systems.
- **Backup and conventional generation**. Fast-reacting gas turbines and other small-scale reciprocating engines can be used to respond to stress events or to meet peak demand where the above measures are not enough.
- **Interconnectors**. Interconnection provides access to generation in the countries neighbouring the UK. It is a large potential source of flexibility, opening access to a much wider energy market, and can be seen as a form of storage and a way of managing excess generation.
- **Demand-side response (DSR)**: This involves reducing or increasing demand in times of high system stress.
- **Electric vehicles (EVs).** EVs represent a potential form of both DSR and storage with smart-charging technologies.
- **Shifting energy vectors.** Where there is excess electricity supply it is possible to store this as thermal energy for use in heating systems, or as chemical energy to produce transport fuels.

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[153] Zeni, L., Rudolph, A., Münster-Swendsen, J., Margaris, I., Hansen, A. and Sørensen, P., 'Virtual inertia for variable speed wind turbines', *Wind Energy*, 2013, vol. 16, no. 8, pp. 1225-1239. https://doi.org/10.1002/we.1549
[154] Heptonstall, Gross, Steiner, *The costs and impacts of intermittency – 2016 update*.

As expressed above the primary technical concerns for an energy system with a high penetration of renewables are system balancing, meeting peak demand, and maintaining system inertia.

- **System balancing** can be provided by types of generation or storage that can act on a minutes to seconds basis. For electricity this includes certain types of gas turbines, batteries, some forms of DSR, interconnectors and other options such as small reciprocating engines (backup generation).
- **Peak demand** in times of low renewable production can also be met by either shifting demand to periods of high renewable generation, or by storing the excess renewable generation for periods of high demand. Peak demand comes at predictable times, which leaves more opportunity to ready other forms of generation that are slower to react.
- **System inertia.** There are solutions being trialled for maintaining system inertia with the possibility of using power electronics to provide so-called synthetic inertia so that variable renewables are able to provide some rapid access to the energy stored in their rotating plant.[155,156]

As the following sections make clear, a combination of these solutions will certainly permit the energy mix described in the chapters above while ensuring the system is reliable.

5.3 The importance of a "whole energy system approach"

Maximising renewable and low-carbon energy by 2030 requires cross sector coordination an often minute by minute coordination of infrastructure and systems around buildings and energy use, heat supply, electricity supply, and transport. These sectors will no longer operate in isolation, but rather be interactive, and so their development must be part of a coordinated strategy.

As stated by the National Grid: "A whole system view across electricity, gas, heat and transport underpins a sustainable energy transformation. Widespread digitalisation and sharing of data is fundamental to harnessing the interactions between these changing systems."[157]

Balancing our electricity network will inevitably affect the infrastructure sectors that have potential to provide flexibility – for instance, the energy, transport, planning, waste and wastewater sectors. The integration of energy systems across different vectors, technologies, networks, services and related sectors will lead to a reduction in the capital and operational costs of our energy networks. However, the overall benefits have not all been quantified to date, according to research conducted by Imperial College's Energy Futures Lab.[158] The better we integrate these systems into a whole systems approach to planning, the more likely we are to benefit from renewable energy penetration in terms of better use of existing assets, reduced curtailments and reduced need for power sector investment.

There are several ways in which sectors will provide flexibility across the supply and consumption of energy. In the electricity sector, renewable energy generation will increase, and technologies – such as those involving waste-to-energy plants and hydrogen fuel cells – will diversify. Electricity users will be subject to DSR mechanisms to reduce their electricity demand for balancing supply or responding to price signals. In the heating sector, there will be a drive to reduce gas consumption by switching to heat pumps, deploying district heating schemes and capturing waste heat from underground transport systems, power generation plants, and wastewater treatment plants. As noted elsewhere, this provides tremendous opportunity for DSR through the use of thermal storage. This is crucial given the huge peak heat demand across the UK.

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[155] EIRGRID and SONI , *Ensuring a Secure, Reliable and Efficient Power System in a Changing Environment,* EirGrid, Dublin, June 2011.
[156] EIRGRID and SONI, *RoCoF Alternative & Complementary Solutions Project: Phase 2 Study Report (A DS3 programme report)*. EirGrid, Dublin, March, 31, 2016.
[157] http://fes.nationalgrid.com/fes-document/
[158] Richard Hanna, Evangelos Gazis, Jacqueline Edge, Aldan Rhodes and Robert Gross, *Unlocking the potential of Energy Systems Integration.* Energy Futures Lab, London, 2018.

In the transport sector, the rise in EVs will lead to additional charging capacity, while providing for flexibility opportunities through storage and vehicle-to-grid applications. In the planning sector, planning permissions should be granted for distributed generation, storage and EV facilities, while demand side management (DSM) will encourage the uptake of energy efficiency measures among energy users (through lighting retrofits, HVAC improvements, heating system upgrades, building automation upgrades, and so on). A large DSM potential could be unlocked if combined with the housing retrofit program. Additionally, efforts to reduce climate change will impact the operation of these various infrastructure sectors, while cities will require coordinated approaches to provide services to a growing population through smart-city approaches. These examples are not exhaustive, but they do shine a light onto the interactions between different infrastructure sectors in relation to the energy sector.

The integration of these sectors will require strong policy support from different ministries, and hence cross-departmental cooperation within the national government. The ministerial departments directly affected include the Department for Business, Energy and Industrial Strategy (BEIS), the Department for Transport (DfT), and the Ministry of Housing, Communities and Local Government (MCCLG). In addition, efforts to engage citizens will require the involvement of the Department for Education (DfE) and the Department for Digital, Culture, Media and Sport (DCMS). Similarly, efforts to promote the UK's energy leadership on a global scale will require cooperation with several other ministries. The coming years will experience a change across several dimensions within our energy systems and related infrastructure, including changing markets, regulatory frameworks, physical networks, technology development, finance mechanisms and consumer behaviour, therefore it is important for all participating cross-departmental political stakeholders to plan for the UK's future in a coordinated approach.

There is significant agreement from industry on need for a whole-system approach[159], with the National Grid making at focus of their 2019 Future Energy Scenario's report.

There is also a substantial body of evidence that the costs of renewable integration are hugely dependent on the flexibility of the system to which they are being added. Cost estimates based on flexible systems can be several times lower than estimates based on assumptions of inflexible systems. Additional costs will be minimised if electricity systems are optimised to facilitate the integration of variable renewable generation. This optimisation includes changes to both the technical and economic characteristics of electricity-generating plants, potential contributions from flexible demand, storage and increased interconnection capacity, as well as changes to system operation, regulatory frameworks and the design of electricity markets.[160]

5.4 Demonstrating that the lights and heaters will stay on in 2030

Given the very wide range of balancing solutions available, there are an even wider range of possible overall scenarios for ensuring the UK's energy supply is managed over both a short- and long-term basis.

While there is no exactly comparable example – in other words, no large, industrialised country with an energy system exactly like that required to maximum UK renewable and low-carbon energy by 2030 – there is extensive research and modelling undertaken by a wide range of academic and industrial organisations on this question, with many scenarios modelled that deliver high reliability. There are also other countries that have a high proportion of electricity supplied renewable plant, even if not on quite the same scale. The following sections outline the findings of some of this research and compare the UK to other high-renewables countries, the conclusion being that the level of renewables described in this document will not result in an unmanageable system.

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[159] https://www.energy-uk.org.uk/publication.html?task=file.download&id=5722

[160] Heptonstall, Gross, Steiner, *The costs and impacts of intermittency – 2016 update*.

5.4.1 Storage, grid upgrades and backup generation can alone stabilize the system

A research project at the University College London (UCL) has demonstrated that investing in enhancements to the electricity grid, maintaining fossil fuel backup generation and investing in power battery storage to levels of around 10GW result in a system that is more than stable, with no more outages than today. This is the case even without any DSR or interconnection, both of which would result in huge improvements to stability. **The project's findings, published in 2018, show that the most up-to-date research implies that the energy mix described in the preceeding three chapters can be comfortably achieved without the "lights going out."**

The UCL project modelled a number of weather scenarios for 60% and 80% renewables penetration. [161] The paper's 80% model is similar to the energy mix suggested in this white paper. In fact, in various ways, the system they assess is more challenging than ours, as Table 19 shows.

Table 19. System Comparison.

Quantity	This strategy (by 2030)	UCL research 80% (by 2050)
Renewable and low-carbon electricity output (TWh)	392	416
Wind offshore (GW)	52	68
Wind onshore	30	27
Solar	35	50
Marine	3	0
Hydro	2.5	1.6
Biomass	3	0.4
Nuclear	9	12.4

The UCL research uses 10 years of weather data to capture and explore the inter-variability of weather conditions. This approach allows it to model the intermittent nature of renewables and the system effects of an 80% renewable penetration.

Indeed, the UCL research demonstrates that systems with much higher levels of intermittency than the 69% expected by 2030 (see Table 18), are still entirely viable.

The UCL research's 80% scenario gives a Levelised Cost of Electricity (LCOE) of £90/MWh if sufficient transmission grid enhancements are made, assuming 38 GW of flexible generation and 11 GW of storage. In the context of our report, however, LCOE includes investment and operation, rather than just the latter (the normal determinant of the wholesale price of electricity). They model the storage as NaS batteries and the flexible generation as open-cycle gas turbines (OCGT). The report highlights that enhancing the transmission grid to allow for high spatial diversification of renewables is vital.

Here is how this study's model and the resulting scenario addresses each of the issues with intermittency highlighted above:

- **Short-run system balancing**. The study looks at time scales on an hourly basis, though does not consider seconds to minutes time scales. OCGTs and NaS batteries, however, have an almost instant ramping period and can be used for seconds-to-minutes system balancing.
- **Meeting peak demand**. Periods of low variable renewable generation are covered by flexible natural gas generation: low-capital-cost, high-marginal-cost gas is used to cover all-time peaks in during peak demand and periods of low storage availability due to low variable renewable energy (VRE) output. It is more cost effective for storage to be cycled daily to cover diurnal peak load.

[161] Marianne Zeyringer, James Price, Birgit Fais, Pei-Hao Li, Ed Sharp, 'Designing low-carbon power systems for Great Britain in 2050 that are robust to the spatiotemporal and inter-annual variability of weather', *Nature Energy*, vol. 3(5), 2018: pp.395-403.

- **Transmission network capacity**. The model increases transmission network capacity to allow high spatial diversity of VRE, an important measure.
- **Curtailment**. Excess production is either used to permit the daily cycling of storage or is curtailed.
- **Thermal plant efficiency.** OCGT is the only source of carbon-intensive generation considered, and thermal plant efficiency is not an issue for OCGT.
- **System Inertia:** This is not considered within this study.
- **Energy markets:** This report does not go into energy markets.

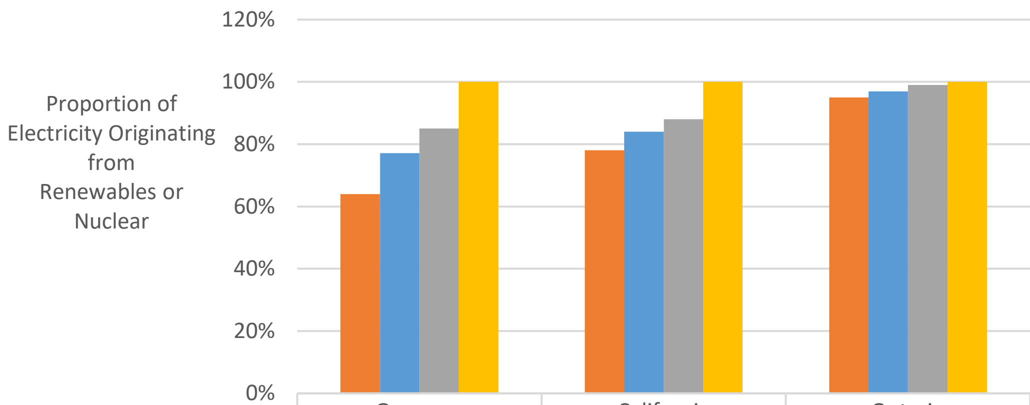
Since the research did not consider significant amounts of interconnector capacity or DSR as additional sources of flexibility, these options are considered below as additional enhancements that could be made to help optimise the energy system for renewables.

5.4.2 Comparison with research on other countries

Now that we have demonstrated the technical feasibility of balancing the 2030 grid, we will draw some comparisons to other countries where very high levels of renewables are planned or have already been achieved. There are multiple studies that demonstrate how intermittent renewable generation could reach very high levels of penetration, even to the extent of 100% penetration on the grid.[162,163,164] This assumes that renewables generation is scaled up to meet the demand of the countries studied.

One study by Taneja *et al*. in particular has analysed in-depth the potential for high levels of penetration on grids in Germany, California and Ontario.[165] The study scaled historic supply profiles of wind and solar in all three grids, while minimising overall lifetime costs of wind and solar in the respective countries to find how their operation effects the ability to match demand projections. Taneja *et al.*'s analysis calculates the excess generation that would result from scaling up the renewable generation to meet the respective demands in those countries. This is important as it quantifies energy waste (the higher the excess, the greater cost of renewables) and technical challenges (how the grid can address the large fluctuations in generation). Therefore, it is an important indicator of both appetite and grid capability to accommodate higher renewable energy penetration. In all situations, the paper states that 100% renewable penetration can be met. It does however take into account that this 100 % penetration would result in huge excesses in generation (>100% that required) and therefore it considers which penetrations of renewables would be easier to accommodate for grid operators and consumers. The findings are summarised in Figure 43.

[162] 'Renewable Electricity Futures Study', National Renewable Energy Laboratory, https://www.nrel.gov/analysis/re-futures.html.
[163] Australia Energy Market Operator , *100 Percent Renewables Study – Draft Modelling Outcomes,* https://www.environment.gov.au/system/files/resources/d67797b7-d563-427f-84eb-c3bb69e34073/files/100-percent-renewables-study-modelling-outcomes-report.pdf
[164] *100% Renewable Electricity – A Roadmap to 2050 for Europe and North Africa*, PricewaterhouseCoopers, https://www.pwc.co.uk/assets/pdf/100-percent-renewable-electricity.pdf
[165] Jay Taneja, Virginia Smith and David Culler, A comparative study of high renewables penetration electricity grids, University of Berkeley - http://users.ece.cmu.edu/~smithv/docs/renewables_sgc_2013.pdf



	Germany	California	Ontario
10% excess generation	64%	78.00%	95%
25% excess generation	77%	84.00%	97%
50% excess generation	85%	88.00%	99%
Hard limit	100%	100%	100%
Assumed proportion of grid supplied by nuclear or hydro	0%	28%	57%

Figure 43. Graph showing the proportion of renewable or nuclear energy that can be achieved with different excess generation thresholds.

It is important to note that the study assumes no storage or DSR, which if used would help minimise the necessary supply, mitigating its negative implications. The use of energy storage from lithium-ion batteries, pumped hydro or other storage technologies would enable wasted energy to be used at other times, resulting in a smaller capacity of renewables to achieve these proportions. The graph indicates that the total penetration of renewables or nuclear for each locale is closely linked to the proportion of electricity originating from nuclear and hydro. Ontario can have 95% penetration (38% from wind and solar) with only 10% excess of supply. In comparison Germany is limited to 64% penetration (all of which is solar and wind) due to having no nuclear in future systems.

Extrapolating from these results, one could assume that the UK – which could still maintain nuclear, further develop its hydro and utilise interconnectors – would fall in between Germany and California. If the UK's capacity of baseload supply (hydro and nuclear) can be maintained between 20 and 30%, then it can achieve 80% renewables-or-nuclear penetration without exceeding 25% excess of generation.[166] It is important to note that Taneja *et al*. do not take into account transmission limitations or upgrades, nor does it discuss whether or not achieving the scale of annual generation from solar and wind needed is possible.

In summary, all the above research implies grid balancing is possible for renewable and low-carbon scenarios, and both cases use less than a full complement of options. Next section explores these options to further improve stability beyond the above research.

Recommendation 28: **Research shows that there are viable solutions that will enable balancing of demand and supply for the scenario outlined in this strategy. Therefore, there is no need to delay delivery of Recommendations 1-25.** As an example, the lights would stay on with the energy system outlined here_by maintaining current backup gas generation capacity in the 2020s; expanding power storage to at least 20GW; and investing in grid enhancements. This demonstrates that there are definitely workable solutions, and so work on goals 1,2 and 3 can begin in earnest, right away.

[166] This assumes that the capacity factors of wind and solar are similar in the UK to Germany.

5.5 Further solutions for balancing supply and demand

Section 5.4 above shows how it is entirely possible to ensure the lights stay on with just a portion of the available resources for grid balancing. To give even greater confidence that the system will remain balanced and power will be available when needed, this section demonstrates that there is in fact much greater balancing capacity available from a set of other additional sources, in particular DSR, interconnectors, and greater short-term storage. These are all entirely additional to the systems described above.

5.5.1 Demand-side response: available capacity

DSR actions are defined as changes in electric use – by demand-side resources – from their normal consumption patterns in response to changes in the price of electricity, or when system reliability is jeopardized. Demand-side measures are generally designed to either enable load curtailments in times of peak demand or to shift loads to times of low demand.

According to Hans Christian Gils's 2014 paper on theoretical demand-side potential, the UK's current theoretical maximum potential for DSR is around 40 GW.[167] The paper considers a total of 30 different processes and appliances from the residential, tertiary and commercial sector. The majority of the DSR potential is however found in the residential sector, which makes it unlikely that the full potential will be able to be realised due to impacts on comfort and convenience.

A 2017 report by Poyry and Imperial College London looked at the system-wide benefits of integrating new sources of flexibility. That paper gives a number of different scenarios for the amount of DSR that could likely be achieved by 2030.[168] The scenarios considered are low, medium and high levels for a given flexibility technology. The potential GWs of capacity that DSR could provide in the low, medium and high cases by 2030 are 3.42GW, 10.26GW and 17.1GW respectively. While the high-capacity case is considered highly optimistic, it is not unlikely that 10.26GW of DSR capacity will be available to help balance the grid by 2030.

Our scenario proposes levels of heating-network electrification that are also likely to lead to significantly higher DSR potential. If thermal storage was also considered in the retrofit programme, the load increase resulting from electrification of heat could be majority demand-side managed.

DSR programmes require information and communication infrastructure allowing for the transmission of and reaction to load, price and control signals. Markets for flexible loads range from on-site peak load reduction and increased internal PV consumption to participation in energy trade, the provision of operating energy and the clearance of imbalances in the transmission system operator (TSO).

The successful implementation of DSR techniques is contingent on the willingness of residential, industrial and tertiary consumers to accept them. This, in turn, depends on any negative effects the techniques might have on these consumers.

DSR is another possible source of network flexibility that could be used to directly reduce peak energy demand. Under Poyry and Imperial's medium-level scenario the 10.6GW of DSR would represent a serious reduction in peak demand. Currently, electricity demand peaks at just under 60GW in winter and 40GW in summer. Some residential DSR would be required for such high levels. The use of price signals could encourage consumer acceptance, as there would inevitably be a price where you would have residential buy in. Whether approach was worthwhile, however, would depend on determining the most cost-effective ways of enhancing system flexibility.

This very significant extra capacity (up to 10GW of instantaneous demand management through DSR) gives

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[167] Hans Gils, 'Assessment of the theoretical demand response potential in Europe', *Energy*, 67, 2018: pp.1-18.
[168] *Roadmap for flexibility services to 2030,* Imperial College London, Poyry, 2017.

further confidence that a high renewable and low-carbon energy system in 2030 would be manageable.

5.5.2 Interconnectors: available capacity

Interconnectors are physical links that connect electrical transmission systems of two countries together, enabling a country to access the grid systems of other countries. Due to the UKs geographical position, all interconnector transmissions to and from the UK are via subsea cables.

This helps the UK and other countries to access cross-border VRE generation, reduce investment in peak demand generation capacity, improve grid security and take advantage of the international energy trade market. The UK currently has access to 4GW capacity through interconnectors. This is approximately 5% of the UK's current electricity generation capacity.[169]

Ofgem intends to run five cap and floor regimes to encourage capacity growth and investment for interconnectors.[170] The cap and floor regime principles have been created by Ofgem to ensure that the annual operating expenditure and service debts of the interconnector operators are met while capping the revenues shared with the equity investors to ensure that sufficient but not excessive returns are distributed to them.[171]

As of July 2018, two regimes have been held successfully in 2014 and 2016. The completion of all the projects in the first regime window alone will increase the interconnector capacity from 4GW to 11.7 GW by 2023 and to 17.9GW if all the projects in window 2 and Aquid (interconnector outside of the floor and cap regime) were to proceed. [172] The capacity should increase to 20GW by 2035 according to National Grids Two Degree scenario. Furthermore, if the remaining three cap-and-floor regimes are conducted in the near future, the interconnector capacity could surpass the 20GW capacity by 2035.

