The Institution of Engineering and Technology

# UK renewables – limitless energy or a precious resource?

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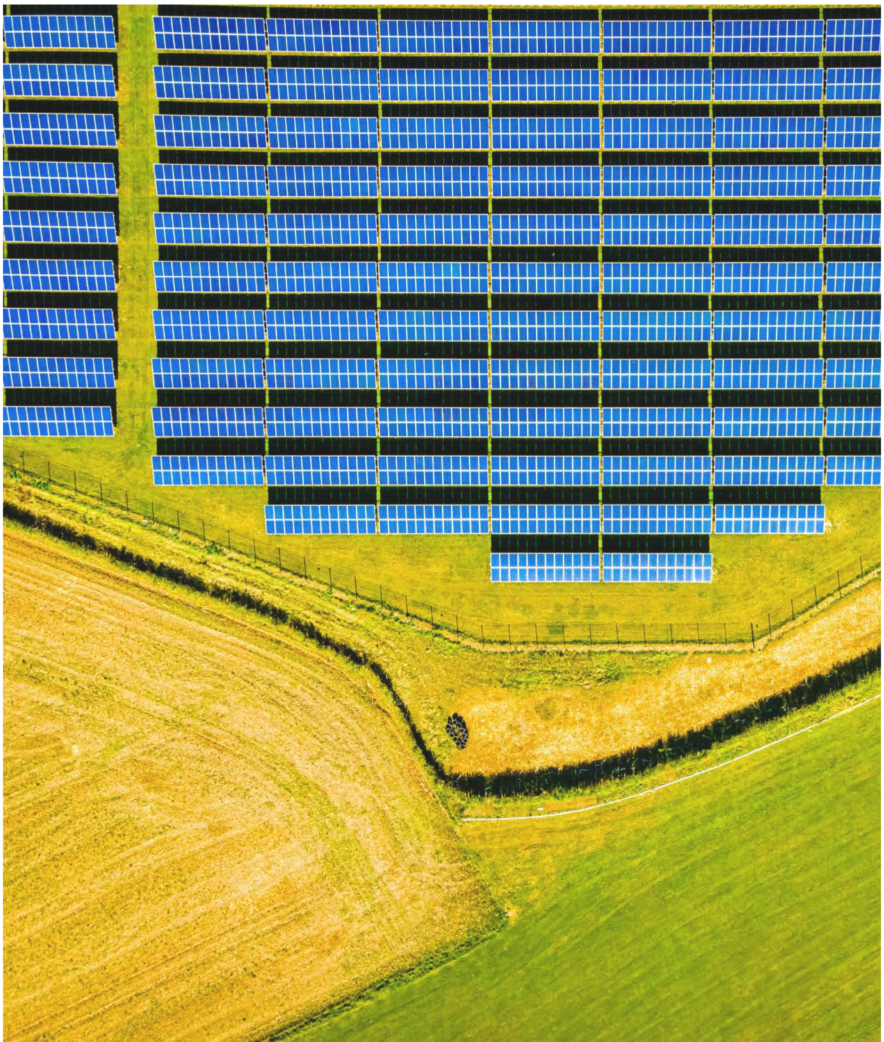

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**UK renewables – limitless energy or a precious resource? is published by the Institution of Engineering and Technology (IET).**



The IET Energy Policy Panel would welcome any comments you may have on the contents of this guide and your ideas for future publications. Please get in touch by emailing **sep@theiet.org**.

The Institution of Engineering and Technology

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# 1. About this report

This report has been produced by the Institution of Engineering and Technology (IET) to examine the available renewable energy sources in the UK. Written for those looking for a high level view of the UK's transition to a net zero energy system, this report looks at future energy needs, options for delivering a net zero system, energy independence and more.

The UK has reasonable levels of renewable energy available but at the same time needs substantial non-intermittent electricity generation capacity. Our report shows that there are some important demand and supply side deployment options, and that today's decisions can have a large impact on the scale of renewables needed.

The transition to a largely non-fuel based system also benefits energy independence, but it is not an incremental process - a real step change is needed in planning, investment, engagement and action. Clear and consistent strategic direction along with a focus on energy efficiency is vital to help minimise the scale and cost of energy production and delivery.

Jeff Douglas
CEng, FIET

This report was commissioned by the IET Energy Panel, an expert volunteer group that creates thought leadership and policy advice to inform Government, regulators, energy, and communication sectors. The author of this report is Jeff Douglas CEng, FIET. Jeff has a background in electricity networks, the decarbonisation of heat, and whole energy system development. He has worked as an Energy systems specialist for the Energy Technologies Institute and the Energy Systems Catapult. We would also like to thank to Olivia Carpenter-Lomax, co-chair of the Energy Panel and John Scott, member of the Energy Panel for their contributions and support.

Please note that the views expressed in this publication are not necessarily those of the IET. The guide only intends to identify the relevant issues and to inform a public policy debate around the topic, rather than to provide a definitive solution.

The IET Energy Panel would welcome any comments you may have on the contents of this guide, and your ideas for future publications. Please get in touch by emailing **sep@theiet.org**.