Currently active interconnector projects in the UK connect France, Denmark, Norway and Ireland to the UK's grid. Other upcoming and potential projects could further connect the UK to Germany, Iceland, Belgium and the Netherlands.

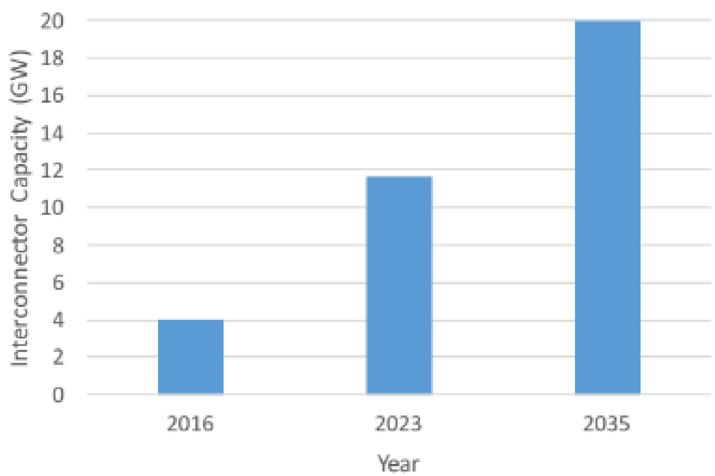

Figure 44. Timeline of potential interconnector capacity (GW)

[172] https://www.ofgem.gov.uk/electricity/transmission-networks/electricity-interconnectors

The key factors for any interconnector development depend on enabling regulatory, climate change and political environment. The biggest barriers are currently uncertainties that exist due to the lack of post-BREXIT policies regarding non-EU electricity export/import charges and whether the UK power sector will invest in technologies that enable the UK to keep pace with the EU's accelerated transition towards an EU smart grid.

If it is assumed that interconnector capacity of at least 20GW is built by 2035, the interconnectors alone could help meet 19% of the 105GW 'intermittent generation' projections stated above in this report. That potential equals approximately 36% of the current electricity peak demand.

In addition to the benefits of interconnectors already considered, the suggested interconnectors will provide multiple links to the upcoming EU smart grid. Their deployment will help make the UK resilient to events such as a Beast from the East and will also help utilize renewable power generating from countries across Europe during days or seasons when UK renewable generation is low. This potential provides further confidence that the UK will be able to meet energy demand on both a short- and long-term basis throughout the year in 2030.

5.5.3 Expanded short-term storage: available capacity

The work in Section 5.4 describes a total of 10 GW of storage as being sufficient. However other research outlines there is even greater capacity than this should the UK need it. Storage enables short- and long-term intermittency to be addressed by performing grid-balancing measures, primarily frequency response and reserve necessary for a grid to operate correctly.

Historically this sector has been dominated by pumped storage, which has been relied on for the 'black start' of the grid (if the entire grid goes down) and daily or weekly arbitrage of electricity to ensure that supply matches demand, with excess generation stored until there is a shortage. Currently there is 2.8 GW of pumped storage capacity split according to the table below[173].

Table 20 UK pumped storage facilities

Project	Year of Commissioning	Capacity (MW)
Dinorwig	1984	1,728
Foyers	1975	305
Cruachan	1965	440
Ffestiniog	1963	360
Total		2,833

There is scope to vastly increase the amount of pumped hydro storage with Day *et al*. suggesting there is 514 GWh of storage potential in the UK.[174] However, such sites are far from UK centres of energy demand and physically limited, meaning that there are likely to be significant costs involved in connecting projects to the grid. Also, there has not been a new scheme since 1984. The National Grid low-carbon scenario, which includes 18.3 GW of storage by 2040, will therefore be met by a mix of technologies.[175] Innovation in this sector has been substantial and other technology options offer an alternative storage mechanism for balancing supply and demand. In particular, growth in lithium-ion batteries has been very significant due in part to their largescale use in EVs driving down costs.[176]

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[173] http://www.r-e-a.net/upload/rea_storage_report-web_accessible.pdf
[174] Day, G., Foote, P., McCloy, D. & Wilson, G. Storage Available. University of Strathclye (2004). at http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/wind/content/storage available.html
[175] http://fes.nationalgrid.com/
[176] http://www.r-e-a.net/upload/rea_storage_report-web_accessible.pdf

The deployment of lithium Ion batteries is therefore predicted to be very large as their cost comes down in the future. In the UK, there are currently 453MW of new storage projects that are planned or in development, including at least 1,500 residential battery projects.[177] This number is thought to understate the long-term growth of these batteries, however. UK Power Networks reports having received 12.2GW of storage capacity over 15 months in 2016/7.[178]

Other technologies, including other battery chemistries and gravitational storage typologies, are also receiving a large amount of investment with pilot schemes deployed on grids around the world. These are likely to compliment the offering of pumped hydroelectric storage and lithium-ion batteries having advantages of these two now incumbent technologies. Moving forward lithium-ion batteries have massively increased in uptake with the predicted capacity to more than double in the next year alone, and there also appears to be great potential for redox flow batteries.[179]

5.6 Ensuring long-term energy security and the Beast from the East

Seasonal storage is the storage of electrical or thermal energy over several days to several months. This storage is currently required to meet supply and demand imbalances to provide heating over a sustained period of time in the winter, and electricity in gas-fired power plants on a daily basis. Seasonal thermal energy is stored in natural gas within underground salt caverns. The seasonal variations in demand are a consequence of the overall gas demand in the winter being higher than in the summer. The importance of providing energy in winter months became evident when the National Grid issued a gas deficit warning on 1 March 2018 for the first time in eight years when the UK experienced a cold wave that led to unusually low temperatures and heavy snowfall, which was dubbed the Beast from the East by the media.[180] Hydrogen can be stored in underground salt caverns in a similar way to natural gas.

The 2017 closure of Centrica's Rough gas storage facility, which represented around 70% of the UK's gas storage capacity, and the more recent shutdown of EDF's Hole House have left the UK able to cover only seven days of gas demand from storage. [181] Large-scale gas storage facilities are unlikely to be built in the near future due to low returns. However the government is confident that market forces will be able to meet gas demand with imports, which are predicted to be 80% by 2030.[182] [183] The market has responded recently with the conversion of salt caverns into small-scale gas storage facilities[184].

The UK's current seasonal storage infrastructure arrangements suffice for this strategy, and will at least until the late 2030s. This is because most of heating will still be connected to the gas grid until then, while an increasing proportion of buildings will make use of heat pumps over time. The gas grid with current gas imports and storage can already meet peak demand. From the late 2020s to early 2030s, the UK must move off gas – either onto full electrification, or to include some hydrogen for heating. Either way we will need a new way of providing winter peak power, which will require storing renewable energy. There are multiple long-term seasonal storage options for this, but the leading one is hydrogen storage.

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177 https://www.r-e-a.net/news/new-data-shows-extent-of-existing-energy-storage-deployment-and-planned-projects-in-the-uk
178 https://theenergyst.com/energy-storage-boom-uk-power-networks-receives-12gw-of-connection-applications/
179 https://electrek.co/2017/12/21/worlds-largest-battery-200mw-800mwh-vanadium-flow-battery-rongke-power/
180 Jonny Bairstow, 'National Grid: UK has enough gas and power to last the winter', Energy Live News, 11 October 2018, https://www.energylivenews.com/2018/10/11/national-grid-uk-has-enough-gas-and-power-to-last-the-winter/.
181 *The UK's need for gas storage: a persistent and growing challenge,* Wood Mackenzie, 2018, https://www.woodmac.com/reports/gas-markets-the-uks-need-for-gas-storage-a-persistent-and-growing-challenge-33032.
182 'Oral evidence: Gas storage, HC 1666', BEIS, 2018, https://www.parliament.uk/business/committees/committees-a-z/commons-select/business-energy-industrial-strategy/inquiries/parliament-2017/inquiry11/
183 'UK gas supply "precarious" without government intervention', Utility Week, 2018 https://utilityweek.co.uk/uk-gas-supply-precarious-without-government-intervention/.
184 Adam Vaughn, 'Salt caverns double as UK gas stores to beat cold snaps', *The Guardian*, 13 January 2019, https://www.theguardian.com/business/2019/jan/13/salt-caverns-double-uk-gas-stores-cold-snaps-beast-from-the-east

Stored hydrogen will be created by power-to-gas, which is when excess renewable energy not in use is used to generate hydrogen and oxygen from water through electric hydrolysis. This can avoid the need for renewables curtailment and enable large-scale inter-seasonal energy storage.[185] Power-to-gas systems have been tested across the world, although the UK has only funded desk studies to date. The stored hydrogen can then be converted into electricity with multi-MW-scale gas turbines for peak power production. Or it can be transported to homes for heating and cooking via pipe networks. See Appendix C – Role of Hydrogen for more detail on other uses of hydrogen.

The UK currently has no grid-scale hydrogen storage facilities. Gaseous hydrogen is stored predominantly in above-ground steel cylinders at a pressure of 200-700 bar.[186] The construction material properties impose limitations on the quantity of hydrogen that can be stored, hence these would only be relevant for intraday storage. The UK has had a number of small (sub 100kW regeneration scale) hydrogen storage demonstration facilities, such as the Hydrogen Office in Fife from 2008 to 2014 and the Hydrogen Centre at the University of South Wales, which is still in operation.[187] [188] Recently the opening of BIG HIT facilities took place on the Orkney Islands of Scotland, recognised as a leading project in Europe, in which hydrogen is stored in tube-trailers to fuel a 75kW fuel cell. [189]

The comparatively low construction costs of salt cavern storage make it much cheaper than surface storage in cylinders.[190] Over 400 billion m^3 of natural gas is currently stored underground worldwide.[191] Hydrogen is already stored in salt caverns in the UK and USA, supporting chemical plants and oil refineries.[192] The use of underground salt caverns for hydrogen is considered essentially mature, with hydrogen stored at pressures up to 120 bar. Alternative geologic hydrogen stores, such as aquifers, depleted gas fields, rock caverns and abandoned mine sites, require testing to demonstrate that they could be safely used.

A 2015 study by the ETI showed that the UK has sufficient salt bed resources to provide tens of GW of electricity. A set of six caverns could hold 600GWh of hydrogen, yielding 150GWh of electricity on a seasonal basis or 30GWh on a daily basis. This is comparable to the current pumped hydro storage capacity of the UK, indicating that we will have sufficient salt cavern space to store hydrogen in the long run, making it an ideal storage solution. The UK is well placed to convert its natural gas system to hydrogen and it will be important to ensure resources are spent on planning for hydrogen storage. The H21 Leeds City Gate project was a feasibility study on converting the natural gas network to a hydrogen network using inter-seasonal storage for the city of Leeds.[193] BEIS is currently undertaking a £25 million Hydrogen for Heat programme, a three-year feasibility study aiming to establish if it is technically feasible and safe to convert natural gas with hydrogen in residential and commercial buildings and gas appliances.[194]

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185 N. P. Brandon, J. S. Edge, M. Aunedi, *UK Research Needs in Grid Scale Energy Storage Technologies*, Energy SUPERSTORE, 2016.
186 *The Role of Hydrogen and Fuel Cells in Future Energy Systems,* H2FC Supergen, Imperial College London, March 2017.
187 Bright Green Hydrogen, Hydrogen Office Project.
188 H2 Wales, Hydrogen Centre.
189 *BIG HIT creates exemplar 'hydrogen islands' energy system for Orkney*, ITM Power, 2018.
190 *Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Long Term Storage of Renewable Electricity by Hydrogen Underground Storage in Europe*, HyUnder project report D2.2, 2014.
191 *Systems Analyses Power to Gas*, DNV Kema, 2013.
192 'The role of hydrogen storage in a clean responsive power system', Energy Technologies Institute, 2015.
193 'H21', Leeds City Gate, 2016.
194 'Hy4Heat's Mission', Hy4Heat, 2018.]

Recommendation 29: Build on analysis in this report to develop a "UK-wide energy infrastructure coordination strategy" to ensure whole system view across electricity generation and supply, heat generation and supply, building retrofit and transportation. An urgent (completed by end 2020 at the latest) and detailed strategy to ensure delivery that is coordinated and minimises cost and maximises efficiency, and in particular:

- **Identify opportunities for win-win coordination points across sector role out strategies.** Such as installing EV charging or ensuring smart appliances and heating to allow grid balancing in homes when retrofitting, as well as coordination of hydrogen use for localized buildings heating and centralized power storage.
- **Model the ideal mix of energy balancing solutions to ensure supply and demand are balanced.** Including hourly modelling and consulting with regulators, generators, academics and system operators; covering technologies such as: demand side management, back-up/peaking generators, power storage (pumped hydro, batteries, pressurized air etc), interconnectors, digitisation and smart meters, short term heat storage, EV smart charging and vehicle to grid (V2G), role of hybrid heat pumps in meeting peak demand, and so on.
- **Long-term electricity and heat storage** – especially for managing long cold stretches, which becomes more important as we shift from natural gas to other forms of heating, such as hydrogen and electricity based options.

5.7 Impact of storage on overall demand: losses

As discussed, given intermittency levels of 69%, it is almost certain that high levels of energy storage will need to be used, largely in the electricity component of the system. Since there are losses associated with storing and then retrieving electricity, this will have an impact on demand, increasing the volume of renewable and low-carbon electricity that is must be supplied.

Estimating the real scale of this impact is challenging at this stage given the uncertainties around final storage volume, energy vector, technology and use. However, to ensure a conservative assessment is made, this study has assumed that that 30% of intermittent generation will need to be stored for later use, and that the round trip losses of doing so are 15%.[195] This means that with the generation mix described in Section 4.4, a total of 13TWh of renewable and low-carbon generation will be lost and will need to be replenished. This total is therefore added onto the total renewable and low-carbon demand, as shown in Figure 22.

[195] Both the 30% and 15% assumptions are based on estimates.

5.8 Summary of recommendations

Recommendation 28: **Research shows that there are viable solutions that will enable balancing of demand and supply for the scenario outlined in this strategy. Therefore, there is no need to delay delivery of Recommendations 1-25.** As an example, the lights would stay on with the energy system outlined here_by maintaining current backup gas generation capacity in the 2020s; expanding power storage to at least 20GW; and investing in grid enhancements. This demonstrates that there are definitely workable solutions, and so work on goals 1,2 and 3 can begin in earnest, right away.

Recommendation 29: Build on analysis in this report to develop a "UK-wide energy infrastructure coordination strategy" to ensure whole system view across electricity generation and supply, heat generation and supply, building retrofit and transportation. An urgent (completed by end 2020 at the latest) and detailed strategy to ensure delivery that is coordinated and minimises cost and maximises efficiency, and in particular:

- **Identify opportunities for win-win coordination points across sector role out strategies.** Such as installing EV charging or ensuring smart appliances and heating to allow grid balancing in homes when retrofitting, as well as coordination of hydrogen use for localized buildings heating and centralized power storage.
- **Model the ideal mix of energy balancing solutions to ensure supply and demand are balanced.** Including hourly modelling and consulting with regulators, generators, academics and system operators; covering technologies such as: demand side management, back-up/peaking generators, power storage (pumped hydro, batteries, pressurized air etc), interconnectors, digitisation and smart meters, short term heat storage, EV smart charging and vehicle to grid (V2G), role of hybrid heat pumps in meeting peak demand, and so on.
- **Long-term electricity and heat storage** – especially for managing long cold stretches, which becomes more important as we shift from natural gas to other forms of heating, such as hydrogen and electricity based options.

6.

Electrification of transport.

6.1 Chapter Summary
ELECTRIFICATION OF TRANSPORT

CHAPTER BACKGROUND

This briefing paper aims to set out how to maximise contribution of renewable and low-carbon electricity and heat in buildings by 2030, as such it does not explicitly focus on transport energy. This is partly due to uncertainty in the transport sector about the pace and scale of electric vehicle (EV) rollout, and the scope set by the Labour Party for the project.

However, given that the transport, energy and building sectors are vitally interdependent, this section considers the impact of increased EV use on maximum renewable and low-carbon energy by 2030, as EV use represents the most significant intersectionality between these sectors. This work has not considered aviation or shipping.

CHAPTER FINDINGS

- EV use is expected to expand dramatically by the 2030s, with Labour Party policy aimed at around 21.5m EV's by 2030[196]. Depending on national policy, EV use could even expand to 25m. Analysis of pathways to reach a 1.5ºC climate target indicates that even if all new cars are ULEVs by 2035 at least 20% mileage reduction and, depending on modelling assumptions, up to 60% mileage reduction will be required, implying a large and rapid shift of journeys to other modes of transport**.** Despite this, expanding EV use could increase UK electricity demand in 2030 by around 10%.
- There are tremendous links between the rollout of EVs and decarbonisation of electricity, both in terms of the volume of electricity required across the UK and how both sets of infrastructure could interact and support each other.
- This report considers how to meet 100% of anticipated EV electricity demand with renewable and low-carbon electricity, and how to add the resulting generation requirement to the generation capacity described in prior chapters for electricity for buildings.
- The increased generation capacity necessary to also meet transport electricity from renewable and low-carbon sources could be achieved in various ways, with around 11GW of extra capacity required.
- It is difficulat to predict the outcomes and impacts of other changes in UK transport – such as increases in vehicle sharing, public transport use and autonomous vehicles; so those changes have not been considered in this report.
- It is considered unlikely that hydrogen will be used at a large scale in transport before 2030, and so hydrogen for transport has not been explicitly in this work.

CHAPTER EVIDENCE

This chapter is based mainly on the data supporting the ***National Grid Future Energy Scenarios 2018***.

CHAPTER CONTENT

The chapter includes the following content:

- Background
- Transport and energy sectors are intimately linked
- Energy impacts of future changes in UK ground transportation
- Anticipated electricity demand from electric vehicles in 2030
- Impact of including EV energy demand
- Summary of recommendations

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[196] Labour Party - The Electric Revolution: Industrial Strategy for the Electric Car and Automotive sector

6.2 Background

Steps one to four of the strategy proposed in this report represent the core recommendations for maximising renewable and low-carbon energy by 2030 in sectors outside of transportation. Some aspects of transportation, though, are so interrelated that they must be discussed to deliver a full picture of how energy demand and supply will evolve towards 2030. To that end, this chapter examines the impact of shifting road-based vehicles from fossil fuel to renewable power. In particular, it reports on how increased electric vehicle (EV) use will affect the maximum feasible level of renewable and low-carbon supply, but only as it relates to the supply of renewable and low-carbon energy. It does not make any transport strategy recommendations, nor does it consider the broader scope and impacts of transport.

6.3 Electric vehicle targets

The Labour Party has recently announced its strategy "The Electric Revolution: Industrial Strategy for the Electric Car and Automotive sector". This includes a raft of measures to support and accelerate the roll out of EV's manufacturing and use in the UK. This includes the policy of requiring all cars sold from 2030 are full EV's. It is stated in the strategy that this would result in around 21.5m EV's on UK roads by 2030. This is therefore taken as the background level of EV's use in 2030.

6.4 Transport and energy sectors are intimately linked

This document has focused on building energy use and supply, at the request of the Labour Party, partly due to uncertainty in future EV use. Therefore, the analysis in previous chapters has *not* included the energy used by transport, and so ignores the very likely growth in electricity demand for transport from the increased use of electric vehicles.

As stated in Section 5.3 above, it is also true that the necessary transitions in the transport, energy, housing and industrial sectors cannot in any way be treated separately or independently: These sectors highly interrelate. What happens in transport has a huge impact on power, as does heating, and vice versa. Any electric vehicles will be connected to the same grid as UK buildings; hence they will be fed by the same electricity mix. So even if transport energy demand has not been included in the total volume of energy against which progress is judged, action would need to be implemented in concert with activities in the transport sector.

As stated above, it is therefore crucial that the maximum renewable and low-carbon energy by 2030 is developed in tandem with strategies for the electrification of transport. See Chapter 5 for more detail.

There are costs of not coordinating efforts, but the efficiencies of coordination are substantial. For instance, the large-scale use of EV batteries for bidirectional charging (or sending power from the vehicle back to the grid, known as V2G) presents tremendous opportunities for managing the local distribution network, or marrying EV charging to surplus renewable electricity generation. It is the firm view of the authors, the many experts consulted during this study, and most research on the topic that any effort to update and deliver a low-GHG, high renewable energy system requires very careful coordination with other key sectors.

For these reasons, while the analysis does not include transport energy, it is entirely reasonable that it could. This chapter explores the options and impacts for doing so.

6.5 Energy impacts of future changes in UK ground transportation

This section seeks to understand the likely scale of transport electricity demand in 2030.

Energy generation is not the only national system, or sector, undergoing a low-carbon transition. Regardless of the emissions-lowering changes proposed in the previous chapters of this document, transport will need to undergo significant change as well, both to reduce congestion and to move away from fossil fuels.

6.5.1 Likely relevant changes to transport sector

Changes in the transport sector likely to impact energy use include:

- **Electrification of transport**. The shift to electric vehicles is quickening and many expect the majority of, if not the entire, vehicle fleet to be electric by the middle of the century. Indeed, the current UK government strategy calls for a ban on new diesel and petrol vehicles– in other words, internal combustion engine (ICE) vehicles– by 2040 to reduce GHG emissions and improve air quality, particularly in the UK's cities.[197] The vast majority of uptake of electric vehicles over the next decade will be privately owned cars, but motorbikes and light goods vans in particular will see significant growth as well. As indicated in Figure 45, National Grid's FES indicates that there will be around 10 million electric vehicles by 2030, 25 million by 2035 and 36 million by 2040, at which point saturation will have been reached. Therefore, we present **a case that assumes 25 million EVs on the road by 2030, since this is closes to Labour's policy for 2030 (21.5m).** This figure represents 62% of the total UK vehicle fleet in 2030 and matches the FES EV projection for 2035. The assumption is that moving the UK policy target on EV vehicles forward to 2032 will also bring EV numbers forward by five years. Also, as noted in FES, the vast majority of EVs by 2030 will be full EVs, rather than plug-in hybrid electric vehicles (PHEVs), which will account for around 1.5 million of the total 10 million EVs in 2030, or around 4% of the total vehicle fleet. Countries such as the Netherlands and Norway have shown that, with the right incentives and regulatory environments, a very rapid transition to electric mobility is possible. The majority of cars sold in Norway are already electrified (when including plug-in hybrids), and fully electric cars made up 38% of the market in January 2019.[198] Particularly while original-equipment-manufacturer EV supplies are low and ramping up, the policies of these nations help ensure that constrained supplies make their way to their markets.
- **Demand management of vehicle use.** Analysis of pathways to reach a 1.5^{o}C climate target indicates that even if all new cars are ULEVs by 2035 at least 20% mileage reduction and, depending on modelling assumptions, up to 60% mileage reduction will be required, implying a large and rapid shift of journeys to other modes of transport**.[199]** This is recognised as a key dynamic in the development of lower carbon transportation in the UK, however there has not been the resources in this project to model the impact properly. They would likely only result in a reduction in the modelled electricity demand from transport, and so not including this impact represents a more conservative approach, by over estimating the volume of electricity required for EV's. If in the end this volume is lower, it will only enhance the deliverability of low carbon energy for the UK.
- **Developments in EV technology that aid grid balancing.** With V2G operation, EVs are able to be charged from the national electricity supply when there is sufficient electricity available and also supply electricity back to the grid at times of constrained generation or transmission and distribution systems. Coupled with intelligent charging controls (smart charging), V2G has significant grid-balancing potential. The FES scenarios include V2G in their modelling, and so its impact is reflected in the peak demand outlined in Figure 46 and discussed below. High-power rapid charging hubs coupled with large, grid-connected batteries will also be able to provide balancing services – adding a value stream for large battery installations that provide wider low-carbon generation integration services.
- **Increased role for vehicle sharing**. Car pools and other car-sharing solutions are increasingly popular and will likely reduce vehicle use to a small degree. However, given limited project capacity, vehicle sharing has not been considered specifically in this work, and it is not clear if it has been considered in the FES scenarios.

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[197] https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017
[198] https://insideevs.com/norway-2019-strong-growth-of-ev-sales/
[199] Hopkinson L and Sloman L 2018 *More than electric cars* Briefing for Friends of the Earth, p.8, downloadable here http://www.transportforqualityoflife.com/policyresearch/transportandclimatechange/

- **Increased public transport.** The shift from unnecessary private vehicle use towards walking, cycling and efficient public transport is a vital component of climate policy aimed at a more efficient volume and use of private vehicles. This shift will likely reduce vehicle numbers (in particular personal cars) and vehicle use overall, and hence also demand for transport energy. The FES scenario captures these reductions in its modelling–which is why, for instance, car volumes decrease post 2040.
- **Autonomous vehicles.** By 2030 the level of autonomous vehicle (AV) use is expected to increase (by some estimates substantially), but still only be a small proportion of all vehicle use in the UK. AV use could result in fewer vehicles being on the road, by ensuring greater utilisation of vehicles. It could similarly lead to more intelligent vehicle charging patterns. The technology is still at an early demonstration phase. While potential is high, it is still too early to determine AVs' likely impact. Therefore, the impact has not been considered in any detail in this work.
- **Hydrogen use in transport.** It is increasingly clear that electricity will be the dominant replacement energy vector for fossil fuels in transport, except for niche uses in hauling heavy goods.[200] This is due to, among other reasons: rapidly and predictably falling costs of battery production; the simplicity and efficiency of the fully electric powertrain; the ease of energy distribution (EVs can already be charged based on the existing electricity network and do not require an entirely new distribution infrastructure); and difficulties in making low carbon hydrogen. The FES scenarios therefore only consider hydrogen vehicles becoming common by 2035, and only for heavy goods vehicles and buses or coaches, and even then only in the order of tens of thousands – miniscule compared to the wider UK vehicle fleet. This may change post 2040, but hydrogen is only feasible as a means of achieving climate targets if UK-wide *zero-carbon* hydrogen infrastructure is installed. However, this is beyond the timeframe of this work, and so hydrogen use for transport has been assumed to be zero for this work.
- **Other fuel use in road transport.** This work assumes that other forms of fuel, such as compressed natural gas or biofuels, will have very low penetration going forward. Biofuels (biodiesel and bioethanol) still create air quality and wider sustainability concerns that are a primary driver for shifting to electric vehicles. Natural gas, meanwhile, does not deliver the GHG emissions reductions required under UK climate policy.

[200] https://uk.reuters.com/article/us-volkswagen-electric-insight/bet-everything-on-electric-inside-volkswagens-radical-strategy-shift-idUKKCN1PV0K4

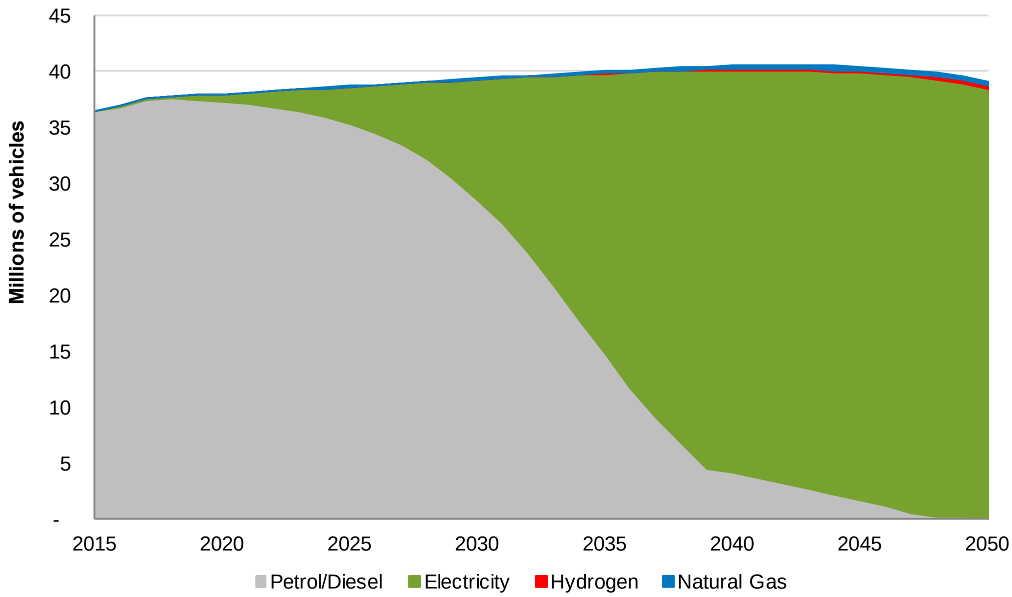

Figure 45. Number of EVs on the road under FES scenarios.[201]

There are other changes that are likely to be of some importance, such as the need to move to biofuel, electric and hydrogen-fuelled planes, or to other lower carbon forms of aviation. However, no attempt has been made to quantify the impact of these shifts due to uncertainty in future direction. Nevertheless, a curbing of aviation-sector emissions growth will be important in the 2030-2050 window due to the strong GHG reductions targeted elsewhere in the economy before then. Accordingly, efforts to shift the trend in this direction in the run-up to 2030 will be important, whether by reducing demand (trips) or carbon intensity.

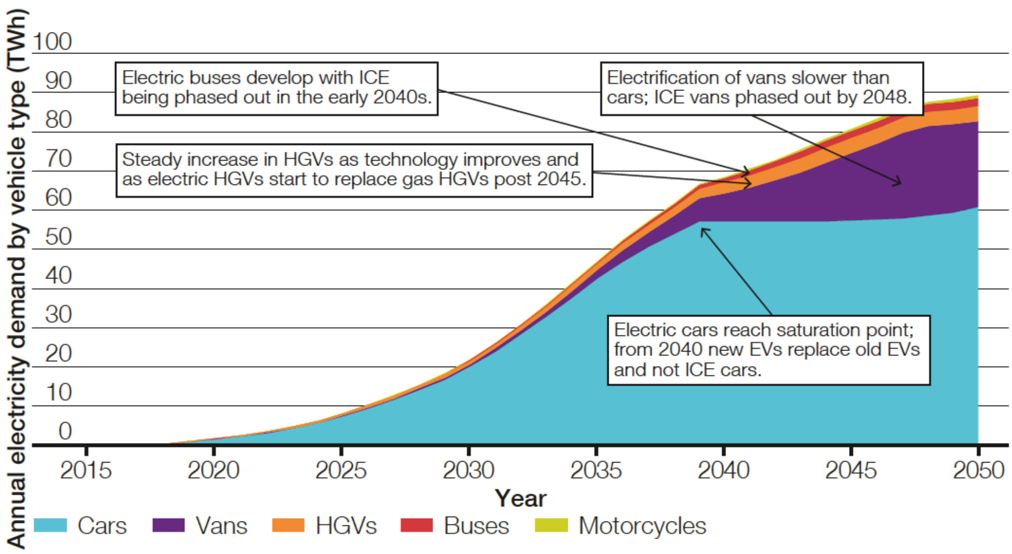

Figure 46. Expected mix of electric vehicles under National Grid's FES.[202]

[201] http://fes.nationalgrid.com/media/1366/2018-fes-charts-v2_as-published.xlsx

[202] http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

6.6 Anticipated electricity demand from electric vehicles in 2030

Figure 47 outlines the expected electricity demand annually resulting from EVs. Overall EV energy use reduces markedly over time, largely due to the higher efficiency of EVs. This figure does not account for the losses in generation and transmission of electricity.

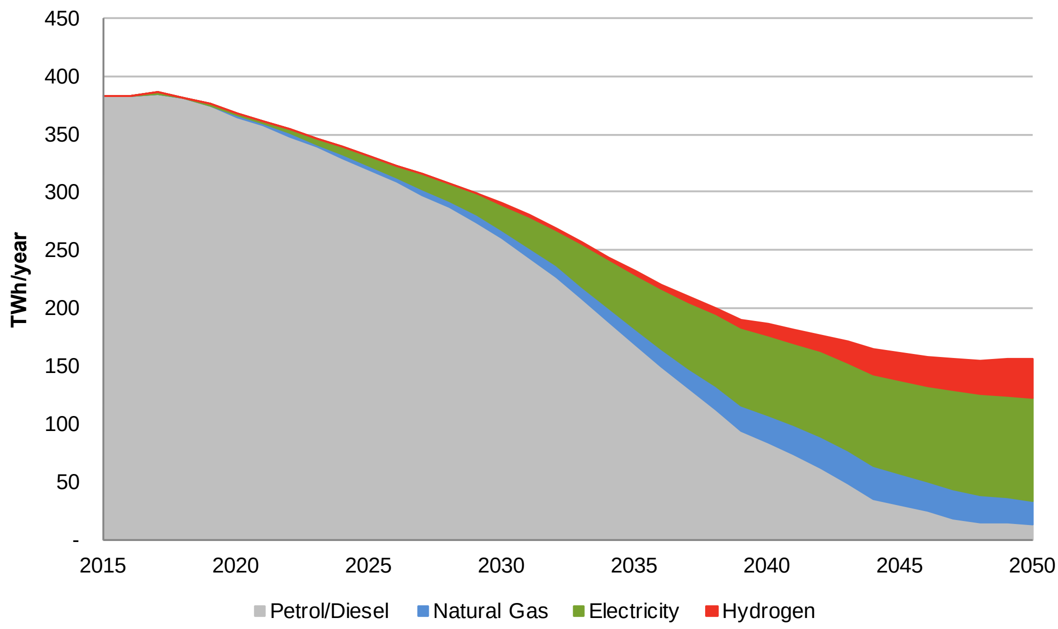

Figure 47 Annual electricity demand for EV's. Source (National Grid Future Energy Scenarios)[203]

The impact of both is outlined in Table 21, which demonstrates the substantially different consequences of these two assumptions. The more ambitious EV rollout results in a 7% rise in the renewable and low-carbon electricity required in 2030, a substantial increase given the very high levels of renewable and low-carbon penetration already outlined in Chapter 4 above.

Note that in the Table 21 calculations, we have ignored the fact that V2G smart charging may actually allow greater use of existing renewable capacity, in which case it would be 'free'. This is because we have no way of modelling the impact.

Table 21. Impact of EVs on renewable and low-carbon electricity demand in 2030.

Case	Total EV transport electricity demand in 2030 (TWh)	Increase in total UK electricity demand in 2030
25m EVs	45.3	10%

6.7 Impact of including EV energy demand

[203] http://fes.nationalgrid.com/media/1366/2018-fes-charts-v2_as-published.xlsx

6.7.1 Ensuring there is enough renewable and low-carbon electricity to provide annual electric vehicle demand

Compared to a total of 382TWh electricity needed (before losses) in the scenario outlined in the previous chapters (265TWh for power, 117TWh electricity for heating), the inclusion of electricity for transport represents a 10% increase in overall renewable and low-carbon electricity demand, to 427TWh/yr (before losses).

This is a nontrivial change, and so the inclusion of EV electricity will have a marked impact on the scale and capacity of electricity generation and transmission that is possible. This is particularly true if it is assumed that all electricity used by EV's should be from renewable and low-carbon sources. Indeed 45TWh represents an 11% increase on the amount of renewable and low carbon electricity generated by the system outlined in earlier chapters. The following section considers the feasibility of making this increase.

Table 22 below summarises how the renewable and low-carbon electricity generation capacity would need to increase from that outlined in Chapter 4 to accommodate all EV demand outlined in Table 21. These results are based on the project team's own modelling analysis and show that extra capacity of around 11GW is required to generate the extra energy required. Figure 48, which outlines the likely peak demand for EV's developed by the National Grid as part of their FES work (including the impact of smart charging in mitigating peak demand), demonstrates a figure.

Table 22 also offers an example generation mix for how this extra capacity could be met, with a focus on slight expansion of wind capacity, and then tidal and solar by small amounts. The estimates are based on the analysis of total available capacity undertaken in Chapter 4.

Component of 2030 strategy		Including electricity for EV's	Excluding transport electricity
Necessary electricity generation capacity (GW)	Wind off-shore	55.0	52.0
	Wind on shore	34.0	30.0
	Solar	35.0	35.0
	Marine (tidal range)	3.0	2.0
	Marine (tidal stream)	1.0	1.0
	Hydro	2.5	2.5
	Nuclear	9.0	9.0
	Biomass	3.0	3.0
	CCS	6.0	2.5
	Sub-total	148	137.0
	Fossil elec. generation	40.0	40.0
	Total elec. generation	188	177
	Extra renewable and low-carbon capacity	11	n/a
	Total renewable and low-carbon elec. (TWh)	448	403

Table 22. Change in generation capacity to accommodate EV transport electricity. Please note the EV case is purely an example and not a proposed scenario

6.7.2 Impact on peak demand versus annual generation

The impact of EV's on peak electricity demand will significantly depends on the sophistication of charging technology employed. The two main options are:

- **Smart charging** enables consumers to manage the time when their vehicle is charged. This could be to take advantage of lower prices or lower carbon electricity or to respond to external signals from third parties such as aggregators or network companies.

- **Vehicle-to-grid** (V2G) technology allows electric vehicle batteries to supply power to, or take it from, the electricity network. This gives the potential to help balance the electricity system at times of high demand or generation and provide operability services to network operators.

As can be seen in Figure 48 below, if these are both employed, the impact on peak electricity generation capacity could be as low as 3GW. This would imply that due to innovations in charging technology, the primary driver of increased generation capacity resulting from electrification of transport will be on an annual basis, to make sure transport remains low carbon, rather than due to there an extra addition to peak demand.

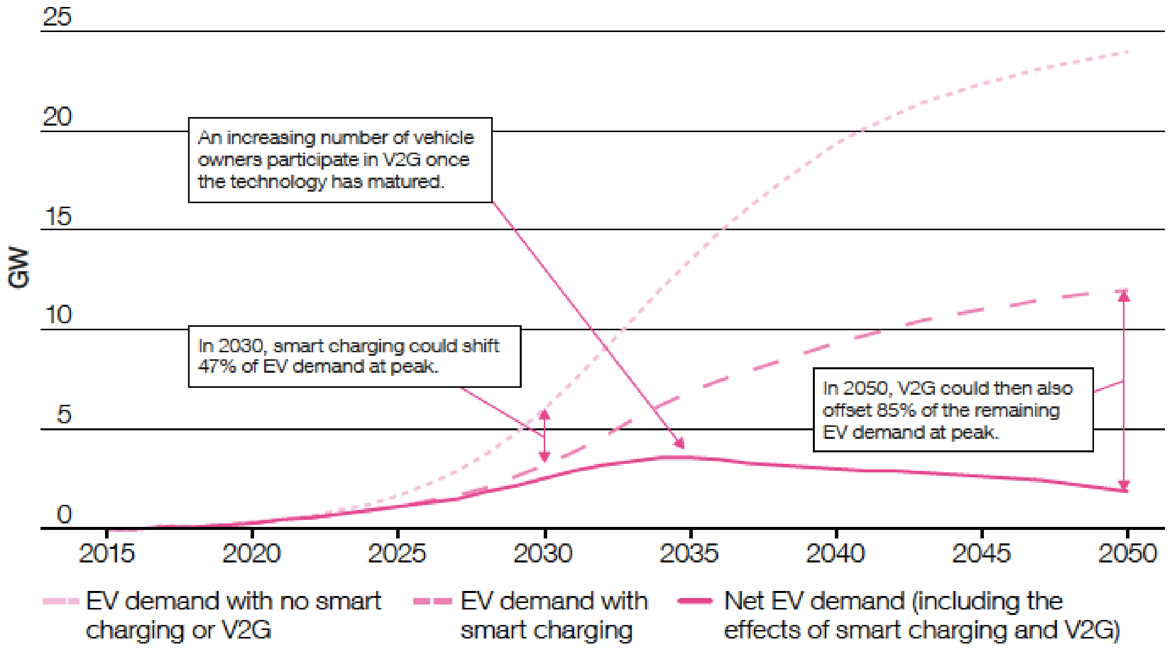

Figure 48. Peak power demand by year for EVs in National Grid's scenario modelling, under different assumption around charging behaviour.[204]

6.8 Summary of recommendations

Importance of developing an integrated plan for transport electrification and wider energy solutions is discussed in this chapter, however, is already covered in Recommendation 27.

Recommendation 30: Expand supply capacity to ensure that electrification of transport is matched by an increase in renewable and low-carbon energy generation. This study demonstrates that this is feasible based on likely rate of roll out of electricity vehicles.

[204] National Grid Future Energy Scenarios, 2019, http://fes.nationalgrid.com/fes-document/

7.
Climate change targets.

7.1 Chapter Summary
CLIMATE CHANGE TARGETS

CHAPTER BACKGROUND

This chapter considers the impact of delivering the above thirty recommendations on UK carbon emissions and whether this is consistent with achieving various climate change targets.