# 2. Recommendations

The UK has significant renewable energy development opportunities, yet even for the most modest demands considered, the new sustainable resources required for heat, transport and industry are significant multiples of current capacity. Critically, today's system choices and decisions could substantially increase those multiples. Almost all our existing sustainable power plants are scheduled to retire before 2050, and the renewable assets we are using today will need re-powering before then. Below are our recommendations to help ensure that renewable resources are treated as finite and precious, rather than abundant and disposable.

## 1 Strategic direction is vital

Markets and businesses can respond to this opportunity, but the system choices made have a large impact on the outcomes achieved. The transition must be driven by an effective strategic planning process to ensure efficient and timely delivery, with consistent direction, clear investment signals, appropriate incentives, and active skills development. This highlights the fundamental need for new whole-system coordination and accountability mechanisms that are not currently a feature of the energy sector.

## 2 The scale of the challenge is huge

All net zero transition routes involve substantial, costly, and potentially intrusive infrastructure. We are not facing an organic process requiring incremental movements, but a real step change in planning, investment, engagement, and action.

## 3 Technology exists for an energy efficient and low carbon future

This includes options for decarbonising heat, transport and industry, where the most appropriate solution can be selected for each application, along with smarter energy management and control. Technology choices must properly integrate the human dimensions and provide the services that both today's and future customers will value.

## 4 There must be a real focus on energy efficiency

Whatever the source, whatever the application, reducing the need for energy and hence the scale of delivery assets must be a real priority. This is particularly important for the existing building stock where significant savings can be made. Retrofitted improvements are costly, but the societal benefits go beyond energy efficiency and are enduring.

## 5 Decarbonisation can help energy independence

The UK's energy system already faces some significant challenges, particularly with its reliance on imported fuels and volatile world markets. The drive to decarbonise our energy system by 2050 offers the nation an opportunity to move from fuel-based solutions and become more energy independent.

# 3. Introduction

In 2019 the UK's Climate Change Act was amended to commit to net zero emissions by 2050 and followed by plans published in 2021 to decarbonise the electricity system by 2035. Whilst the concept of net zero is readily discussed, reaching this goal for the energy system is a real challenge.

Fortunately, we have numerous sustainable resources available to us, but these have not yet been exploited at scale. We also have important deployment choices to make, many of which will require changes to personal lifestyles, so needing societal engagement alongside technological and commercial innovation.

Electricity has a vital role to play in the decarbonisation of modern UK society; not only in creating a net zero energy supply for existing electricity needs, but also providing a viable pathway to many other energy services such as space and water heating, and transport. However, as with all transition pathways, decarbonisation of the power sector is not a simple matter. A large amount of generation infrastructure using sustainable sources will be required to provide the energy needs of society. Additionally, significant engineering changes are needed within the electricity system to maintain security and resilience while accommodating new demands and a generation mix dominated by invertor-based renewables, which are characterised by being intermittent sources that contribute limited system inertia and short circuit in-feeds.

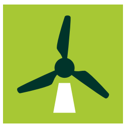
This report focuses on the availability of these sources. Whilst it can be tempting to suggest that we can simply build more renewable generation to support our net zero aims, the report seeks to highlight the scale of the challenge. Can renewables be treated as endless energy or are they a precious resource that should be conserved?

The need for energy system decarbonisation spans the globe, and each region or country will have its own specific factors that shape its thinking on pathways to 2050. These may be geographic, climatic, political, economic or societal characteristics and will certainly be steered by the availability of renewable resources. Whilst this report is based specifically on the UK and its features, the question raised here about the treatment of renewables is surely relevant wherever an energy transition involves substantial new resources, infrastructure, and societal change.

There are many excellent materials available on this subject with a broad range of conclusions. Consolidated information is however limited, so a variety of data sources have been used to outline both the amount of energy needed and the renewable resource available. These are supported by simple models to form a pragmatic view of the likely requirements for sustainable energy in 2050, and how the long term needs of our society might be met.

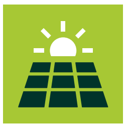
# 4. What primary energy resources do we have?

Whilst there are a number of renewable resources available to us in the UK, all of which will likely feature somewhere in our future, this report focuses on the largest and most accessible of these sources. There is debate about the classification of today's nuclear generation, which is often more accurately described as a sustainable or low carbon source, rather than renewable.



**Wind:** The first of these renewable resources is wind power, where the UK is a leader in innovation for offshore application. New developments in floating platforms introduce the prospect of economic exploitation of deep-water wind resources. Whilst costs are competitive, the intermittency of supply means that the associated costs of essential back up, power system management and storage also need to be fully considered.

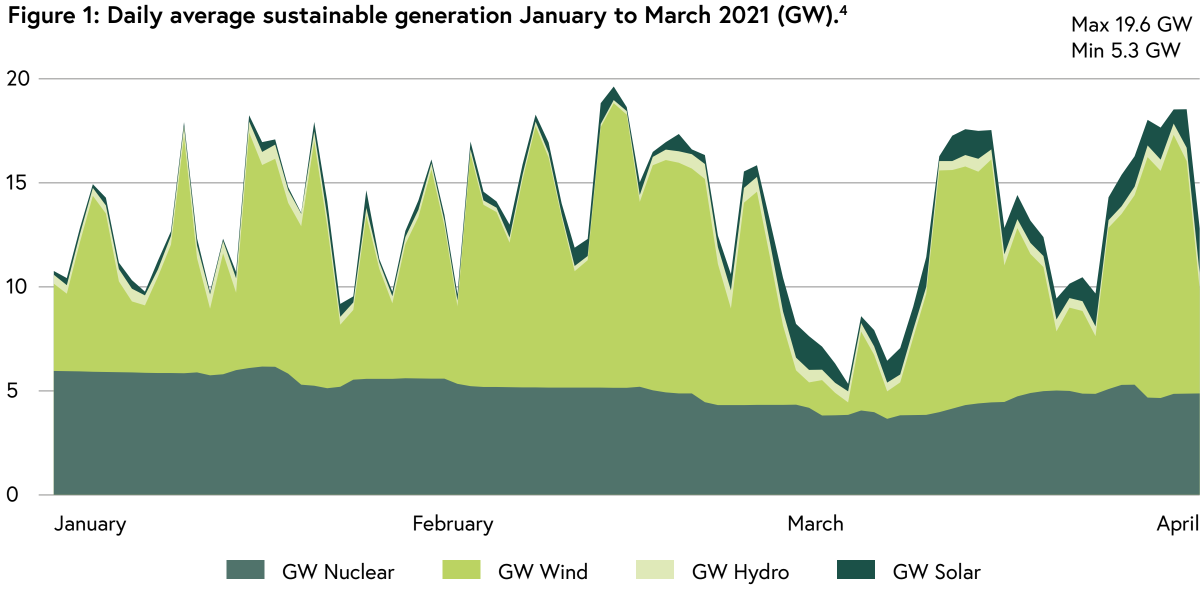
Resource estimates for wind power vary depending on technical and social considerations. The Climate Change Committee's Net Zero Technical report[1] and Sixth Carbon Budget[2] suggest 370 and 430 TWh pa respectively in 2050, whilst the Energy Systems Catapult's centralised 'Clockwork' optimisation scenario proposes 212 TWh pa, and 369 TWh pa for its decentralised 'Patchwork' scenario.[3] A figure of 400 TWh pa is assumed here.



**Solar:** Solar photo-voltaic energy provides a useful input, though with some limitations given the UK's latitude. Its output is more predictable than wind power, but lowest in winter when energy demands are greatest. Solar power installations are particularly good for engaging public hearts and minds and offer the opportunity for individuals and communities to invest in their own power production.

Again, resource estimates for 2050 vary widely, with the Climate Change Committee (CCC) suggesting 85 TWh.[2] Alternatively, the Energy Systems Catapult suggests just 17 TWh and 73 TWh for its centralised and decentralised pathways. A figure of 75 TWh pa is assumed here.

**Figure 1: Daily average sustainable generation January to March 2021 (GW).**[4]




1 Net Zero - Technical report - Climate Change Committee (theccc.org.uk).
2 Sixth Carbon Budget - Climate Change Committee (theccc.org.uk).
3 Innovating to Net Zero - Energy Systems Catapult.
4 Gridwatch.co.uk.

**Marine:** In the UK we potentially possess some great tidal and wave power resources and have built an excellent innovation base, making this a good prospect in the renewables mix. The technical, environmental, and political challenges tend to make these sources look expensive compared to wind, but the predictability of their output adds greatly to their future value. The total possible raw energy resource has been calculated to be around 250 GW[5], but for now it seems that only a small proportion of that is likely to be captured. Here it is assumed this might develop around 20 TWh pa comprising perhaps of one large project along with two small schemes.

**Biofuels:** Biofuels are extremely valuable, though the debate on their future uses is a complex one. There are limited onshore resources and concerns about global habitat damage, the potential for conflicts with food production and the carbon cost of the supply chain. Of particular importance is the ability to develop negative emissions when combined with $CO_2$ capture and storage (termed BECCS), and so help offset some of the most difficult net zero challenges. Biofuels can also be very useful for individual or community energy schemes using locally available feedstock.

It's probable that there will be competition for biofuels from transport and aviation, and the quantities required suggest that it is unlikely they will develop to be one of the largest contributors to power and heat production in 2050.

**Figure 2: Available renewable electricity estimate (2050).**

| Available renewable electricity estimate (2050) | |
|---|---|
| **Energy** | **TWh pa** |
| **Wind** | 400 |
| **Wave/tidal** | 20 |
| **Solar** | 75 |
| **Total** | **495** |

**Geothermal:** Naturally occurring thermal heat can be exploited using ground source, marine source, open water source or mine water source heat pumps where these resources are available, and can be combined with other sources for networked heat. Deep geothermal hot rock supplies have looked likely only to be accessible in parts of the UK, notably Cornwall.[6,7] A British Geological Survey study and modelling of Engineered Geothermal Systems in 2017[8] referred to international wells having an average depth of around 3km. It suggested that continuing developments in drilling technologies could in future access very significant usable resources that are available at depths around 7km across much of the UK. Whilst such resources have great potential, it seems that considerable research and development is needed before these could be reliably incorporated in plans for 2050.

In summary, an overall assessment in Figure 2 suggests 495 TWh pa as an estimate of the major renewable electricity generation sources available in 2050.