SUMMARY OF FINDINGS

- **Energy use is the UK's single largest emissions source**. Electricity and heat use in buildings, when taken together represent 56% of the UK total. The rest being mostly transport, agriculture and waste.
- **Delivering the goals and recommendations outlined in this document will result in UK energy emissions dropping to 77GtCO_2e per year in 2030**. Electricity emissions will have dropped by more than 80% to just 16MtCO2e in 2030, and heat by almost 50%, an entirely unprecedented amount. This is a net 65% reduction relative to 2017, 77% reduction relative to 2010 (the reference year used by the IPCC to track progress) and 81% relative to 1990 (the reference year used by the Climate Change Act and Kyoto Protocol).
- **This will ensure the UK would comply with the IPCC's "central" global average emissions reduction scenario for 1.5°C.** In its 1.5°C Special Report, the IPCC states that the average of interquartile range across its various model pathways (some of which include removal of emissions from the atmosphere post 2050) would represent a "global net anthropogenic CO2 emissions decline by about 45% from 2010 levels by 2030"[205]. The 77% reduction by 2030 relative to 2010 shows the UK would be is in a substantial leadership position relative to this "central" trajectory.
- **Most importantly, delivering the thirty recommendations would go even further, and ensure the UK on track to meet the IPCC's high ambition, "no-overshoot" 1.5°C scenario, avoiding the need for carbon emissions removal from the atmosphere, which the authors of this report consider to be the fairest and safest way forward.** All the other above scenarios assume that global carbon budgets are exceeded, and carbon emissions must be removed from the atmosphere in the second half of the century. Such methods are un demonstrated, and almost certainly far more complex, risky and resource and cost intensive than simply avoiding the emissions in the first place. It also may be too late by then in terms of runaway climate change. Instead it is much preferred that a global trajectory be established that simply keeps emissions within the carbon budgets set by the climate science. This is termed a "no-overshoot scenario". The thirty recommendations scenario meets all the specified criteria set out by the IPCC, and indeed *exceeds* them, in most cases by a large margin, **putting the UK in a position of global leadership, and providing a firm scientific basis under which to justify the immediate adoption of all thirty recommendations.**

CHAPTER RESOURCES

This chapter is built on evidence drawn from multiple sources, in particular:

- IPCC 1.5 Special Report
- Committee on Climate Change
- National Grid
- UK Governmnet (BEIS)

CHAPTER CONTENT

- Energy emissions in the UK
- Estimating the energy-related GHG impact of delivering the thirty recommendations
- Comparing to climate science and targets

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[205] https://report.ipcc.ch/sr15/pdf/sr15_headline_statements.pdf

7.2 Energy emissions in the UK

Energy in buildings, across electricity and heat, when taken together, is the biggest source of emissions in the UK. Figure 49 below compares the difference sources by individual sector. If energy and heat (heat representing the large majority of business and residential emissions outsides of supply) are considered separately, transport is the largest at 27%. When combining energy supply, and heating business and residential, this represents 56% of the UK's emissions in total. This is why this document prioritizes energy emissions.

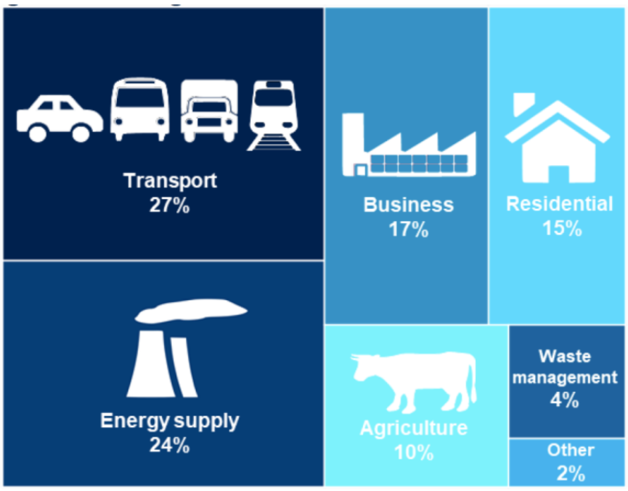

Figure 49 UK emissions sources in 2017[206]

The history of energy emissions is shown in Table 23 below, which is taken from UK government data. This shows that there have already been some substantial changes over the last 30 years, with 15% reduction over the twenty years from 1990 to 2010, and further 35% from 2010 to 2017. This is largely due improvements in energy efficiency and greatly reducing coal fired power generation, being replaced mostly by natural gas and renewable generation.

Table 23 Historical UK energy emissions. Source: UK government data[207]

Emissions source (MtCO2e)	1990	2010	2017
Power generation	204	158	73
Domestic (mostly gas for heating)	114	94	80
Industrial and commercial	80	88	67
Total	**398**	**340**	**220**

7.3 Estimating the energy-related GHG impact of delivering the thirty recommendations

The GHG emission impact of the changes has been estimate for 2030 by the team using the overall energy balance model and numbers, in particular the fuel mix profile across heat and electricity supply, and

206 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/776083/2017_Final_emissions_statistics_one_page_summary.pdf

207 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/789811/Final_greenhouse_gas_emissions_tables_2017.xlsx

comparing to the carbon intensities identified in Appendix D were then applied to these fuel mixes to find the total annual carbon produced. The modelled results are outlined in Table 24.

Table 24 Modelled UK energy emissions resulting from delivering the thirty recommendations and maximizing renewable and low carbon energy [Source: Project team's own analysis]

Emissions ($MtCO_2e/yr$)	**2030**
Direct electricity	16
Heating	61
Total	77

Comparing these figures to historical emissions, it can be seen that this represents very substantial reduction relative to historical emissions levels, as shown in Figure 50, with a two thirds reduction between current levels and 2030. This represents significant increase in the rate of decarbonisation compared to the previous decade, which is all the more significant given saving become harder and harder to achieve once the "low hanging fruit" has been picked. The "easy wins" of simply shutting down coal are not available, and instead rely on the vastly more complex task of decarbonising heating and reaching very high levels of renewable and low-carbon energy in power generation.

It is also an 81% reduction relative to 1990. Until very recently, an 80% reduction relative to 1990 was the level of ambition set by the Climate Change Act, but set for twenty years later than our current measurement date, in 2050. This demonstrates the very substantial increase in ambition shown as wider concerns about climate change continue to grow.

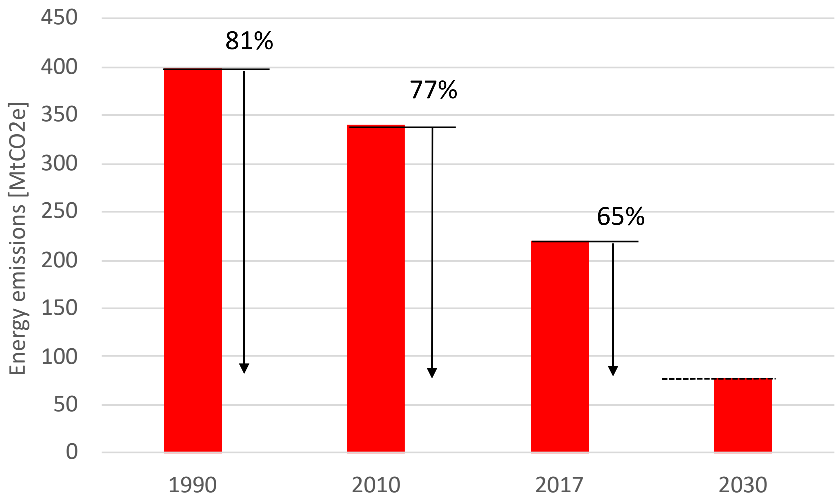

Figure 50 Historical measured emissions from 1990, 2010 and 2017, compared to measured emissions estimate if thirty recommendations implemented, showing per cent reduction achieved by 2030 relative to each. SOURCE: Project team's own analysis.

These significant reductions shown in Figure 50 are due to:

- Removal of all coal and oil for either heating or electricity
- Huge reduction in natural gas use across electricity, and substantial reductions in natural gas for heat.

As will be discussed in the following section, the IPCC in its 1.5 Special Report, uses 2010 as the main reference year, and so this report will do so also. Hence the 77% reduction is the figure that will be reported centrally in the report.

Acting upon the recommendations in this strategy is crucial to ensuring a climate-safe future for the UK, but it is only part of the necessary work required. It is key to note that all the GHG figures and conclusions in this chapter relate only to the energy sector (heating and electricity). They do not reflect the whole emissions of the UK—such as those from agriculture or transport. Nor do they reflect the carbon embodied in the consumption of imported goods. Therefore, any statement made below about whether the strategy outlined in this document achieves the ambition of either the Paris Agreement or Climate Change Act is only from the point of view of the energy sector's contribution. To deliver the Paris Agreement targets, very significant action will be required in other sectors.

7.4 Comparing to climate science and targets

This level of reduction would be a huge step up from anything put forward so far by a UK government, and put the UK far ahead of almost all nations around world, and certainly all comparably sized and industrialized nations. It is also a huge step up from current law, with the UK's official target remains the Climate Change Act, which demands a 100% reduction in emissions but by 2050. However, is it enough? What is the right target for the UK based on the climate science? This remains a complex topic and something on which further clarifying research should be undertaken. In the meantime, this section aims to clarify whether the thirty recommendations outlined in this study are sufficient to put the UK on a trajectory consistent with what the climate science says is necessary.

The UK is a signatory to the CoP21 Paris Agreement, which commits to limiting global warming to a minimum of 2 degrees, with the target of 1.5 degrees. The 195 countries recognized by the United Nations have now signed the Paris Agreement.

It is the aim of this section to determine whether the recommendations are aligned with the *full* scope of the Paris Agreement, and so that means a *1.5°C trajectory*. The following two sections compare the impact of delivering the thirty recommendations with two sets of evidence to determine if they will deliver a 1.5°C trajectory.

7.4.1 Comparing to the UK Committee on Climate Change Net Zero Carbon project

Since it's 2019 update, the UK's own Climate Change Act commits the UK to a net zero carbon economy by 2050, compared to its 1990 baseline (the level of emissions in 1990). This is a unilateral and legally binding commitment made by the UK parliament. This level of ambition has also been supported by the Committee on Climate Change which has stated that the UK should set 2050 as a date for zero carbon to be on a path to 1.5 degrees. When comparing to the energy decarbonisation trajectory set out by the CCC towards that zero-carbon target, the level outlined in this report can clearly be seen to be substantially more ambitious. Indeed, as will be discussed in Chapter 9, the thirty recommendations outlined in this document could well put the UK on a path to zero carbon well in advance of 2050.

The CCC's Net Zero Carbon report, indicates buildings industry and power emissions should be around 100GT by 2050 (Figure 5.3 page 143[208]). **As demonstrated at the start of this chapter, delivering the thirty recommendations will ensure the UK energy sector is well below that figure by 2030, twenty years earlier than the CCC net zero target, and hence meets and far exceeds the level of ambition required by the CCC.**

The CCC states this is necessary based on three factors: *capability* (the UK is richer than most other places, and emissions on a territorial basis are going down); *equity* (the UK has emitted lots historically, and consumes many products made abroad that contribute to others' emissions); and the importance of *showing leadership,* which gives more space for developing countries to keep expanding energy use. The CCC holds that the UK needs to be more ambitious than the world as a whole based on these factors, and the authors of this report agree. However, though their advice has been to set the target to zero carbon in 2050, to deliver our fair share of 1.5, it is not just a question of the end point, but the trajectory to get there, because it is the total, cumulative emissions between now and 2050 that determine whether

[208] https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

emissions budgets are kept to or not. It is like that we will need to reduce emissions quite substantially well before 2050. The CCC does not specify a trajectory to reaching the 2050 target, however the fact that the thirty recommendations deliver the necessary energy reductions many years early bodes well for this being in line with any such increased ambition.

7.4.2 Comparing to IPCC 1.5ºC "central" scenario

Analysis by the IPCC indicates that all countries will need to be zero carbon by 2050 to keep within a 1.5ºC budget. On this basis, as stated by the Committee on Climate Change[209] and National Grid[210], it is clear that the UK is currently far off course for meeting its Paris commitment based on current set of policies, with much greater ambition required.

However as will be outlined in Chapter 9, the recommendations outlined here will put UK on track for zero carbon energy well in advance of 2050, showing that on this simple metric the current plan is consistent with the global 2050 target set by IPCC.

However, it is not just about the long-term target, but about how you get there, and so an earlier target is important also. The IPCC recognize this, which is why in its 1.5ºC Special Report, the IPCC states that "in model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO2 emissions decline by about 45% from 2010 levels by 2030"[211]. The thirty recommendations outlined in this document would deliver a 77% reduction by 2030 relative to 2010, showing how those thirty recommendations would ensure the UK is in line with the short term requirements of 1.5ºC, and indeed far exceed it, at least from an energy point of view, and so demonstrate significant global leadership.

This 45% number set by the IPCC is the interquartile range of global average reductions by 2030 across various 1.5ºC compliant trajectories. Figure 51 outlines the IPCC's various global GHG reduction scenarios for meeting 1.5 degrees–P1, P2, P3, and P4. Each sees GHG emissions peak and start decreasing in 2020. However, each decreases with different gradients, depending on the assumptions made about carbon dioxide removal (CDR) solutions used later. When considering in-boundary, emissions the UK has already peaked its emissions. The 45% figure is the interquartile reduction needed across the P1, P2 and P3 scenarios.

[209] UK Committee on Climate Change Net Zero Report, https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf
[210] National Grid Future Energy Scenarios, 2019, http://fes.nationalgrid.com/fes-document/
[211] https://report.ipcc.ch/sr15/pdf/sr15_headline_statements.pdf

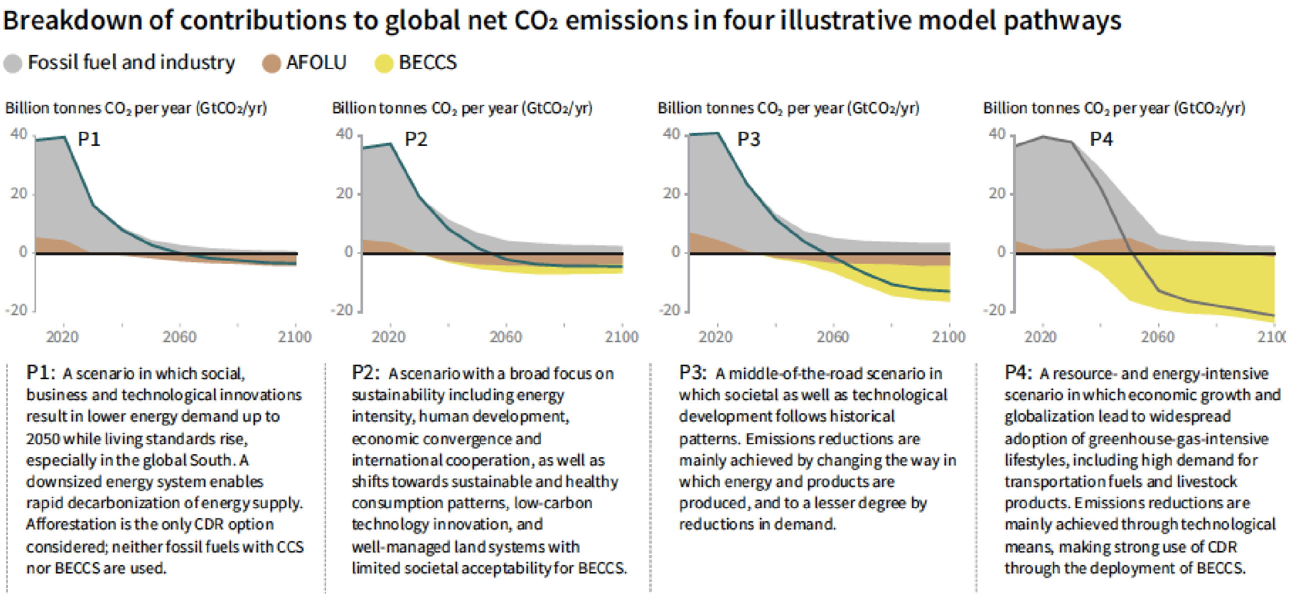

Figure 51. Global GHG trajectories for staying within the 1.5°C emissions budget.[212]

7.4.3 Comparing to IPCC 1.5°C high ambition "no overshoot" scenario

The IPCC considers scenario P4 a "higher overshot" scenario, meaning there are significantly more emissions by 2050 and beyond than are consistent with staying within carbon budgets, meaning large amounts of GHG require removal from the atmosphere. So much so in the case of P4, that half as much is being extracted per year in the second half of the century (around 20 $GtCO_2$), as is emitted per year in the first half (around 40 $GtCO_2$). This is considered to require implausibly huge volumes of bio-energy with carbon capture and storage (BECCS). Therefore, this is certainly not considered a safe trajectory for preventing catastrophic climate change.

This is also a big concern for P3 and even P2, owing to the fact that BECC's is currently un demonstrated, and almost certainly far more complex, risky and resource and cost intensive than simply avoiding the emissions in the first place. It also may be too late by then in terms of runaway climate change. Instead it is much preferred that a global trajectory be established that simply keeps emissions within the carbon budgets set by the climate science. This is the firm view of the authors, and it is recommended that the UK Government, indeed all governments, adopt such a position, for the safety of all today and in the future.

Further to this, it can be argued that the UK should establish a leadership position in driving forward emissions reduction. This could be the case even for a scenario that includes limited or no BECC's (which itself is a leadership position). This would require that the UK is working towards a position that is some way ahead of the average global targets required, to encourage others. There is no firm established approach for estimating how far forward this should under the UNFCCC. However, the following figure and table make a comparison of the impact of implementing the thirty recommendations, with the various targets implied in the IPCC P1 scenario, covering energy reduction, CO2 reduction, renewable energy and so on. These are taken directly from the IPCC's 1.5 Special Report. As can be seen, the IPCC's targets are all exceeded by a large margin, of around 20% or more (except for demand reduction). Demonstrating that by implementing the thirty recommendations in this document, the UK will indeed be occupying such a leadership position. This is a firm basis under which to justify the immediate adoption of all these recommendations.

[212] IPCC 1.5 Special Report, https://www.ipcc.ch/sr15/chapter/spm/

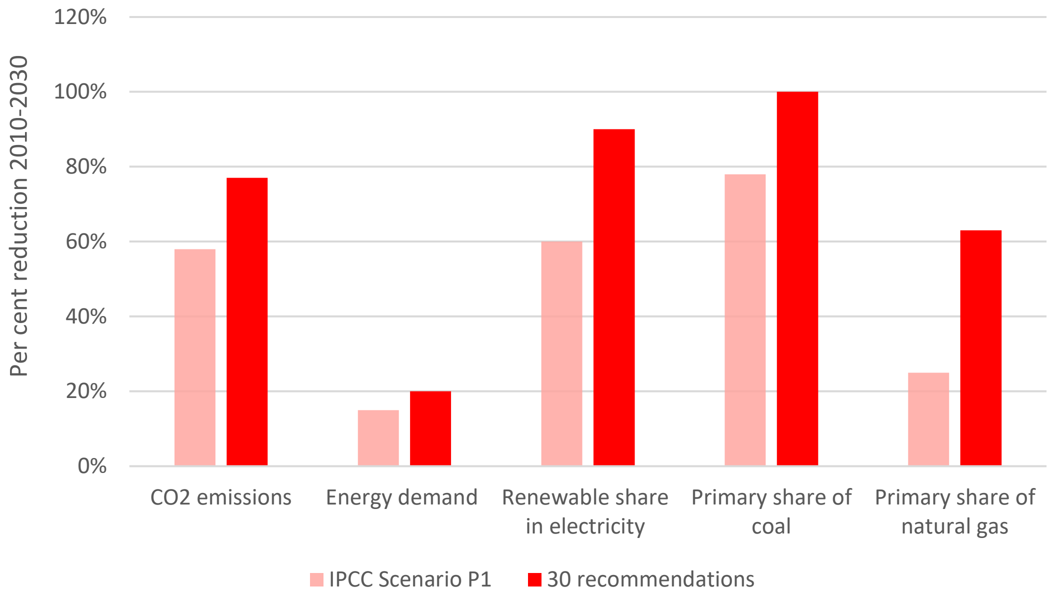

Figure 52 Comparison of thirty recommendations to IPCC's Scenario P1 (high ambition "no-overshoot" scenario, see following table for sources) showing significant overreach on all metrics

Table 25 Comparison of thirty recommendations to IPCC's high ambition, "no-overshoot" scenario, showing compliance on all metrics

Indicator	Per cent global decrease needed by 2030, relative to 2010, by IPCC scenario P1[213]	Per cent UK decrease achieved by 2030, relative to 2010, through thirty recommendations	Out performance of UK
CO_2 emissions	58%	77%	19%
Energy demand	15%	20%	5%
Renewable share in electricity	60%	90%	30%
Primary share of coal	78%	100%	22%
Primary share of natural gas	25%	63%	38%

The above provides clear evidence that by adopting the thirty recommendations, the UK would be implementing a program of work that would put it in a position of global leadership in delivering a 1.5^{0}C trajectory that does not depend on uncertain future carbon sequestration technologies. This is the safest and fairest way forward. It is also as outlined in the rest of this document, entirely possible, and hugely beneficial to the UK economy and public.