This compares with existing wind, wave, and solar renewables output of 77 TWh pa, along with 56 TWh of sustainable nuclear power using DUKES 2020 data for 2019.[9] To put this into context, today's annual electricity consumption is around 320 TWh.

In addition, controllable electricity inputs are vital to provide backup for the intermittent renewable supplies, respond to seasonal variations in demand, and to give stability to the electricity system. Storage technologies and demand flexibility can deliver some limited help, but substantial generation input is needed, with the major potential sources being natural gas, biomass or nuclear.

[5] Sustainable Energy Without the Hot Air, Professor David MacKay, Page 98.
[6] Sustainable Energy Without the Hot Air, Professor David MacKay, Page 98.
[7] The UK Geothermal and Hot Dry Rock R and D Programme - Paul MacDonald, Ann Stedman and Geoff Symons, Energy Technology Support Unit (stanford.edu).
[8] Assessment of the resource base for engineered geothermal systems in Great Britain | Geothermal Energy | (springeropen.com).
[9] Digest of UK Energy Statistics (DUKES) 2020 - GOV.UK (www.gov.uk).

**Figure 3: Brief comparison of potential non-intermittent electricity sources.**

| | Positives | Negatives |
|---|---|---|
| **Natural gas** | – Readily available technology for base and peak power generation. | – Consolidates a future dependence on fossil fuels, even with carbon capture.<br>– Limits energy independence.<br>– Exposed to volatile markets.<br>– Increasingly unlikely to attract corporate investment. |
| **Biomass / biofuels** | – Absorbs atmospheric $CO_2$.<br>– Can be combined with carbon capture to provide negative emissions. | – Planting, harvesting, transport and processing introduce further emissions.<br>– Vast quantities needed, mostly imported.*<br>– Limits energy independence.<br>– Potential habitat and food chain impacts.<br>– Competition from other applications. |
| **Nuclear (fission)** | – Controllable output, stable prices.<br>– Potential for development of modular plant. | – Not renewable, but sustainable.<br>– Relies on imported materials (albeit low in volume).<br>– Requires new long term safe storage for depleted materials.<br>– Societal concerns. |

*Drax power station in North Yorkshire provides the most renewable power of any single location in the UK, some 14 TWh pa.[10]
Each day around 14 specialised trains deliver approximately 20,000 tons of biofuel, producing an output of just over 1 TWh per month.

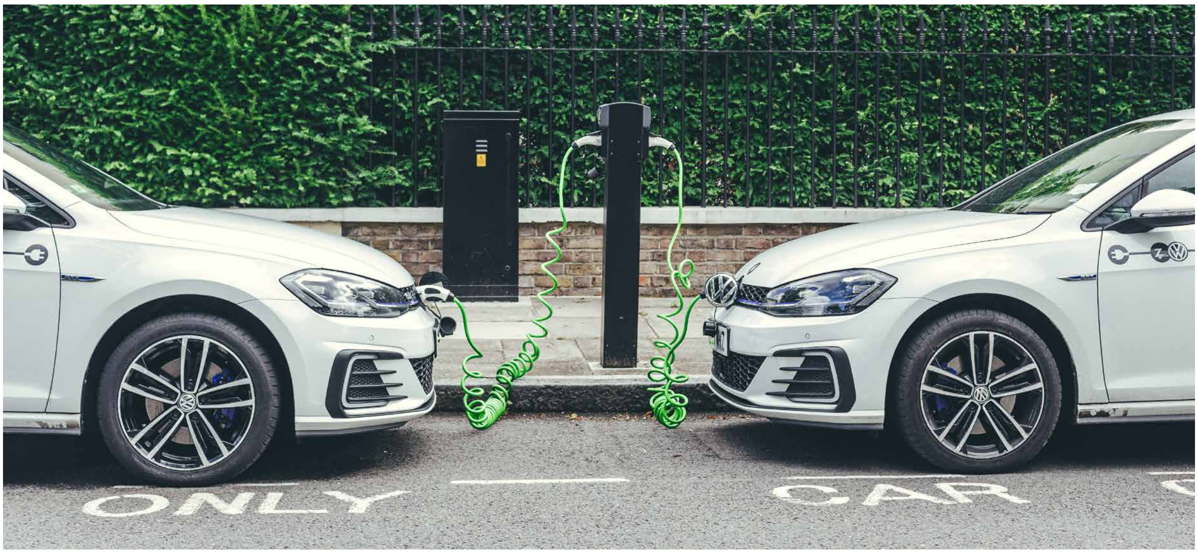
Considering the UK's latitude, seasonal demand variations and need to improve energy independence, it seems hard for many commentators to imagine a future without nuclear power coupled with a safe waste storage regime. The societal perception questions are real and important, and whilst nuclear energy is not considered a renewable resource as it is reliant on mineral extraction, it is sustainable given the small quantities required. The alternative of a massively increased use of generation powered by natural gas or perhaps coal, combined with carbon capture could be helpful in the shorter term, but does little to break our future dependence on fossil fuels. Concerns over the quantities, sources and best uses of biofuels would also face major societal and technical challenge.

Nuclear power options include the further development of new and existing sites, and the introduction of smaller modular reactors (SMRs) that are capable of more rapid factory fabrication, with economies of series production and shorter construction times.

For the longer term it would be remiss not to mention nuclear fusion here. Whilst it's been a promise for decades and we shouldn't make plans for it in the energy mix, the extent of innovation, investment, and progress allow for some optimism that it will one day be an important energy source.

[10] Drax 2020 Annual Report - Driven by our purpose.

# 5. What are our future energy user requirements?




This section assesses the quantities of electrical energy potentially needed in 2050 (TWh pa), starting with the transition of existing power requirements and then adding in the new transport, industry and heat needs. The level of overcapacity needed to deal with supply intermittency is considered later.

**Electricity system:** Using DUKES 2020 data for 2019[11] the transition of the present electricity demands from the current fuel mix to renewable sources would need around 320 TWh pa of renewable power.

**Transport:** Whilst there are some options, the deployment choices for light transport seem to be largely shaped by the improving functionality and emerging international market for electric vehicles, and perhaps a shift from vehicle ownership to trip based or rental services. Solutions for heavy goods, trains and aviation are guided by weight, energy density and range requirements, so a mix of biofuels, electricity and hydrogen looks likely. Taking a view of electricity requirements across National Grid ESO's Future Energy Scenarios[12], the CCC and The Energy Systems Catapult, a figure of 121 TWh pa is assumed here for transport, including rail.

**Industry:** Industrial energy requirements are substantial and vary greatly by process. Whilst there will be innovation steering new manufacturing approaches, for now it seems reasonable to expect a balanced outcome, with environmental pressures and associated carbon taxes being likely to encourage the wider development of electricity-based manufacturing solutions, and some use of hydrogen.[13] National Grid ESO's Future Energy Scenarios data suggests that a range of additional industrial usage is possible, between 10 TWh and 82 TWh. The CCC data shows increases in electricity requirements for manufacturing and construction, and non-residential buildings totalling 73 TWh pa.

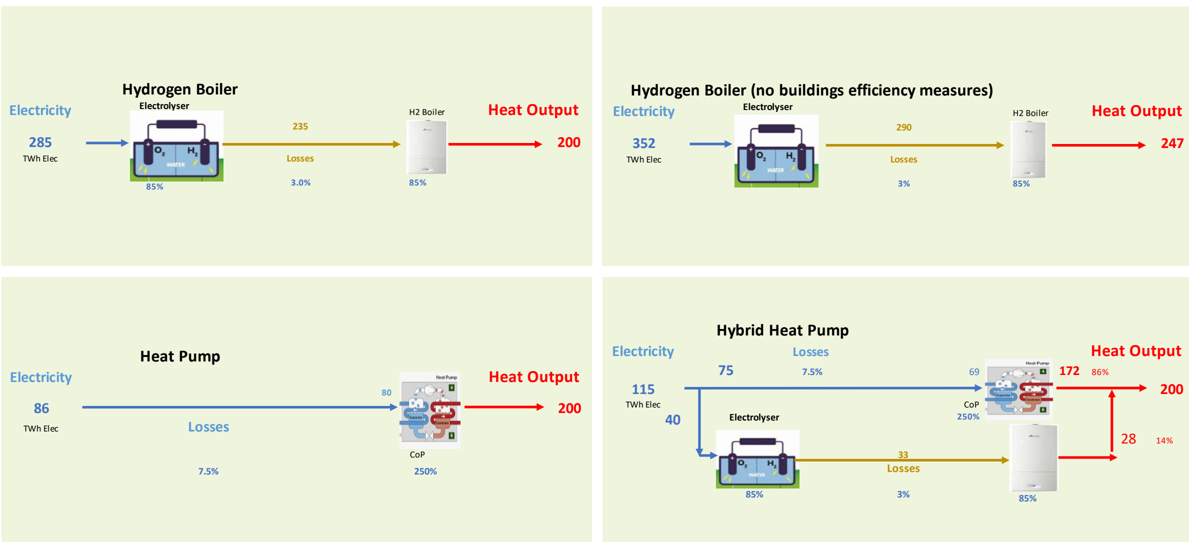
[11] Digest of UK Energy Statistics (DUKES) 2020 - GOV.UK (www.gov.uk).
[12] Future Energy Scenarios 2021 | National Grid ESO.
[13] Deep-Decarbonisation Pathways for UK Industry (Element Energy) - Climate Change Committee (theccc.org.uk).

**Heat:** Space heating remains an area of much debate as there is little agreement on a single, clear, sustainable solution that has minimal adverse customer and societal impact and low cost compared to the current natural gas system. With some significant work, the gas grid and homes could be converted to use 100% hydrogen produced from natural gas combined with $CO_2$ capture. While this route would perpetuate a dependency on fossil fuels, hydrogen could alternatively be produced by electrolysis using renewable electricity sources. However, if derived this way it is inevitably more expensive than the electricity it uses. This suggests that, if practical, direct use of the electricity for home heating is preferable to introducing hydrogen to that supply chain. In addition, heat pumps powered by electricity offer a way to significantly multiply space heat output efficiency, using as little as one third of the renewable electricity resource needed for hydrogen production by electrolysis.