[213] IPCC 1.5 Special Report, Summary for Policy Makers, Page 16, https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

8.

Impacts on the economy, employment and public health.

IMPACTS ON THE ECONOMY, EMPLOYMENT AND PUBLIC HEALTH

8.1 Chapter Summary

CHAPTER BACKGROUND

The recommendations outlined in this report show that investing to maximise renewable and low-carbon sources by 2030 is not a pipe dream. It has also shown how this will require a transformation of UK building and energy infrastructure unlike anything seen in a generation, which will in turn require a likewise mobilisation of the UK workforce and industry. It will allow the UK to develop a more prosperous, 21st century economy, and address many of the root causes of multiple health issues affecting the UK population. This chapter aims to consider and quantify some of the most significant of these impacts.

SUMMARY OF FINDINGS

The over-riding conclusion from an analysis of the wider impacts of delivering the recommendations, is that there is a clear economic case for doing so, and so would be justified even were there no such thing as global warming.

Specifically, delivering the thirty recommendations would[214]:

- **Deliver UK wide economic benefits that *far* out way the economic costs**. The recomednations would require and investment of 1.9% of GDP each year, however this would be more than balanced by the resulting value added to the UK economy. The recommendations would results in an average 11% higher GDP growth rate between 2020 and 2030. This result in a net benefit (after accounting for costs) of £800 billion for the economy by 2030. This is quivalent to the entire economy of Holland or Turkey. This is even when ignoring the specific costs of climate change, which Stern put to be between 5-20% of annual GDP over the long term. When considering these avoided costs as well, it is clear the recommendations are the basis for a vastly more prosperous future.
- **Create a jobs revolution, with an average of 850,000 new jobs across the green energy sector across the 2020s**. This would be distributed around the whole of the UK, bringing substantial benefit to all regions.
- **Households will be better off as a result**. Household energy *bills* will not need to be increased to pay for the investments, and due to increased economic prosperity wages will also increase by 2% across the economy. Reduced energy wastage in homes will also help eradicate fuel poverty, benefiting the 2.5m UK homes it currently effects.
- **The UK population will be much healthier** – Burning less fossil fuels will result in 6,200 avoided deaths a year by 2030 due to improved air quality. In total this also represents an increased 46,000 life years across the UK population as a result of avoided deaths in 2030, and an average increased life expectancy of UK citizens by 23 days. It is also possible to monetise these mortality and morbidity impacts. This will provide an equivalent value to the UK economy, through gained productive work hours, of £1.6bn, and also an avoided £400m of annual costs to the NHS. By upgrading dwellings through a UK wide home retrofit program, there could be up to 560,000 fewer cases of asthma by 2030 due to reduced damp, and 1,500 avoided deaths from cold.
- **A huge opportunity for business**. With net profits in the private sector to be an extra £500bn over the decade, as a result of this program of work, depending on the policy landscape.
- **Government finances will be improved**. For every £1 of capital investment made by the UK government, nearly £2 will be captured through increased tax revenues due to a more prosperous economy. The cumulative benefit by 2030 would be enough to fund the entire NHS for whole year, or pay for HS2 twice over, or Crossrail more than eight times over.

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[214] All results cover the decade from 2020-2030 and are relative to a modelled base-case of where no further investments in green energy beyond business as usual.

CHAPTER RESOURCES

This chapter is built on evidence drawn from a wide range of sources, in particular:

- Exclusive study by University of Leeds assessing the macro-economic impacts of delivering the 60%-by-2030 target
- UK Office for National Statistic
- C40 Cities Climate Leadership Group
- Stern Report
- London School of Economics
- PWC

CHAPTER CONTENT

- Introduction
- Avoiding the costs of doing nothing on climate change
- Investment
- Macro-economic impacts
- Fuel poverty
- Employment impacts
- Health impacts

8.2 Introduction

8.2.1 Wider impacts

The preceding chapters outline what maximising renewable and low-carbon energy by 2030 entails, and the climate impact of doing so. Clearly, delivering such a large-scale update across UK infrastructure will have many impacts beyond just reducing GHG emissions. The strategy includes changes the buildings we all live and work in, with 24m homes needing upgrading, which will, for instance, have an impact on the health of individuals living in poor quality accommodation. A very substantial "make-over" for energy systems will also be unlike anything in a generation in terms of pace and scale of shift, with huge implications for economy and employment. Not least of all due to the fact that the UK will become far less dependent on fuels of all types.

This chapter aims to consider and quantify some of these impacts. These are often referred to as co-benefits. Though this term is not ideal because it makes these benefits appear secondary, and as will see in this chapter, these wider benefits are substantial enough to justify this plan on their own, even if there was no such thing as global warming. Indeed, in itself justification enough for taking forward the recommendations outlined in this strategy, a wide range of other impacts will be experienced across the UK. Therefore, the term "wider benefits" will be used throughout this chapter.

There are many wider benefits that could result from different aspects of maximising renewable and low-carbon energy by 2030. One example list of impacts is outlined in Figure 53.

THEME	IMPACT GROUP	IMPACT (examples)	SPECIFIC GROUP (examples)	INDICATORS (examples)
SOCIAL	Health	Physical health	*Healt hazards and death*	Life expectancy at birth
			Disability	Disability adjusted life years
			Physical activity	Share of time spent doing physical activity
		Mental health	*Stress*	Suicide rate
			Dementia	Incidence of dementia
	Quality of life and urban liveability	Housing	*Housing affordability*	Cost of rent as share of disposable income
			Housing quality	Living area per household
ECONOMIC	Wealth and economy	Economic prosperity	*Economic production*	Total city income (GDP)
			Labour productivity	GDP per job
		Employment	*Employment figures*	Unemployment rate
			Job quality	Earnings quality
		Economic innovation	*Innovation*	Number of patents created
			Local sector development	Number of start-ups
ENVIRONMENTAL	Environmental quality	Biodiversity	*Biodiversity protection*	Proportion of natural areas under protection
			Ecosystem services	Daily volume of natural freshwater extracted
		Air quality	*Indoor pollution*	Types of cooking fuels used
			Outdoor air pollution	Number of days above WHO pollutants recommendations
		Noise	*Indoor noise*	Indoor noise levels (dB)
			Outdoor noise	Noise level from traffic (dB)

Figure 53 Climate Action Impacts Taxonomy[215]

[215] C40 Climate Action Impact Framework, https://c40-production-images.s3.amazonaws.com/other_uploads/images/1605_C40_UCAIF_report_V3.original.pdf?1518203136

8.2.2 Approach

The aim has been to quantify the UK wide impacts of delivering the delivering the thirty recommendations for maximising renewable and low-carbon energy by 2030, presented as either a cumulative figure to 2030 (for instance for total increased GDP across the UK economy), or average between 2020 and 2030 (for instance in the case of new jobs available). Varied approaches and methodologies have used for different impacts, technologies and sector.

It is beyond the scope of this study to make a thorough assessment of all the impacts outlined in Figure 53 above, and so to best use the time and resources available in this study, wider impacts have been chosen based on:

- *Estimated likely scale of impact* – based on project team experience, the impacts with the largest likely impact, and highest relevance to UK citizens and business, have been chosen
- *Availability of evidence and ease of estimation* – Those that can be calculated most readily have been prioritised, due to readily available data and usable methodologies available in the literature.

This has tended to result in a slightly greater focus on economic impacts. Partly due to the high dependency of social impacts on local factors making national level figures more complex to estimate, and partly due to the sheer size of economic impact this program of work is likely to result in.

A separate and more detailed report is under development outlining how the results presented in this chapter were developed. Instead, an overview is provided here, and then expanded on slightly in each of the following impact specific sections.

In most cases no new primary research has been undertaken, rather example data has been identified in the literature and scaled and adjusted to the scenario figures appropriately. In the case of the macro-economic impacts a specific study has been undertaken by the University of Leeds, developing a scenario specific MARCO-UK model, with a separate output report developed including the findings. Section 8.5 below summarises these results. Primary analysis has also been undertaken in the case of certain health benefits, where known methodologies have been applied to the scenario case, generating a bespoke calculation. See Section 8.8.

In some cases, such as employment or investment, a bottom up approach been used by technology. In others a UK wide analysis has been undertaken, such as in the UK of a MARCO model for macro-economics, which does not distinguish between technologies, but instead looks at the impact across the whole of the UK economy.

The impacts considered are:

- Avoided costs of climate change
- Investment – high level outline of the data on investment required across UK
- Employment – direct, indirect and induced jobs, as well as reduced unemployment
- Macro-economics – GDP, wages, government returns.
- Fuel poverty
- Health – improved air quality, reduced damp and reduced cold.

The remaining sections of this chapter consider each impact in more detail.

8.3 Avoiding the costs of doing nothing on climate change

Climate change, if not unmitigated or adapted to, will have a tremendous human and economic cost, globally and for the UK. There is surprisingly little evidence on the expected costs to the UK. While the Committee on Climate Change makes a regular assessment of climate change risks, these are not quantified across the economy.

The Stern Report, now 13 years old, highlighted that the costs of climate change are likely to be 5% of GDP per year over the long term[216]. Follow up work by Sir Stern[217] building on the Stern review, in 2013, demonstrates a similar range of costs across different climate change models.

8.4 Investment

Bottom up investment levels have been developed for each year out to 2030, covering each technology and solution, at the UK wide level (rather than regionally). This has been developed based on a review of literature and comparison to the proposed scale of deployment required to maximise renewable and low-carbon energy by 2030.

The analysis implies that annual investment will less than 2% of GDP, this is in line with what was estimated by Committee on Climate Change as required to deliver zero carbon by 2050, and by Stern to avoid the worst of climate change.

This in not government investment, but is the investment required across the whole UK economy, with part from industry, part from government. This report does not consider means of implementation and so no breakdown of investment numbers has been provided.

8.5 Macro-economic impacts

NOTE: *This section provides only the summary findings of a larger research effort, detailed of which are to be published in a separate paper*

A team at the Sustainability Research Institute, School of Earth and Environment at the University of Leeds have undertaken analysis to determine the economic impact to the UK between 2020 and 2030 of delivering the thirty recommendations outlined in this strategy. This team is led by Professor John Barrett, and includes Paul Brockway and Jaime Nieto Vega. The team will be publishing the full paper in due course outlining in more detail the particulars of this analysis. The content that follows in this section is a summary of the approach and findings.

8.5.1 Approach

The analysis has relied to the use of a MARCO-UK model to estimate the behaviour of the UK economy from 2020-2030, under the conditions created through the implementation of the thirty recommendations outlined in this report.

MARCO-UK is a macro-econometric (ME) model based (as is common) on post-Keynesian economic theory, where agent behaviour is not based on optimisation but is instead determined from econometric equations based on historical data. The model contains over 70 socio-technical-economic variables, including thermodynamic-based energy variables (primary energy, final energy, and useful exergy; thermodynamic efficiency at primary-to-final and final-to-useful conversion stages). A fuller description of the model is contained in Sakai et al[218].

The main technical project team, provided to the Leeds economics team, the following inputs for the model:

- the overall investment volume and timing by technology / intervention (summarised in Section 8.4 above)

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[216] https://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm
[217] http://personal.lse.ac.uk/sternn/128NHS.pdf
[218] Sakai, M.; Brockway, P.E.; Barrett, J.R.; Taylor, P.G. (2019) Thermodynamic Efficiency Gains and their Role as a Key 'Engine of Economic Growth'. Energies 2019, 12, 110. Available at https://doi.org/10.3390/en12010110

- the estimated government capital investment required by technology / intervention – this is taken to be around £150bn of capital investment over the ten years from 2020-2030.
- Energy savings in electricity and gas – as outlined in the technical chapters above.

All remaining variables have been established within the model. Because MARCO-UK is an econometric model, a 'no-policies' simulation will return the *Business as usual* or *Baseline* results, representing a projection of past trends. The is condition against which the scenario outlined in this report is compared, and unless otherwise stated, are the cumulative impact of the strategy from 2020-2030. \

The following sections outline the headline findings of the analysis.

8.5.2 GDP impact

Between 2020 and 2030 the impacts of delivering the recommendations, compared to no such action, are highly positive, and represents a very substantial uplift to the GDP of the UK over that period. This is due to large volumes of capital investment, both government and private, and improved energy efficiency which saves costs to the economy as a whole.

Economic growth will be significantly higher as a result, with the annual growth rate being up to 11.4% higher across the decade than the reference case.

This will mean the UK economy will perform significantly better, and cumulatively over the period between 2020-2030, create an extra £800,000,000. This is around about the annual output of the whole of Turkey or Holland, or nearly 30% of the entire UK economy today. This demonstrates the huge value this strategy represents to the UK on purely economic terms.

8.5.3 UK economic cost-benefit

A vital metric is the economic cost-benefit across the UK. This is the ratio between the total economic cost and the economic return. That analysis indicates that the benefit is significantly higher than the cost, with a 32%-35% GDP return on investment across the UK economy broadly over the decade. Demonstrates that the recommendations are not a net cost the UK, but in fact are an extremely sound investment for the country.

This of course is ignoring the cost of climate change, which if left unchecked, would need to be factored into this estimate, and would very significantly increase the relative rate of return of implemented in the recommendations.

8.5.4 Impact on households

The analysis indicates the not only can the thirty recommendations be delivered without cost to householders, householders will in the end be better off. This is demonstrated over two metrics, showing how energy bills will not go up and could even come down, and then incomes will likely increase.

8.5.4.1 Energy bills

The very substantial capital costs of decarbonising UK energy supplies, would in natural conditions likely lead to energy cost increases. This increase in unit prices is as a reaction to reduced energy demand and capital investment costs. To model the impact of preventing this, two scenarios have been created where energy costs have been fixed in two different ways, and then the total extra cost of maintaining this fix, for instance through subsidising household energy costs, has also been estimated. These are:

- *Keeping energy **prices** the same as the baseline* – meaning the cost per kWh of energy stays the same as if the recommendations were not implemented. Since energy demand is reducing due to improved energy efficiency, this will result in a fall in energy bills for homes. To ensure this an annual subsidy (in some form or other) would be required of £10.6 – £16.4bn per year. As outlined in the following section this is considered highly "affordable" given the wider economic benefits across the economy.

- *Keeping energy **bills** the same as the baseline* – meaning that energy costs per kWh are allowed to increase in proportion to how much energy efficiency is driving energy use down, which would result in annual energy bills across the country remaining the same, meaning no extra annual cost to bill payers. Because this allows energy price increases, a lower annual subsidy (in some form or other) would be required than the first option, being only £2.6 – £3.7bn per year. As outlined in the following section this is considered highly "affordable" given the wider economic benefits across the economy.

8.5.4.2 Household net incomes and disposable incomes

A significant increase in both salaries and disposable income would come out of delivering the recommendations. The hourly wages increase vs baseline would reach more than 2% by 2030. The increase in wages is triggered by the enhanced energy efficiency and GDP growth rates, as well as the improvement of labour productivity (GDP/People employed). Labour productivity, in turn, has been encouraged by the demand-side measures and the additional capital investment and government expenditures increased the economy's capability to hire new workers beyond its initial status.

As a consequence of the growth in salaries, disposable income is also expanded. Disposable income would rise by 0.40%-1.35% after the UK Energy Plan is implemented, similarly to hourly wages.

8.5.5 Impact on government finances

This section considers whether delivering the thirty recommendations would result in a net cost to the UK governmental accounts, or a net benefit. This is assessed by comparing government capital investment and the cumulative impact on government tax receipts, and finds that the government's investment would be paid twice over, having a very substantial net positive impact on the UK government balance sheet.

8.5.5.1 Government investment

Substantial public investment will be required to deliver the recommendations outlined in this document. While further work will be required during the policy development phase to determine a precise number, this work assumes that £150bn of capital investment from a National Transformation Fund.

8.5.5.2 Government income

Investment can then be compared to the change in government income from taxes due to the impact on the economy of implementing the recommendations, relative to the reference case. Given as already established, the recommendations result in a much more prosperous UK, tax revenues also increase. Given government tax across GDP is historically in the UK around 37%, this has been assumed to remain level out to 2030, resulting in up to £290bn greater government income cumulatively by 2030. This would mean that for every £1 the UK government spends, up to £2 would be received as a direct result in tax, effectively paying back the government's investment twice over. This would have a very substantial net positive impact on the UK government balance sheet.

Furthermore, this demonstrates that the maximum of £16.4bn outlined \above as necessary subsidy to maintain energy prices, could be very comfortably accommodated. If the government were for instance to make a direct subsidy to that effect, this would still mean that for every £1 spend the government would receive at least £1.8 in extra tax receipts. This is why the model outputs confirm that it is entirely possible to ensure that delivering the recommendations in this report can be done without any increase in energy bills for households, or even reducing them.

8.5.6 Impact on private companies

Depending on the policy framework, very substantial increased profit would be available to the companies or organisations involved in delivering the recommendations in this strategy. Indeed firms profits could be as much as £500bn higher cumulatively over the decade to 2030.

8.6 Fuel poverty

Over recent years around 2.5m households across the UK have been considered to be in fuel poverty, or around 10% of homes[219]. A household has historically been classified as being in fuel poverty if more than 10% of household income is spent on energy (While the devolved nations of the UK retain that classification, England now measures using the Low Income High Costs (LIHC) indicator, which considers a household to be fuel poor if they have required fuel costs that are above average (the national median level); and were they to spend that amount, they would be left with a residual income3 below the poverty line).

Given that only a small proportion of homes experiencing fuel poverty occupy homes of EPC rating C or higher, it is clear that the 23% reduction in heat use and 11% reduction in electricity use expected in homes will be of most benefit to those homes in fuel poverty, and is one way this strategy will reduce the number of such householders. This is as long as the costs of these retrofits are not passed on to those low income households, which is why Labour's separate and ongoing work into the policies and interventions required to deliver the home upgrade program, recommends a "shift from supplier obligation-based scheme to government grants for fuel poor households, allowing funding up to an EPC 'A' rating."

8.7 Employment impacts

One of the most important benefits of maximising renewable and low-carbon energy by 2030, is the impact this has on employment. This section considers this impact. The analysis has been split by type of jobs. Upgrading very close to the entire UK building stock and investing in a 21st century energy system will require a lot of work. It will create huge opportunity for all around the UK, given its necessarily distributed around all the UK. This will be of particularly significant impact for those parts of the country that have suffered most since

Create huge number of new *direct* jobs in research and development, construction and operation of new solutions and energy systems. These tend to be in the bracket of high skilled, high pay jobs.

8.7.1 Direct and indirect jobs

The focus of this work is on estimating the direct and indirect jobs, with the total estimated impact being the creation of on average across the 2020s 850,000 jobs in the green energy sector. The break down by technology and job type is include in the table below (numbers have been rounded to the nearest 100):

219 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829006/Annual_Fuel_Poverty_Statistics_Report_2019__2017_data_.pdf

Table 26 Summary of jobs impact of maximizing renewable and low-carbon energy. [Source: Project team analysis[220]]

Technology	Direct	Indirect	Total
Homes retrofit	256,700	202,900	459,500
Commercial/public retrofit	51,700	36,200	87,900
Industry retrofit	35,000	24,500	59,500
Off-shore wind	50,000	36,000	86,000
On-shore wind	12,600	16,300	28,900
Solar	10,400	9,900	20,300
CCS	8,400	8,400	16,800
Marine	7,700	7,700	15,300
Grid upgrades	5,600	4,500	10,100
Heat decarbonisation	31,400	33,400	64,900
Total	**469,500**	**379,800**	**849,200**

To develop these numbers, no new primary analysis was undertaken, rather all the numbers are based on academic or industry publications. The project team looked at predicted numbers of jobs in the literature for each technology, for direct, indirect and induced jobs. The focus for the work has been on direct and indirect jobs, even though data has been collected on induced, where it has been found. The jobs figures in the literature have then been scaled to relevant level for the 60%-by-2030 scenario, and in all cases scaling has been linear. Numbers have been developed for the whole of the UK. Numbers are the average new level of employment between now and 2030.