Studies by Element Energy show that relatively small heat pumps in a hybrid system can provide a large proportion of domestic heat requirements (81.9% for an insulated semi-detached home and 85% for detached homes).[14] Future heat provision does not need to involve the purchase of expensive assets or kilowatt hours of energy by the householder. Instead, this could be based on payments for the desired outcomes – carefully controlled warmth. For example, the Energy Systems Catapult has conducted research into the provision of Heat as a Service.[15]

Figure 4 shows the difference between heat choices. Estimates of electricity inputs range here from 86 TWh for a system largely based on air source heat pumps combined with buildings efficiency measures, to 352 TWh for the deployment of hydrogen boilers without buildings improvements.

**Figure 4: The energy supply impacts of space heat options.**

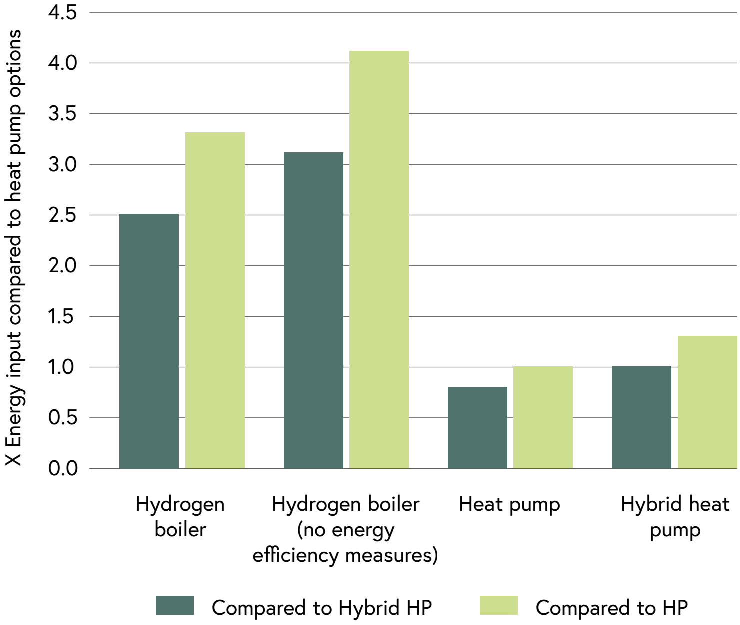



[14] Hybrid heat pumps final report (publishing.service.gov.uk).
[15] SSH2: Introduction to Heat as a Service - Energy Systems Catapult.

This simplified representation compares energy inputs required to provide a similar space heating outcome (200 TWh being an estimate of UK heat requirements after efficiency measures not met by other sources in 2050). Heat pump options offer the prospect of substantially lower energy inputs.

Note - It is sometimes stated that energy efficiency measures would not be an important feature of hydrogen boiler deployment, so this option is included for completeness.

**Figure 5: Comparative electricity input requirements for space heat options.**

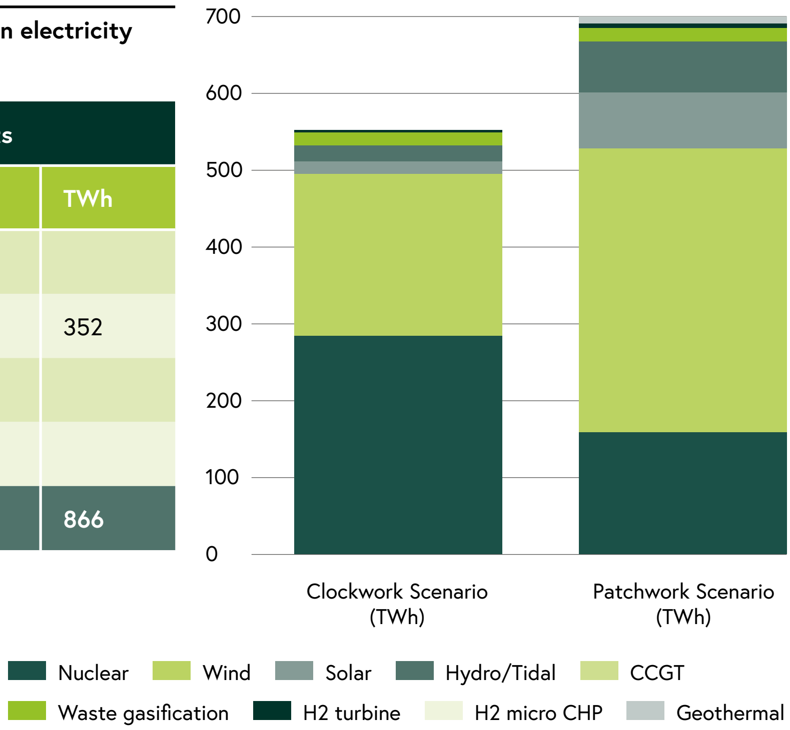



Summarising these estimates in Figure 6 suggests total electricity generation in a range between around 600 TWh pa and over 800 TWh pa, with the greatest variable component being the solution chosen for space heating.

**Figure 6: Estimate of 2050 low carbon electricity requirements.**

| Low carbon electricity requirements | | |
|---|---|---|
| | **TWh** | **TWh** |
| **Electricity system** | 320 | |
| **Heat (range)** | 86 | 352 |
| **Transport** | 121 | |
| **Industrial/commercial** | 73 | |
| **Total** | 600 | 866 |

**Figure 7: For comparison, optimisation studies by The Energy Systems Catapult result in a 2050 electricity production requirement of 554 TWh pa for the 'Clockwork' (centralised) pathway, and 700 TWh for the 'Patchwork' (decentralised) pathway.**

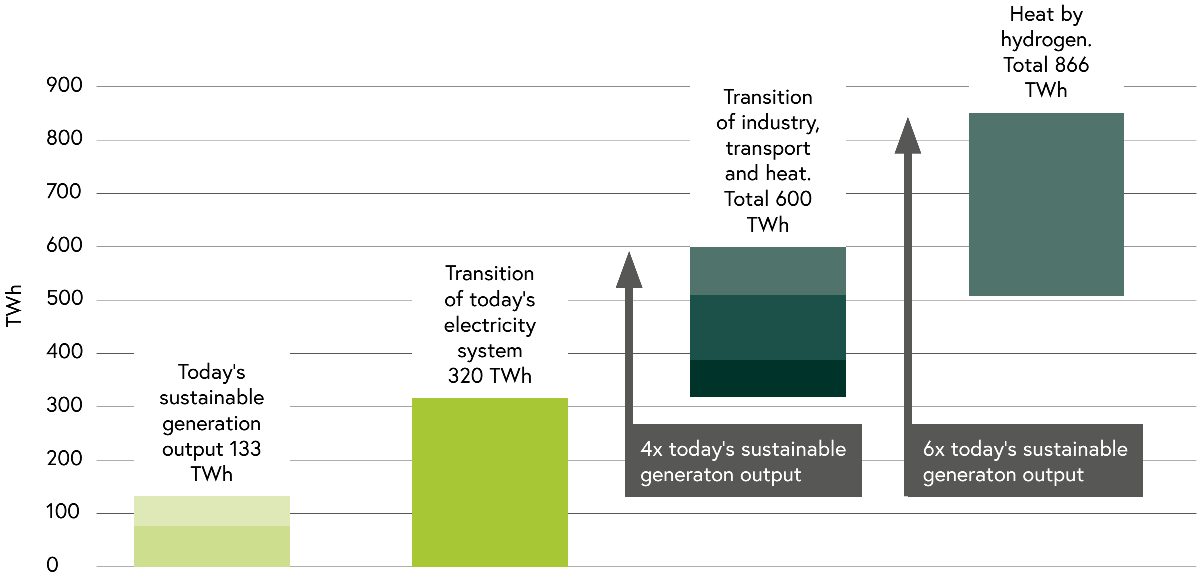



Energy Systems Catapult 2050 Electricity Production (TWh) (chart constructed using ESC data).

# 6. Comparing today's sustainable resource with the energy we need

Figure 8 shows the 2050 sustainable electricity needs compared to the existing annual renewable electricity outputs of 77 TWh for wind, wave and solar, and 56 TWh nuclear power (total 133 TWh). The minimum sustainable generation output requirements in 2050 are more than four times current levels, or around six times current levels for the hydrogen boilers without buildings efficiency measures case.

**Figure 8: 2050 sustainable electricity requirements for the transition of the electricity system, industry, transport and heat, compared to today's sustainable generation output.**