Caveats for the analysis:

- Figures are for **new** jobs in **green energy sector**, and as such not net jobs across economy. The figures do not include lost jobs elsewhere in the economy, and so are not "net"
- Data based on various studies, taking varied approaches, and undertaken at a range of times, which impacts on collective reliability and consistency. Ideally a dedicated study would be undertaken to assess the jobs available collectively.
- No account has been made for double counting between sectors
- No assessment has been made of the quality of the jobs, however it is considered likely that most oar high paid high skill jobs.
- Does not break down by region
- In cases where data has not been available, broad comparisons have been made with other infrastructure projects, assuming comparable investment to jobs ratios. This is a very rough approximation and will need refining.
- Nothing has been stated or included about what must be undertaken to ensure these jobs remain within the UK, or the wider potential for export of technologies or skills.

8.7.2 Induced jobs

The above analysis covers direct jobs (those either building or operating energy systems) or indirect (those in the supply chain providing materials and support), which tend to be secure and high skilled. A third category is induced jobs, which are those jobs elsewhere in the economy as a result of the greater affluence resulting from more direct and indirect jobs in the green energy sector. These jobs are much broader, and reflect a similar distribution to the wider economy. For this reason, they have been treated separately from the main jobs figures presented in this report.

[220] Project team developed based on wide range of sources including: Data from UK Office of National Statistics, and publications from BVG Associates, Cambridge Econometrics, PWC, Solar-Trade, and the TUC.

A figure has been found in the literature indicating 0.55 induced jobs for each direct job established[221]. Using this figure, maximising renewable and low-carbon energy by 2030 would result in around 266,000 induced jobs. This allows us to summarise the total jobs figures in Table 27. However, given the difficulty in accurately estimating induced jobs, and the uncertainty around job value, this report recommend the 850,000 jobs figure is the most appropriate to focus on when discussing the impact of maximising renewable and low-carbon energy by 2030.

Table 27 Combination of direct, indirect and induced jobs

Job type	Total
Direct	469,500
Indirect	379,800
Total direct and indirect	**849,200**
Induced	266,600
Total	**1,115,800**

8.7.3 Reduced unemployment

All the above analysis demonstrates the likely number of jobs in the green energy sector. These are not necessarily additional across the economy. Many workers will come to these roles from previous employment, and it is considered likely that these jobs will be higher paid and higher skilled than previous roles.

To understand the impact of maximising renewable and low-carbon energy by 2030 on total employment levels, see the following sections, and the results developed from UK wide economic modelling undertaken by Leeds University's, which ultimately lead to 200,000 additional jobs expected. This represents a 0.2% reduction in unemployment.

8.8 Health impacts

The impacts of maximising renewable and low-carbon energy by 2030 on the health of the UK population will be substantial. Given the available resources for the development of this report, not all the possible health impacts could be calculated, and so only those expected to have the most impact have been considered. The most substantial benefits are associated with improving housing stock across the UK. Given that an upgrade to homes via the home retrofit program will improve the building fabric and quality, these issues will be greatly reduced. As well as direct result there will be health benefits, reduced energy demand in homes will reduce the amount of money needing to be spent on energy, and hence reduce energy poverty.

Another leading topic is air quality. Although transport systems are more commonly associated with driving poor air quality and associated health issues, research indicates that stationary power generation using fossil fuels is a contributor to general background levels of PM10 and PM2.5 particulates, which have a negative effect on health, and exacerbate the air quality issues found in densely populated areas due to transport systems.

The following sections outline the methodology and findings for each of these health metrics.

[221] https://www.solar-trade.org.uk/wp-content/uploads/2015/03/CEBR-STA-report-Sep-2014-1.pdf

8.8.1 Reduced damp: impact on asthma

Methodology

4% of UK homes have serious damp concerns, and 17.5% of the UK population have been diagnosed with a form of asthma according to the World Health Survey[222]. Damn is known to cause asthma, and so improving the quality of all UK homes, with a focus on damp, will result in higher likelihood of asthma. The mould – asthma risk ratio is around 1.4. Using this evidence, and a methodology developed and used by C40[223], estimates can be made of the fewer cases of asthma expected by 2030 by removing the majority of cases of damp (assumed 90% success rate).

Results

It is estimated that by 2030 around 560,000 cases of asthma will have been avoided through reducing the amount of damp housing in the UK.

8.8.2 Reduced cold: avoided cold deaths

Methodology

In the 2017 to 2018 winter period, there were an estimated 50,100 excess winter deaths in England and Wales. The number of excess winter deaths in 2017 to 2018 was the highest recorded since winter 1975 to 1976. This is for a whole range of reasons, but poorly insulated and cold homes is a contributing factor. C40 have developed a methodology for estimating the impact of increasing the average temperature of the coldest homes on cold deaths. This methodology was used to estimate the impact of increasing internal temperatures by an average of 2 degrees centigrade, more than feasible based on a whole home retrofit as proposed in this document.

Results

It is estimated that of the roughly 50,000 extra deaths due to cold each year, around 1,500 can be avoided through delivering a UK wide home retrofit program as proposed in this document.

8.8.3 Improved air quality: avoided deaths

Methodology

Poor air quality can have a huge impact on human health, with some estimates indicating around 36,000 deaths a year due to poor air quality[224]. This is a result of nitrous oxides and particulate matter emitted during the burning of fossil fuels. Certain fuels, such as coal, have a particularly devastating impact on local air quality, as can the impact of local traffic, both through exhaust fumes but also through the impacts of tires on the road shedding particulate matter. Natural gas typically has a lower impaction air quality that some of these fuels, but still leads to emissions of NOx and PM10 and PM2.5.

This strategy has outlined how coal and oil use will be entirely removed by 2030, and how gas use over all with be reduced by 78% in total across power generation and building heating. This will lead to an improvement in background levels of air quality, and so a lessening of associated health impacts. Given this is a nation wide strategy, a very high level analysis has been used to estimate the impact on background air quality. Gas combustion leads more to higher levels of PM2.5 than PM10, and NOx levels dissipate more readily on a UK wide level, and so PM2.5 has been the focus.

It is estimate that local PM2.5 levels are 21% local non-transport (stationary combustion) and 45% regional UK. This implies a 66% of local PM2.5 levels have some dependence on fossil fuel combustion, this has

[222] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3353191/table/T1/?report=objectonly
[223] https://www.c40.org/benefits
[224] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

been assumed to be 50%, so 33% over all[225]. Then of that 33% impact, a reduction of 78% will be seen due to the recommendations of this report as we move away from fossil fuel based electricity and heat generation.

These assumptions have been applied using a methodology based on work undertaken by C40 Cities Climate Leadership Group[226], to estimate the overall health benefits of delivering the above thirty recommendations.

Results
It is estimate that by 2030 this very significant reduction in fossil fuel use for energy could save 6,200 avoidable deaths per year. In total this also represents an increased 46,000 life years across the UK population as a result of avoided deaths in 2030, and an average increased life expectancy of UK citizens by 23 days. It is also possible to monetise these mortality and morbidity impacts. This will provide an equivalent value to the UK economy, through gained productive work hours, of £1.6bn, and also an avoided £400m of annual costs to the NHS.

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[225] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1204301513_AQD2010mapsrep_master_v0.pdf
[226] https://drive.google.com/file/d/1wSORn0yOYS5kcZXql_nEH98EEvC1OscR/view

9.

Foundations for a truly zero carbon UK energy system.

Delivering the thirty recommendations will advance the UK towards a zero-carbon energy system tremendously. This section offers some high-level thoughts on how the path looks after 2030 to get the rest of the way.

9.1 The right level of ambition for 2030

Delivering a minimum 20% reduction in demand, 90% renewable and low-carbon direct electricity, and 50% renewable and low carbon heat, by 2030, is right the focus, level of ambition and timeframe.

It is the right level of ambition. The thirty recommendations represent the upper limit on feasible action by 2030, and will require truly unprecedented and transformational program of national action. Doing so will tackle some of the hardest elements of decarbonisation. Almost every household in the UK will require some level of upgrade, in many cases quite substantial changes such as solid wall insulation or a complete refit of all windows. The sophistication of energy supply distribution will need to increase tremendously requiring substantial infrastructure upgrade. It represents the maximum current technical limit for electricity decarbonization, and a truly huge change to heating, going from nearly no zero-carbon heat to nearly half. The use of energy will need to change, with customers taking a much more dynamic role. There remains to this date no credible research that demonstrates a significantly faster decarbonisation trajectory than outlined in this document is possible.

Is the right time frame. As often stated by the IPCC and others, it is the next ten years that will determine whether the world avoids the worst of climate change, and huge emissions reductions must be delivered by 2030 as outlined in the Chapter 7. Many of the solutions, while in advanced development, are not yet on the market. It is simply not possible today to buy low carbon heating infrastructure of the type needed to deliver zero carbon UK wide heating, such as CCS or zero carbon hydrogen. This capacity and technology must be developed, and will require coordinated and determined national action on a scale not seen in a generation.

This is the right first focus area. Transport, consumption, agriculture and energy in buildings should all be addressed in parallel, as outlined elsewhere in this document. However, given electricity and heating in buildings is the largest source of emissions today, it is utterly vital for avoiding climate disaster that action begin immediately on reducing energy emissions.

9.2 Progressing to net-zero carbon energy

9.2.1 Why consider post 2030

The report has not considered post 2030 in great detail because forecasts beyond 2030 are highly path dependent, there will still be some way to go to get to zero carbon in the 2030s. Given the large number of uncertainties around technology development, public acceptance of retrofit measures and so on, there is uncertainty about the rate at which this could be achieved.

That said, there could be significant benefit in developing a provisional idea of when to aim for full zero carbon energy, and key steps along the way. This would give industry the needed long-term assurance to invest in testing, hardware, skills and research. For instance, to develop the role of heat pumps, hydrogen and so on, which are not currently established technologies and markets, but potentially crucial to delivering zero carbon. If there is no clear trajectory, or in the least some form of commitment post 2030, this may limit the confidence with which investments can be made.

9.2.2 What is a net-zero carbon energy system

A net-zero carbon energy system is considered to be one that over the course of a given year, either no GHG's are emitted into the atmosphere, or those that are emitted are accounted for by an equal amount of carbon dioxide removal, for instance through bio-energy with carbon capture and sequestration (BECCS). As outlined in Section 7 above however, the authors of this report advise caution regarding the future viability of BECCS at scale, and certainly do not consider its use to draw down long standing carbon deficits as a credible solution. It is far safer to avoid the emissions in the first place. Therefore, in this case the target should be a UK energy system where GHG emissions are prevented from entering the atmosphere.

To do so, the UK must remove fossil fuels from electricity generation, and from heat provision, or ensure that all fossil fuel generation is used only with complete carbon capture and storage. Through delivering the thirty recommendations, the only fossil fuel left in 2030 will be natural gas. The amount used for heat, 300TWh, will be around ten times the amount used for power generation, at 30TWh. The following section considers how this could be encouraged to ensure zero carbon heat and electricity.

9.3 Important issues

There are several core decisions, and challenges or factors, that will impact on how the UK reaches zero carbon energy, and how fast it can do so.

9.3.1 Choice of heating technology

As outlined in Chapter 3, there are three main long-term options for heating the UK:

1. **A predominantly hydrogen-based system** – with most buildings using hydrogen heating appliances, nation-wide hydrogen transmission infrastructure, and renewable or low-carbon production facilities and storage. This option provides significant benefit from a balancing point of view due to hydrogen being easier to store than electricity. Note that H2 – natural gas blending is no longer viable, as this would not be zero carbon.
2. **A predominantly electricity-based system** – with most buildings using heat pumps (HP) for heating, and an electricity only national transmission system, requiring measures to ensure demand can be balanced, such as localised heat storage, and also potentially enhancements to the transmissions system to accommodate significant higher demand. This scenario would be made significantly more viable after the building retrofit program has been completed, by significantly reducing the peak heat demand of most of the UK's buildings. Note this system may still rely of large volumes of *centralised* renewable and low carbon hydrogen storage as a means of matching supply and demand. Note hybrid heat pumps are no longer viable at this stage, as they are not zero carbon.
3. **Some mixture of both electricity and hydrogen** – assuming there are sizeable levels of heat supplied through both technologies, likely with a UK patchwork approach with one technology dominating in different areas to avoid duplication of infrastructure.

It is considered most likely that the third option will prevail, though the final mix will depend on technology developments in the 2020s. Note DHN's, SHW and biogas grid injection have all been maximised by 2030 and so no sizeable expansion is likely after that.

The choice of option naturally has a significant impact on the volume and shape of electricity demand. Option 1 could mean a lower relative growth in electricity use for heating than the others, and 2 the highest. However, this is further complicated by a further decision; which technology is chosen for hydrogen production. **Either way there will likely be a need for large-scale, cost-effective, renewable and low-carbon hydrogen.** Currently the costs associated with this are very high, so investment in research and development is vital. There are two main options. A, gas reformation with CCS, turning natural gas intro hydrogen as storing the CO2 that is produced in the process, or B, using renewable electricity to split water using electrolysis, creating hydrogen. The former will lead to a much lower increase in electricity demand, the later a very significant one. Both result in balancing benefits. The relative merits are discussed more in the appendices.

9.3.2 Balancing demand and supply

Need to develop technology solutions to ensure system balancing possible at 100% zero carbon electricity. The 2030 scenario currently meets 10% of the 2030 energy demand from natural gas-fired generation, such as OCGTs or CCGTs, which will still have a vital balancing role by 2030. The UK will likely continue to need that grid-balancing natural-gas reserve into the mid 2030s. By removing the remaining fossil fuels back up, would need to replace gas peaking plant with a zero-carbon source that is able to provide the same crucial balancing role, as well as maximising other means of balancing the system as outlined in Chapter 5, in particular local heat storage and demand side management. This is one of the largest challenges facing zero carbon system and a primary constraint on the pace of decarbonisation. A range of solutions could be used, but which is preferred will become clear over time once the technologies are tested and better understood. The decision will partially rest on cost effectiveness. Either way, given the challenges presented in maturing and deploying these technologies, this process isn't expected to be completed until the mid 2030s.

9.3.3 Demand increase meaning needing greater renewable and low carbon generation capacity

Naturally renewable and low carbon generation capacity will need to increase even further from 2030 as the UK tends to zero carbon. Based on the above discussion there are a huge variety of possible scenarios and options. Two are explored below. The first is an upper bound case for the volume of low carbon electricity needed, the second a lower bound.

Full zero carbon energy, In a case of balanced electricity and hydrogen for heating, and all electrical road vehicles. Example zero carbon energy scenario (purely indicative, not a recommendation):

- Heat is 40% HP with renewable supplied electricity (223TWh), 40% hydrogen (223TWh), and 19% others such as district heating or biogas (106TWh).
- Requiring a total of 730TWh of electricity / renewable hydrogen, when combining direct electricity and heating electricity. If all road transport were also electrified (or moved to renewable and low carbon hydrogen) this would add a something like a further 70TWh, meaning a final total of 800TWh of electricity needed across the UK. This is nearly triple todays total power generation.
- *Very* high levels of energy storage and demand side management.
- This would require significant increase in generating capacity. An example system that would meet the required output could be as outlined in the table below.

Table 28 Example generation mix for zero carbon energy UK, in a case of balanced electricity and hydrogen for heating, and all electrical road vehicles

Technology	Capacity (GW)
Wind off-shore	80.0
Wind on shore	45.0
Solar	45.0
Tidal shift	5.0
Tidal stream	6.0
Hydro	2.5
Nuclear	18.0
Biomass	3.0
CCS	32.0
Total	236.5

This would represent a large increase in non-intermittent low-carbon sources such as nuclear and CCS, and large scale storage options. It would also push intermittent output very high. This is deemed technically possible, with all renewable technologies having a "technical resource" availability that allows further growth. A priority will be increasingly placed on technologies that provide reliable long term output.

In a case of mostly hydrogen produced by CCS, for heating and transport, so not much more power is needed, with the priority being in plugging the gap and getting from 90% renewable and low-carbon direct electricity in 2030 all the way to 100%. This would add at least another 30TWh of demand onto the electricity generation profile. An example of how this could be done is outlined in Table 29.

Table 29 Example generation mix for zero carbon energy UK, in a case of heating and transport mainly met through hydrogen from CCS

Technology	Capacity (GW)
Wind off-shore	55.0
Wind on shore	33.0
Solar	35.0
Tidal shift	2.0
Tidal stream	2.0
Hydro	2.5
Nuclear	9.0
Biomass	3.0
CCS	4.0
Total	145.5

9.3.4 Possible need for seasonal storage

Full decarbonisation of heat likely to require seasonal storage to prepare for winter. Managing a predominantly intermittent generation mix will require very large-scale storage, including seasonal storage. As transportation and heat is electrified, and as that electricity gets close to being entirely zero carbon, storage will be critical – both to help meet peak demand and to store the very large volumes of renewable energy available at peak supply times. This would allow capture of spare renewable and low-carbon electricity at high supply times, to prevent curtailment of renewable generators. There are various technical options for filling this need. Research is needed to ensure they are viable in time. Using electrolysis to convert excess renewable and low-carbon electricity into hydrogen is considered a potentially very important element. This can then be discharged when necessary through the hydrogen turbine plant described above.

9.3.5 Maximum pace of roll out

Reaching zero-carbon heating in the UK

Continuing to from 50% renewable and low carbon heat in 2030 all the way to 100% will require significant continued and coordinate effort across the UK economy and country. This is partly due to the UK still relying on large volumes of gas, and its requiring a shift in transmission infrastructure (at least partly) and end use appliances across wide tracts of the country. Both are more disruptive than simply changing supply side generation technologies, making this more complex than reaching 100% renewable and low carbon electricity.

So how fast could heat be decarbonised after 2030? It is extremely hard to say with certainty. The maximum pace naturally depends on a wide range of issues such as public acceptance, success in demand reduction, chosen technologies, capacity of generation to keep up and so on. However, if the same average annual volume of renewable and low carbon heating were added to the system in the 2030s as was undertaken in the 2020s, heating would be fully decarbonised by 2040. Assuming the balancing issues outlined above can be managed, this should be considered the lowest level of ambition post 2030.

However, it is quite likely that in fact the deployment rate could be increased post 2030, once the preferred technology is deployed at larger scales and costs come down and skills and familiarity go up. If the annual average rate of deployment were to increase by 25% then heat would be fully decarbonised by 2038. If increased by 50%, it would be reached some time before 2037, and if double by 2035. It is considered plausible therefore, given the above-mentioned complications in meeting *all* the UK's very large and peaky heat demand, that the UK heat system could decarbonised by the late 2030s.

It is also noted that based on current research and evidence, there is no reason to suspect any one of the three main heating technology options is much quicker to decarbonise than any of the others. This is therefore a stated assumption and should be updated should any contradictory evidence be forthcoming.

Reaching zero carbon electricity in the UK
Based on this analysis, we can consider the impact for rate of decarbonisation of electricity. As mentioned this depends on heating technology, because the choice of heating solution significantly changes the size and shape of UK electricity demand. Larger and more complex increases will take longer to fully decarbonise. An assessment is now made for each of the options explore in the previous section:

1. Hydrogen Two sub options:
    a. If using CCS to reform natural gas, this will ensure the electric and heating systems remain more independent of each other. This would mean the electricity grid can continue to decarbonise without significant increase in demand, meaning zero carbon electricity can be reached relatively quickly, likely in the first half of the 2030s.
    b. If using electrolysis with renewable electricity. Would mean significant growth in annual need for electricity, but easier on balancing side as can store it. Therefore, would be possible potentially to match the annual volume, ie get rid of fossil fuel elec before heat is fully decarbonised, and continue to increase renewable and low carbon elec in line with increased heat demand.
2. Relying on heat pumps will mean a very significant increase in electricity required. More complex, and very hard to predict, but to take a conservative estimate would possibly be by mid-decade at earliest to reach no fossil fuel.
3. Same as option 2.

Therefore, the main finding is that it depends, but that zero carbon electricity could be anticipated as early as 2034-2040, and zero carbon heating 2036-2040. These dates are not a firm proposition or recommendation for this report. However if the thirty recommendations begin implementation immediately, and by the mid to late 2020s there has been success in ensuring very strong uptake and support from across the UK population, a greatly expanded UK green energy manufacturing sector and workforce, and advanced levels of development in key new technologies – it *may* be possible to consider increasing ambition towards zero carbon at an even earlier date. If in 2025 the UK population are welcoming retrofit work to their homes, if there are 100,000's of skilled craftspeople upgrading buildings, if there are 1000's of skyscraper sized off-shore wind turbines being built in UK factories and installed in UK waters, if those using gas for heating are shifting to alternative and the grid is successfully accommodating that process, if all new homes are being built zero carbon, if our businesses, research and development institutions are in overdrive developing and proving working hydrogen and CCS infrastructure, then the UK will be in a position to consider bringing forward the date for a zero carbon UK energy system.

9.4 Beyond energy to a zero-carbon UK

For climate action, energy is the top priority and the area that needs most urgent action due to its being the largest emissions source and one of the easiest to address. Focusing on energy, both heat and electricity, is the highest priority if the UK is to deliver on climate change targets. The recommendations in this report are therefore the first steps that must be taken in the UK to address the coming climate disaster.

However other vital areas that are beyond the scope of this analysis, must also be addressed to avoid climate catastrophe. The UK also need to take a leadership position on these as soon as possible. Includes:

- **Remaining territorial emissions** - those UK based, or territorial emissions, also referred to as Scope 1 and 2 emissions, not included in energy generation and use in buildings. A territorial emissions inventory is the methodology the United Nations uses to measure the emissions of countries and so is the leading approach around the world. The remaining sectors, after energy, include:
    - *Transport* (ground) – 27% of UK emissions, mainly resulting from the combustion of petrol and diesel in personal vehicles, trucks/haulage and public transport.

- *Agriculture* – 10%, a mixture of sources, from sources like livestock methane, livestock wastes, fertilisers and land use shifts. This is a primary contributor to emissions from food.
- *Non-energy industrial emissions* – such as emissions associated with chemicals manufacture.
- *Waste management* – mostly methane emissions from landfill sites

In due course it will be vital to develop decarbonisation pathways for each of these sectors that can be shown to also be consistent with keeping global warming to 1.5°C.

- **Consumption emissions** – Another way of accounting for emissions, is point of use rather than source. To give an example of the difference, if we use a territorial methodology to look at emissions from cars in cities, then we would only measure the pollution from the fuel used when they are being driven around. But only half of the emissions associated with cars come from their being driven. The other half comes from the process of their manufacture, which usually occurs outside the city it was bought in. Using a consumption based methodology we trace back the emissions of the car right back up the supply chain, looking at the energy used in the factory where it was built, through to the extraction and processing of rubber for the tyres and metals for the engine. These consumption emissions also include, for instance the embodied carbon in building materials (emissions released in producing the materials, with cement being a particularly carbon intensive example), food, goods and products imported from abroad, and aviation. These all lead to emissions expended in other countries on behalf of UK consumption. A true path toward a zero-carbon 2050 also requires us to look at the impact we have beyond our own borders. Many of the products and services produced abroad are for consumption in the UK, and so the impact of consumption can be said to have a role in driving up emissions in other countries. These are referred to "scope 3" emissions by the UNFCCC.

Addressing these will allow opportunity for deep change. Allow us to cut to core of profound and commonly rooted issues. The first step is through ***better production and consumption***. Covering agriculture and food, imported goods and services, aviation, shipping through a shift towards a circular economy. Can be addressed through measures like:

- Designing out waste and pollution
- Keeping products and materials in use
- Regenerate natural systems

For instance, the provision of healthy, locally sourced plant-based food, with local valorisation of waste streams, will deliver huge health benefits for citizens, foster local employment and community cohesion, and drive GHG reductions. This is already being pioneered all around the world. Amsterdam's Circular Strategy estimates that reusing materials has the potential to create a €85 million of value per year, with 700 additional jobs within the construction sector, €150 million of value per year and 1,200 additional jobs in the agriculture and food-processing industry.[227]

Then the final step to ensure emissions are eliminated and remain eliminated, required even deeper change. There is increasing recognition of the underlying economic basis for increasing emissions, and its commonality with other issues the world faces today. As Pope Francis put it in his encyclical: *"We are faced not with two separate crises, one environmental and the other social, but rather with one complex crisis which is both social and environmental. Strategies for a solution demand an integrated approach to combating poverty, restoring dignity to the excluded, and at the same time protecting nature."*

This will ultimately require societal mindset change, that addresses the trajectory of our economy and begins to broaden our vision of progress beyond simplistic GDP growth to include more complete picture of prosperity, including health, wellbeing, clean air, education and so on. Focusing on a ***distributing and regenerative 21st century economics*** that puts people and planet first, so that all humans can live a good life within planetary boundaries. This is what it will take to fix the climate emergency.

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[227] https://www.circle-economy.com/case/developing-a-roadmap-for-the-first-circular-city-amsterdam/#.WyzQjhJKigw v

10.

Conclusions and next steps.

10.1 Conclusions

This study presents a robust outline of what maximising renewable and low-carbon energy could look like for the UK by 2030. Our key findings are:

maximising renewable and low-carbon energy by 2030 for buildings and heating will be challenging but feasible. It is possible to deliver the 90% for electricity and 50% for heating, over course of approximately 10 years.

If deployment of this approach starts later, for instance as late as 2022, the possible deployment by 2030 would have to be reassessed based on the real-world progress made in the meantime, both in terms of UK government policy, and the wider global market conditions for solutions like renewable energy.

Maximising renewable and low-carbon energy by 2030 depends on achieving four goals to transform UK energy supply and use within a decade. The report makes thirty recommendations to meet these goals, with high confidenc**e** in their shape and scale. 1: Reduce energy waste, and thus demand, in buildings and Industry. 2: Decarbonise heating. 3: Boost renewable and low-carbon electricity generation. 4: Balance the grid.

Action on all four of the goals will need to be undertaken and coordinated in parallel. However, aspects of each will be delivered in three main phases. Phase 1: Immediate action. There is absolute clarity on the steps required until the mid 2020s. Phase 2: learn, deepen and accelerate. Some areas require further testing before decisions are made in the mid 2020s regarding their later deployment. Then post 2030, Phase 3 will take the energy system on towards net zero carbon as early as possible.

Some aspects of the stated 2030 levels of deployment may shift over the next decade as technological developments are made, costs changes and markets fluctuate, and so the numbers stated in this strategy seen as guidelines. As a result, ongoing assessments will need to be made to ensure target numbers remain optimal. The immediate next steps outlined in Phase 1 have a very high level of certainty. As an example, the urgent need for expanding onshore and offshore wind and solar, which are mature, low-cost technologies with clear and demonstrated large-scale resources in the UK. As a result, it is certain that these technologies will be the dominant sources of electricity by 2030. However, the exact balance of on-shore wind, offshore and solar may change to a small extent from that outlined in this report depending on prices, market conditions, policy measures and so on. Therefore the numbers outlined in this report should be seen as a guidelines, and continue to be updated as developments are made through the 2020s.

Eliminating energy wastage will reduce the amount of energy required for heating significantly, by 20% across all building types by 2030. Going further than this would be highly challenging. Most of this reduction is achieved in domestic buildings, at 23%, with commercial/service buildings following at 19% and industrial buildings at 13%. **Efficiencies will bring a smaller reduction in electricity demand,** with an 11% saving expected across the board, which is similar to historical reductions over the last decade.

A nationwide building retrofit programme would need to be the backbone of the approach to maximising renewable and low-carbon energy by 2030. Existing homes would need to be the central focus, with the aim of bringing at least 24 million homes in the UK up to the highest energy efficiency standards technically possible by 2030 – and in the process reducing damp and draughts and improving comfort, health and well-being, security, safety and community spaces. This scale of retrofit programme delivered over 11 years will require the vast majority of UK homes to have a whole-house retrofit, achieving EPC level A or B, and at the very least, EPC C. **Zero carbon building standard introduce in 2020s.**

The levels of renewable and low-carbon heat generation needed are transformative, growing from very low levels today to just under half of UK heat by 2030. This is entirely possible however, with the majority of heat customers needing no changes to their current systems by 2030. Around half of heating remains natural gas. Biogas or hydrogen mixed into methane can also be deployed through the existing gas network. Meaning more than two thirds of buildings will remain on the gas grid.

There is very high confidence in the specific approach recommended to decarbonise heat until at least to the mid 2020s, and so largescale deployment of renewable and low-carbon heat solutions can and must begin immediately. Towards the late 2020s, there is some flexibility in aspects of the approach, in particular the balance between heat pumps using renewable and low-carbon electricity, and hydrogen use. Research and investment must begin right away so that these options can be better understood and the right choices made in the mid 2020s.

Wind power is absolutely central to maximising renewable and low-carbon energy by 2030. Wind will meet more than half the UK's needs, which is entirely appropriate given that the UK has one of the largest wind resources in the world and that wind can be harnessed without impacting the lives of UK residents. Capturing the scale of this potential will require an unprecedented focus on expanding this industry in the UK. This is particularly true of offshore wind, which has the potential to have the largest scale-up of all renewable or low-carbon energy generation by 2030.

Various new renewable and low-carbon sources will be taking hold by 2030. Carbon capture and storage, and tidal power, are likely to both be reaching large scale towards the end of the 2020s.

Nuclear is very helpful for maximising renewable and low-carbon energy, and has been assumed to remain at level output levels in 2030. The scale of nuclear energy generation is assumed to remain constant through the 2020s and beyond in this analysis, despite current financial challenges. High levels of maximising renewable and low-carbon energy by 2030 is still technically feasible, even up to 90% penetration for electricity, without any further development of nuclear energy beyond Hinckley C, however greater efforts will be required in grid balancing to account for the reduced volume of low-carbon baseload power.

All coal and oil-fired power generation will be discontinued by 2022 at the latest. Some natural gas electricity generation will remain to 2030. Some gas-fired fossil fuel generation would be required for managing demand, likely from a mix of existing and new plants, and a mix of open-cycle gas turbines and combined-cycle gas turbines. Gas use will drop by 71%, however.

The lights will stay on as long as we invest in infrastructure and flexibility. Much has been made of the challenge of maintaining a stable energy supply when relying on sources like the wind and sun, however advances in the technologies and solutions available for managing supply and demand of energy mean that it is feasible to support high levels of intermittent renewables from sources such as the wind and sun. This report draws on research showing that even a partial selection of the cost-effective technical solutions available today to balance energy supply and demand would be more than sufficient to ensure the lights, and crucially heating systems, remain on whenever they are needed. Effective grid balancing will only happen, however, with sufficient investment in electricity storage and transmission and distribution infrastructure, as well as incentivising flexibility of demand. Managing the large peak heat demand in the UK makes heat storage in buildings key, showing the importance of coordinating housing policy with energy policy. Therefore, **a whole energy system approach is necessary, ensuring planning and implementation for each sector must be part of a fully integrated strategy**. There is also a strong case for including transport electricity in due course.

The electrification of transport should be supported by an increase in renewable and low carbon electricity, and so in due course would ideally be included within the target. Doing so would be entirely possible. Expanding the renewable or low-carbon target to cover the electricity for electric vehicles would require an increase in generation of renewable and low-carbon electricity by about 6%, resulting in something in the region of a further 9GW of renewable energy capacity needed.

This plan will put the UK on track to meet climate change targets. In particular:

- **The thirty recommendations will ensure the UK demonstrates considerable leadership in relation to the IPCC's "central" global average emissions reduction scenario for 1.5°C.** In its 1.5°C Special Report, the IPCC states that the average of interquartile range across its various model pathways (some of which include removal of emissions from the atmosphere post 2050) would represent a "global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030"[228]. The 77% reduction by 2030 relative to 2010 shows the UK would be is in a substantial leadership position relative to this "central" trajectory.
- **Most importantly, delivering the thirty recommendations would go even further, and ensure the UK on track to meet the IPCC's high ambition, "no-overshoot" 1.5°C scenario, avoiding the need for carbon emissions removal from the atmosphere post 2050, which the authors of this report consider to be the fairest and safest way forward.** All the other above scenarios assume that global emissions budgets are exceeded, and so emissions must be actively removed from the atmosphere in the second half of the century, for instance though bio-energy and carbon capture and sequestration (BECCS). However, such methods are undemonstrated, and almost certainly far more complex, risky and resource and cost intensive than simply avoiding the emissions in the first place. It also may be too late by then in terms of runaway climate change. Instead it is much preferred that a global trajectory be established that simply keeps emissions within the carbon budgets set by the climate science. This is termed a "no-overshoot scenario". The thirty recommendations scenario meets all the specified criteria set out by the IPCC (such as reduced use of fossil fuels, energy demand reduction, GHG emissions reduction and so on), and indeed *exceeds* them, in most cases by a large margin. **Putting the UK in a position of global leadership, and providing a firm scientific basis under which to justify the immediate adoption of all thirty recommendations.**

Maximising renewable and low-carbon energy by 2030 would make the UK a pioneer. The scope and pace of change would bring challenges, as outlined in this report, but also first-mover advantages. Moreover, taking the steps outlined in this report would allow the UK to avoid high-carbon lock-in for the country's infrastructure and to build the kind of unique skill and knowledge base that other countries will also require as they go through their energy transitions. This expertise will provide a huge opportunity for the UK to demonstrate industrial leadership.

The transition proposed would deliver huge benefits – to the economy and to health and well-being – across the UK. Delivering the recommendations outlined above would allow the UK to develop a more prosperous, 21st century economy, and address many of the root causes of multiple health issues affecting the UK population. The over-riding conclusion from an analysis of the wider impacts of delivering the recommendations, is that there is a clear economic case for doing so, and so would be justified even were there no such thing as global warming. This is vital because the international leadership on climate change represented by implementing these recommendations, would be valuable if other countries are encouraged to adopt a similar path, which will be greatly encouraged by it delivering wider benefits.

Maximising renewable and low-carbon energy by 2030 will require a concerted effort unlike anything seen in a generation. All the transformations outlined in this document will require significant activity to achieved. In particular, two areas that will require firm energy, enthusiasm and commitment are retrofitting and upgrading most if the UK's buildings, and the process of expanding provision of renewable and low-carbon heat from today's very low level, to around 50% by 2030. However, if implemented correctly – with sufficient training and support for reskilling – the benefits to communities across the UK will be substantial.

10.2 Next steps

Main call for this document is to immediately implement the thirty recommendations. To meet our climate targets and deliver huge benefits to the prosperity of the UK economy and health of UK citizens, this should be the urgent priority of any government, right now.

This document explicitly does not consider the means and measures to deliver the recommendations, and so these must be developed with urgency. This is in effect an **implementation plan** outlining 'how' this will be achieved. This will need to cover:

- **The policies, interventions, partnerships and actions that will be put into place**, particularly in the first parliament, to unlock this transition. Given the very substantial expansion needed in key energy systems, a policy platform that will result in immediate investment and growth.
- **The roles of local government, business, civil society and citizens, all of which** will be absolutely critical in delivering the targets outlined in this document.
- **Equitable returns.** That the economic benefits of this new industry are captured in an equitable way across society.
- **More detail on the role of decentralised energy**, related to the two preceding bullets, outlining the strategy for maximising community involvement and ensuring the energy system can accommodate this. This is highly related to separate work underway by the Labour Party on democratisation of the energy sector.
- **A just transition**. Ensuring there is sufficient provision to ensure a *just transition* for those currently working in high carbon sectors, for whom, as demonstrated above there is more than sufficient work in the growing green energy sector, but may need retraining and support in transferring from one sector to another. Ensuring that the transition does not result in certain communities or professions losing out, and leads to better employment for all.

10.2.1 Further research and feedback

The project team welcomes and encourages feedback from industry, civil society and academia on any and all elements of our analysis, findings and proposals (however we cannot in any way guarantee a response to all reaching out.

To consolidate the findings of this project, we have identified the need for further research and analysis that was beyond the resources of this project including:

- Detailed energy balance modelling to map the hourly performance of the energy system.
- More detail on the exact technical improvements needed to ensure system balancing.
- More analysis of cost and location of grid enhancements.
- More analysis of how heat and electricity storage could work in concert.

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Appendices

Appendix A – Role of District Heating

District heating refers to insulated pipes under-ground, transporting hot or warm water from one or more heat sources to usually very many heat customers, domestic or non-domestic. This technology has is used at large scale in many contexts around the world, from Denmark to China. This allows capture of large point sources of waste heat that would otherwise not be practically useable, for instance waste heat from a power station condensation circuit, waste low or high temperature industrial process heat, waste heat from sewage treatment works, water heat sources such as rivers or lakes (requiring the use of heat pump if DHN is high temperature) and so on. Naturally the extent to which these heat sources can be tapped into, and the available resource nationally, depends on the prevalence of available waste heat, and the proximity of a suitable density of heat customers.

Based on the international success of large scale district heating, current and recent government policy, and the national and local level, has been to enthusiastically support the expansion of DHN's across all dense urban areas in the UK[229]. DHN often considered a "no-regret" solution[230], and this is often the case. However DHN's are not always viable or beneficial in all situations. DHN's are often talked about as a heating solution, when in fact they are a heat transmission solution, and in and of themselves are not good or bad.

Part of the current national plan is to expand networks in all urban areas in preparation for future energy sources. This requires installation of new networks, with own dedicated heat sources, such as a boiler or CHP, where there is no waste, or free heat. Deploying district heating across the UK at the district scale where, and in locations where there is sufficient density of heat demand to justify a new local DHN with *dedicated* heat source built especially for that DHN, rather than co-locating it with a waste heat source. In the past this has been due to the historical GHG savings achieved through using CHP as the main heat source (through being able generate electricity on site and capture the waste heat for local use, driving net efficiencies up to 80%), which requires a DHN to make use of the captured heat. However the main fuel source available for CHP at large scale is natural gas with associated GHG emissions, and will only deliver net GHG savings if the electricity-grid carbon intensity is above a certain level. This level is constantly dropping however due to the acceleration of renewable energy in the UK grid mix, meaning that any gas CHP installed from today will have a net higher GHG impact than just a conventional gas boiler and grid electricity, and so is a negative impact on overall emissions. An alternative fuel would be biomass fired CHP, for which there are various technologies such as gasification, however for reasons outlined in Box 3, biomass is not considered a viable large scale fuel source, and biomass CHP has remained an expensive and unreliable. Therefore, DHN's not using a waste heat source are not considered useful or beneficial in and of themselves.

The remaining argument for deploying DHN's at scale across the UK is to begin the installation of DHN infrastructure ready for a future point in time where larger scale renewable heat sources can be
This is possible because they are "source agnostic" and can be swapped from one heat source to another relatively easily. For instance a future fuel cell using renewable hydrogen, or perhaps large heat pump (other than that using river/lake sources, which have been grouped with waste heat sources) perhaps using air source.

The final concern about the deployment of DH is the impact of the building retrofit program at the core of this work, which will result in drop in heat demand by on average 25% which will further reduce the already marginal returns for DHN operators.

[229] https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge
[230] https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/

Given that there is no clear long term benefit today in rushing the installation of DHN's with their own dedicated heat sources, and the upfront capital costs, and hence potential opportunity costs should other options turn out to be more sensible, are extremely high. Therefore this strategy does not deem the widespread deployment of DHN's in the first parliament a priority, at least until there is more evidence on the relative benefits of the options laid out at the start of this section.

Policy Implications for DHN's:

- **DHN's will be installed across the country to make use of all commercially viable waste heat sources, this includes river source HP's, sewage source HP's, EFW, low-temp waste heat source HP and high-temp waste heat (mainly industry).**
- **Existing DHN's will be continued**
- **Until cost effectiveness proven, large new DHN with new dedicated heat sources will be not be priority (unless has majority genuine waste heat).**
- **Trails for low temperature heat networks**

Appendix B – Role of Biomass In Delivering

Bioenergy is often discussed as a potentially important and large part of the long-term energy mix, and has potential applications in heating, power generation, industry and transport, and various forms of production.

There are various common concerns around the use of bioenergy, all of which must be satisfied in each application of bio-energy:

- **Long-term, reliable, large scale availability of bioenergy sources** – There are clear constraints to the available sustainable supply of different types of bioenergy (even though they are not all in direct competition with each other). This is a primary constraint in their use at large scales
- **Ensuring bio-energy is renewable or zero carbon** – For instance if woody biomass is taken from virgin forest and not replanted, it is neither renewable or low carbon. If global demand for timber were to reach levels required for woody biomass to make a significant contribution to energy demand, it would be increasingly difficult to ensure all such wood is sustainably produced. Certain bio-fuels are also known to require high levels of processing which can severely impact their carbon content.
- **No wider negative impacts of harvesting bioenergy –** There are often wider documented impacts of harvesting bio-energy. For instance, concerns around sourcing using large volumes of solid woody biomass fuel, and whether growing of large volumes of mono-crop has impacts on wider ecosystem services provided by forests, and the extensive damage done to the low growing plants from timber extraction.
- **Competing uses for the fuel stock** – There is a limited supply of biomass globally, and so it is vital that it be used for the highest impact and value purpose. As outlined above for aviation, and many industrial processes, biofuel is the only viable option and so should be focused on this. Also, there expected to be a growing demand for wood as a low impact alternative construction material, which would be a priority in GHG terms.

This is a complex area there, and when considering different forms of bioenergy for different energy uses, it is important to consider each carefully. Fuel sources can be:

- **Biomass** - in the form of wood, or garbage/waste, used for direct combustion in a boiler. This heat can then be used to meet heat demands directly, for instance heating a home or office, or it can be used to raise steam to generate electricity. Solid, woody biomass should be used for building material, and further down the line once CCS is developed, as a means of carbon sequestration. However, at this stage large scale *expansion* in the use of woody biomass for either heating or power is not recommended. Also, burning biomass in buildings can have negative local air-quality impacts. Use woody biomass to whatever extent it is available as true waste, for instance arboricultural arising's, however this is considered to be a very small volume compared to UK heat or power demand.
- **Liquid biofuel** produced from bio-crops or waste food sources. A high value form of bioenergy because it can be used to provide a LZC alternative fuel source for aviation and certain industrial processes, both of which will find it very challenging to find alternative renewable and low-carbon solutions. Ground based vehicles - with the shift towards electric propulsion already underway, should not be prioritised for biofuel. A primary challenge for biofuel is that they are currently derived mainly from high sugar/oil energy crops, which compete directly with food crops for quality arable land, an increasingly important concern as climate change impacts food availability around the world. Liquid biofuel should therefore not be used for either heating or power generation.

- **Bio-methane** (CH4, chemically the same as natural gas) which comes from two main sources, that together represent around 5% of current UK gas demand[231]:
  - **Biogas** – Placing organic waste (organic wastes, food or garden waste for instance) in an anaerobic digester, which produces methane and compost as outputs. This is a zero-carbon energy source and can then once cleaned can be injected into the gas grid. This is a high priority form of bioenergy and should be maximised. It is important this does create a market incentive to reduce measures to limit food waste, which is certainly the higher priority in terms of GHG saving.
  - **Landfill gas** – the extraction of methane that results from the anaerobic digestion taking place within old landfill sites. It is both dangerous to allow this to accumulate, and very high driver of GHG to allow it to escape, and so it's capture and injection into the gas grid as a zero-carbon energy source in a top priority.
- **Syngas** – synthetic gas, or hydrogen, produced through the gasification of biomass or carbon based material. This is a high cost technology that is not considered viable at very large scale and so is not proposed as a core solution[232].

Importance of bioenergy in long term: As mentioned bioenergy considered an important solution for aviation, shipping and potentially industry, and so there is much commentary on the fact that to meet long term GHG targets, for instance on the Paris Agreement, around 10% of UK GHG savings will need to come from bioenergy.

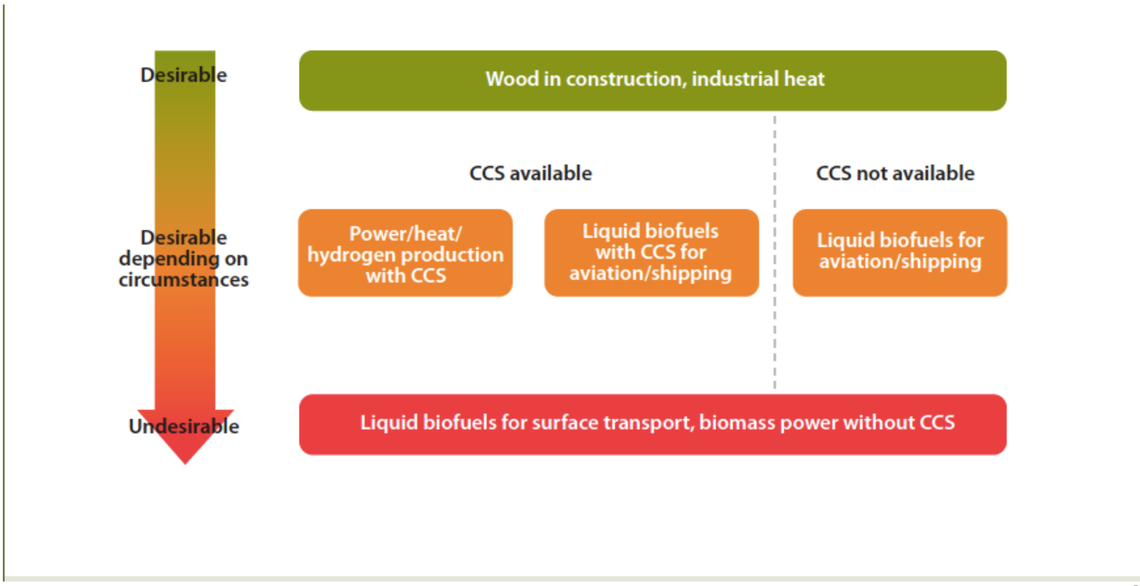

Figure 54 Hierarchy of appropriate use of biomass in 2050. Source: Committee on Climate Change Bioenergy Review[233]

<u>Policy implications (all consistent with CCC recommendations)</u>:

- **Large scale *expansion* in the use of woody biomass for either heating or power is not recommended, instead the current capacity and output for both is assumed to stay the same**
- **Biogas injection into the gas grid to be prioritized out to 2030, although food waste reduction policies should always take priority over waste valorisation**
- **Biofuel resources should be prioritised for aviation, shipping and where necessary, industrial process heat.**

[231] https://www.theccc.org.uk/publication/bioenergy-review/

[233] https://www.theccc.org.uk/wp-content/uploads/2011/12/1463-CCC_Bioenergy-review_bookmarked_1.pdf

Appendix C – Role of Hydrogen

RENEWABLE / ZERO-CARBON HYDROGEN

Hydrogen is an often talked about solution for low carbon energy transmission, both in buildings and transport. Some key themes when considering the likely role of hydrogen for maximising renewable and low-carbon energy by 2030:

Technical immaturity of large scale hydrogen transmission and distribution: Hydrogen infrastructure is still an early technology, with no large-scale examples anywhere. Although some research puts it at a lower cost than providing heat electrically, it is impossible to say given hasn't been installed. Likely to be risks and difficulties, especially when looking at large dense areas with lots of old legacy piping that needs shifting from steel to plastic piping. For these reasons, immediate large scale adoption of hydrogen is not considered sensible, but rather must be tested and proven at the area scale.

Making renewable or zero carbon hydrogen: A primary challenge for hydrogen in maximising renewable and low-carbon energy by 2030 is producing hydrogen in a way that is renewable or zero carbon. Currently, the majority of the world's hydrogen is produced by reforming natural gas, which releases high levels of GHG as part of the process, and so is neither renewable or zero carbon, and so would not contribute towards renewable and low-carbon supply. However, there are two alternative solutions for producing suitable hydrogen:

- **Natural gas reformation with carbon capture and storage** – As outlined above, CCS is a key long term solution for staying within carbon budgets, and given its remaining an immature technology at scale, will be invested in as part of this strategy, with moderate capacity expected by 2030. However, it is simply not possible today or in the next 5-10 years, to go out and buy such a plant at commercial scale. It will not be deployed at enough scale by 2030 to permit large scale hydrogen production for heating. There are also other concerns around locking-in long term dependence on natural gas, a fossil fuel, for heating, for instance around long term pricing and energy security. Of the two options this is the one the CCC prefer.
- **Electrolysis of water using renewable electricity** – This is the preferred option or a number of reasons:
  - Is a genuinely renewable and indigenous energy source, and so avoids the risks and concerns of CCS
  - Enables higher penetrations of renewable energy across the board, both in heating but also power/transport, because it allows capture of excess available renewable power at points where demand not high, providing option for large volumes of long term storage. This

  However, despite the above strengths, and reasoning fro this being a long-term option to be energetically pursued, currently the cost of electrolysis is extraordinarily high, several times more than gas reformation, due to the high costs of electrolysis equipment and lack of economies of scale. It is therefore not a commercially viable option currently, and so does not feature explicitly in the plan before the later 2020s. This is shown in Figure 19.

Potential importance of hydrogen in long term to meet Paris Agreement. Hydrogen produced through electrolysis of water with renewable electricity, will be important for reaching very high levels of renewable and low-carbon energy, going towards 100% before 2040 as required to deliver on the ambition of the Paris Agreement. This is because will need to be able to store large amount of renewable energy to meet peak demands, which by 2030 will still be getting help from fossil fuels to meet. Would require large scale hydrogen storage.

Transport sector has firmly moved towards electrification rather than hydrogen. A process that has been underway for over a decade, is the recognition that electrification of transport is by far the preferred transport energy solution over hydrogen, certainly for personal vehicles. Therefore the previous expectation of some that the need for hydrogen refuelling stations around the country would lead to the development of hydrogen infrastructure by the transport sector has not come to pass.

Policy implications:

- ***renewable and low-carbon hydrogen will not be viable at scale for the majority of the 2020s, and so hydrogen is not considered a major option for contributing towards the 50% renewable and low-carbon heat target, and only be introduced commercially at moderate volumes towards the end of the 2020s.***
- ***To enable this, two main pilots will be necessary:***
    - ***Trialling area based hydrogen transmission and distribution – the Leeds project is a good example and Labour would support the taking forward of a project like this***
    - ***Investing in research and trial projects around large scale hydrolysis with the explicit aim of bringing down capital costs of this potentially key technology***

Appendix D –Modelling Assumptions

Non-Domestic Building Energy Demand Reduction Assumptions

Table 30 Detailed breakdown of savings from the service sector

Measure	*Electricity (TWh)*	*Natural Gas (TWh)*	*Petroleum (TWh)*	*Total (TWh)*
Public Buildings				
Compressed air	-0.018			-0.018
Computers - energy Management	-0.114			-0.114
Heating - more efficient air conditioning	-0.077	-0.001		-0.078
Heating - most energy-efficient boiler	-0.013	-0.918	-0.091	-1.023
Heating - optimising start times	-0.133	-0.621	-0.015	-0.769
Heating - programmable thermostats high	-0.419	-1.777	-0.042	-2.238
Heating - reducing room temperature	-0.209	-1.136	-0.026	-1.372
Heating - TRVs fully installed	0.000	-0.268	-0.033	-0.301
Lights - basic timer	-0.293			-0.293
Lights - most energy-efficient lighting	-0.015			-0.015
Lights - light detectors	-0.031			-0.031
Lights - sunrise-sunset timers	-0.031			-0.031
Lights - turn off lights for an extra hour	-0.159			-0.159
Monitors - energy management	-0.266			-0.266
Most energy-efficient cavity wall insulation	-0.021	-0.006	0.000	-0.027
Most energy-efficient double glazing	0.000	-0.001	0.000	-0.001
Most energy-efficent flat roof insulation	-0.042	-0.103	-0.003	-0.148
Most energy-efficient pitched roof insulation	-0.047	-0.049	-0.002	-0.097
Motor - 4 Pole Motor - EFF1 replace 4 Pole	-0.001			-0.001
Photocopiers - energy management	-0.016			-0.016
Presence detector	-0.085			-0.085
Printers - energy management	-0.030			-0.030
Stairwell timer	-0.054			-0.054
Variable speed drives	-0.001			-0.001
Vending machines energy management	-0.006			-0.006

Commercial Buildings				
Compressed air	-0.113			-0.113
Computers - energy Management	-0.301			-0.301
Heating - more efficient air conditioning	-1.728	-0.027		-1.755
Heating - most energy-efficient boiler	-0.036	-2.470	-0.246	-2.752
Heating - optimising start times	-0.359	-1.672	-0.039	-2.070
Heating - programmable thermostats high	-1.127	-4.782	-0.114	-6.022
Heating - reducing room temperature	-0.563	-3.058	-0.070	-3.692
Heating - TRVs fully installed	0.000	-0.721	-0.088	-0.810
Lights - basic timer	-1.797			-1.797
Lights - most energy-efficient lighting	-0.090			-0.090
Lights - light detectors	-0.189			-0.189
Lights - sunrise-sunset timers	-0.191			-0.191
Lights - turn off lights for an extra hour	-0.977			-0.977
Monitors - energy management	-0.704			-0.704
Most energy-efficient cavity wall insulation	-0.057	-0.016	-0.001	-0.073
Most energy-efficient double glazing	-0.001	-0.002	0.000	-0.003
Most energy-efficent flat roof insulation	-0.114	-0.276	-0.007	-0.397
Most energy-efficient pitched roof insulation	-0.126	-0.131	-0.005	-0.261
Motor - 4 Pole Motor - EFF1 replace 4 Pole	-0.006			-0.006
Photocopiers - energy management	-0.043			-0.043
Presence detector	-0.523			-0.523
Printers - energy management	-0.079			-0.079
Stairwell timer	-0.332			-0.332
Variable speed drives	-0.007			-0.007
Vending machines energy management	-0.017			-0.017

Table 31 Detailed breakdown of savings from the industrial sector Source: [2]

Refineries

Measure	*Electricity (TWh)*	*Natural Gas (TWh)*	*Solid Fuel (TWh)*		*Total (TWh)*
Advanced Control and Improved Monitoring	0.000	-0.100			-0.100
Flaring	0.000	-0.021			-0.021
Lighting	0.000	-0.067			-0.067
Maintenance - Fouling control		-0.021			-0.021
Motors, Pumps, Compressors, Fans	-0.001	-0.164			-0.165
Process Heaters and Furnaces		-0.071			-0.071
Storage Tanks		-0.120			-0.120
CD: Crude Unit Upgrades (best available technolog		-0.032			-0.032
FCC: Design Improvements (best available technolo	0.000	-0.015			-0.015
HC: Design Improvements (best available technolog		-0.004			-0.004
Steam: Utilities Optimisation		-0.057			-0.057
VDU: Design Improvements (best available technol	-0.001	-0.012			-0.012

Paper and Pulp#

Measure	*Electricity (TWh)*	*Natural Gas (TWh)*	*Petrol*	*Solid Fuel (TWh)*	*Total (TWh)*
Energy management including installing meters for	-0.131	-0.166		-0.010	-0.307
Improved process control across the entire mill (pr	-0.357	-0.454		-0.028	-0.839
Focus on maintenance	-0.113	-0.144		-0.009	-0.265
State-of-the-art steam system: includes condensat	-0.096	-0.122		-0.007	-0.226
Use flash steam from condensate	-0.021	-0.026		-0.002	-0.049
steam box to increase sheet temperature and dryn	-0.029	-0.037		-0.002	-0.068
Extended Nip Press	-0.206	-0.261		-0.016	-0.483
Hot pressing	-0.067	-0.086		-0.005	-0.158
Impulse drying	-0.072	-0.094		-0.006	-0.172
Increase dew point in hood from 55°C to 70°C	-0.042	-0.053		-0.003	-0.098
Oxygen trim control to adjust burner inlet air	-0.015	-0.019		-0.001	-0.034
Economisers on steam boilers	-0.028	-0.036		-0.002	-0.066
Energy management including installing meters for	-0.027	-0.034		-0.002	-0.063
Improved process control across the entire mill (pr	-0.073	-0.093		-0.006	-0.172
Focus on maintenance	-0.023	-0.029		-0.002	-0.054
State-of-the-art steam system: includes condensat	-0.020	-0.025		-0.002	-0.046
Use flash steam from condensate	-0.004	-0.005		0.000	-0.010
steam box to increase sheet temperature and dryn	-0.006	-0.008		0.000	-0.014
Extended Nip Press	-0.042	-0.054		-0.003	-0.099
Hot pressing	-0.014	-0.018		-0.001	-0.032
Impulse drying	-0.015	-0.019		-0.001	-0.035
Increase dew point in hood from 55°C to 70°C	-0.009	-0.011		-0.001	-0.020
Oxygen trim control to adjust burner inlet air	-0.003	-0.004		0.000	-0.007
Economisers on steam boilers	-0.006	-0.007		0.000	-0.013

Iron and Steel

Measure	*Electricity (TWh)*	*Natural Gas (TWh)*	*Petrol*	*Solid Fuel (TWh)*	*Total (TWh)*
Improved Automation & Process Control		-0.020		-0.019	-0.039
Improved Planning & Throughput Optimisation - se		-0.138			-0.138
Installing VSDs on Electrical Motors (Pumps & Fans	-2.007				-2.007
Reducing yield losses		-0.023		-0.022	-0.045
Scrap Densification / Shredding	-0.067				-0.067
Compressed Air System Optimization	-0.019				-0.019
Re-heating Furnace Optimization		-0.128			-0.128
Use of premium efficiency electrical motors	-0.386				-0.386
Endless Strip Production (ESP)		-0.250			-0.250
Steam / Power Production System Upgrades		-0.209		-0.203	-0.412
UHP Transformers	-0.067				-0.067
Heat Recovery & Re-use - Innovative Options		-0.025		-0.024	-0.049
Improved Process Control - EAF	-0.025				-0.025
Stove Flue Gas Recycling (without CCS)		-0.002		-0.027	-0.029
Advanced Technologies without CCS & Rebuild		-0.005		-0.084	-0.089

Glass					
Measure	***Electricity (TWh)***	***Natural Gas (TWh)***	***Petrol***	***Solid Fuel (TWh)***	***Total (TWh)***
Batch pelletisation		-0.117		-0.008	-0.125
Batch reformulation		-0.038		-0.003	-0.041
General utilities	-0.050				-0.050
Improved furnace construction - Conventional		-0.131		-0.009	-0.140
Improved furnace design - Innovative		-0.096		-0.007	-0.103
Improved process contraol		-0.128		-0.009	-0.137
Increased use of recycled glass - container		-0.143		-0.021	-0.165
Increased use of recycled glass - flat		-0.048		0.000	-0.048

Current sector energy demand assumptions

The current energy demand has been estimated for both industrial and service sectors based on data from the UK, Department for Business, Energy and Industrial Strategy, 2017[234]. This source data is presented in TOE unites, and so has been converted into TWh figures here for use in the rest of the study.

Table 32 Industrial energy demand 2017, all units TWh, [Source: see description above]

Energy Source	Gas	Oil	Solid fuel	Electricity	Bioenergy & Waste1	Total
Space heating	12	1	2	7	7	29
High temperature process	19	2	14	11	-	45
Low temperature process	40	3	5	16	-	64
Drying/separation	14	1	2	6	-	24
Heat total	86	7	22	40	7	163
Motors	-	-	-	31	-	31
Compressed air	-	-	-	9	-	9
Lighting	-	-	-	3	-	3
Refrigeration	-	-	-	5	-	5
Other	12	1	3	5	-	20
Overall total	98	8	25	92	7	229

Table 33 Service sector energy demand 2017, all units TWh, [Source: see description above]

Source	Gas	Oil	Solid fuel	Electricity	Bioenergy & Waste1	Total
Space heating	64	12	0	13	2	91
Water heating	12	1	0	3	0	17
Cooking/catering	7	1	0	12	0	20
Heat total	83	14	0	29	2	128
Computing	-	-	-	6	-	6
Cooling and ventilation	0	-	-	8	-	9
Lighting	-	-	-	38	-	38
Other	1	0	-	12	-	14
Overall total	85	14	0	93	2	194

[234] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

Energy Generation Modelling Assumptions

Table 34 Capacity Factor Assumptions

Technology	Assumed capacity factor
Wind off-shore	38%
Wind on shore	26%
Solar	12%
Marine	21%
Hydro	36%
Nuclear	80%
Biomass	70%
CCS	80%

Table 35 Energy Modelling Assumptions

Variable	Assumed Value	Unit
UK wide average heat pump COP in 2030	2	n/a
Heat pump COP for those using waste heat sources for DHN's	3.5	n/a
Hybrid heat pump gas burning efficiency	82	%

Carbon Modelling Assumption

Table 36 Carbon Intensities of different technologies assumed

Technology	Carbon Intensity (gCO2/kWh)	Source
Electricity Generation		
Biomass	120	National Grid Methodology
Coal	937	National Grid Methodology
Gas CCGT	394	National Grid Methodology
Gas OCGT	651	National Grid Methodology
Oil	935	National Grid Methodology
Other	300	National Grid Methodology
Solar	0	National Grid Methodology
Wind	0	National Grid Methodology
Pumped Storage	0	National Grid Methodology
Hydro	0	National Grid Methodology
Nuclear	0	National Grid Methodology
Heating		
Natural Gas Boilers	204	Government Conversion Methodology
Biogas Boilers	0.2	Government Conversion Methodology
Oil Boilers	263	Government Conversion Methodology
Coal	362	Government Conversion Methodology
Electric Heaters & Heat Pumps	Dependent on the electricity	N/A

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