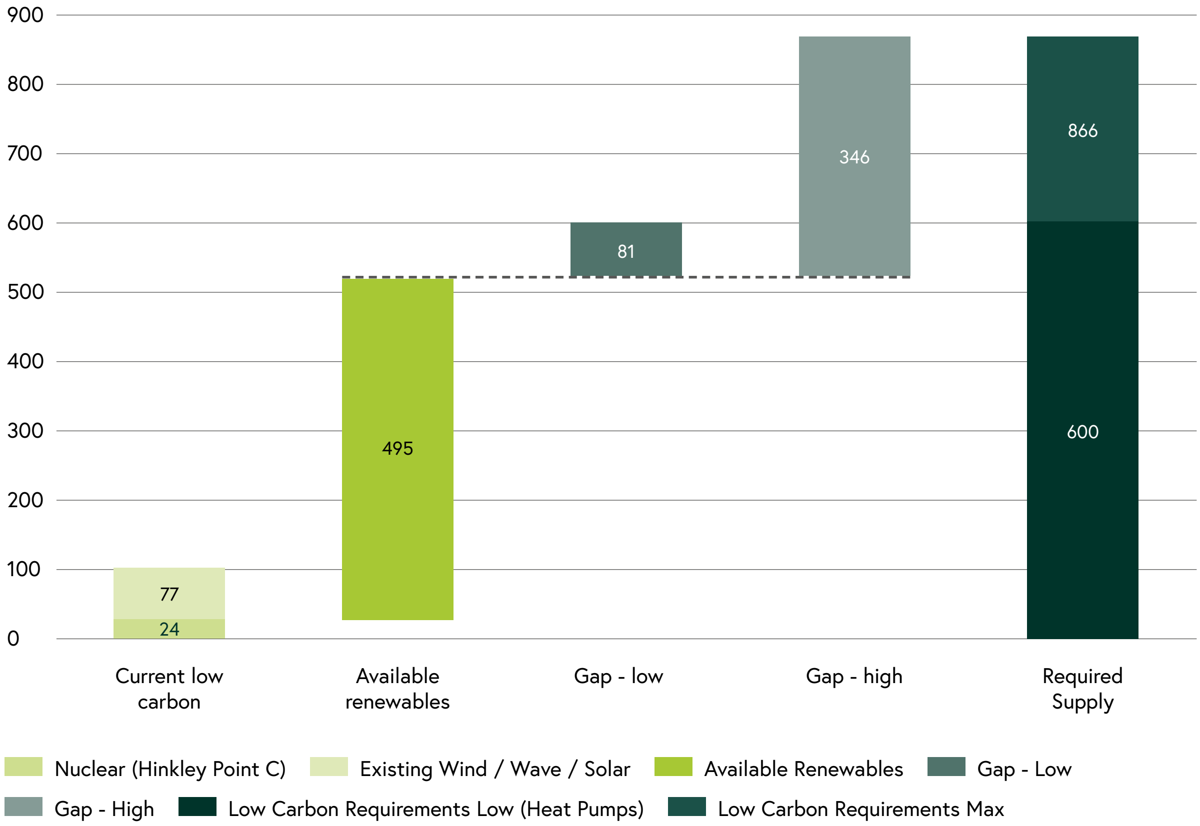



In Figure 9 the renewables estimate (495 TWh pa) combined with the resources not due to be retired by 2050 (24 TWh from Hinkley Point C), shows a gap of around 81 TWh pa for the low heat case using heat pumps, rising to 346 TWh for the high heat case using hydrogen without buildings efficiency measures. Purely to illustrate the scale, closing the gap would require the equivalent annual output of more than three Hinkley Point C stations for the lower heat case, or 14 if hydrogen produced by electrolysis is used for heat, without buildings efficiency measures.

Whilst the estimate here is useful to illustrate annual generation TWh outputs, it is misleading as wind and solar supplies are inherently intermittent, and importantly often hit very low levels during winter anticyclone periods. These times will coincide with peak energy usage, so a more detailed study of temporal demand and supply would be needed to assess the critical levels of non-intermittent generation plant capacity (Gigawatts) required to maintain supplies.

Options for meeting demand peaks and renewable energy shortfalls include: hydrogen turbines using stored hydrogen, biofuels combined with carbon capture storage (CCS), hybrid heat pumps using relatively small amounts of stored hydrogen during peak periods, the further use of interconnectors, and the management of transportation batteries and demand flexibility during short term peaks. A defined level of non-intermittent generation will be vital for

**Figure 9: Sustainable electricity resources currently planned to be available in 2050, an estimate of available renewables and the gap to be closed to meet 2050 needs.**




Note* It is assumed that the existing 77 TWh renewable resource will require re-powering during this period.

the secure operation of a system designed around intermittent renewable sources, ensuring supplies during sustained shortfalls in output and providing system stability and resilience. Projections for such capacity vary depending on modelling assumptions and economics, particularly given the potentially minimal utilisation of plant that provides back up generation.[16] National Grid Future Energy Scenarios suggest an average cold spell peak electricity demand of around 100 GW in 2050 across its scenarios and approximately 100 GW of non-intermittent generation capacity, which is around 35% of the total.[17] Similar levels of non-intermittent capacity are suggested by the Energy System Catapult's ESME analysis.[18]

Whilst this would be met from a number of sources including interconnectors, purely to illustrate the scale this requirement equates to the equivalent installed capacity of around 30 Hinkley Point C stations, or almost 40 Drax Biofuel plants with carbon capture applied.

16 Accelerated Electrification and the GB Electricity System - Climate Change Committee (theccc.org.uk).
17 Future Energy Scenarios 2021 | National Grid ESO.
18 Innovating to Net Zero - Energy Systems Catapult.

# 6. Conclusions

The assessment in this report, along with other studies points to at least a doubling of today's annual electricity supply from all generation sources, or more than four times the present low carbon generation output. The solutions chosen, particularly for heating could increase this figure substantially, and there is also the need for non-intermittent generation of sufficient capacity to ensure system security and operability. Fundamentally, for efficient transition at this scale, renewables cannot be considered as limitless and should be treated as a valuable and precious resource.

Whilst further production resources are under discussion, only one nuclear plant is currently scheduled for availability in 2050. It can be assumed that the existing renewables fleet will require repowering during that period, so the challenge is even greater.

This high-level look at renewable energy makes an inescapable case for it to be regarded as a precious resource. It will require national decisions that will have a huge impact on the scale of generation and infrastructure needed, along with thoughtful consumer actions that combine to provide the best route to achieving a sustainable future.

The conclusion also leads to a compelling case for comprehensive energy efficiency measures that start by reducing energy demands. Around 75% of dwellings were built before 1980 when buildings standards paid little attention to energy efficiency.[19] Substantial improvements are essential whichever heating solution we choose, and whilst costly, in addition to energy efficiency gains they provide great social and welfare benefits and help make our buildings fit for their future purpose.

The transition of our energy system offers a unique opportunity to think carefully about the long term, and not just today's starting point. This of course will need a technical foundation, but also must be planned with our best view of the functionality that society will need into the next century. Changes to commercial arrangements will be essential as will agility in the development of important codes and standards. None of this is straightforward, and whilst we may say the world is being slow to act seriously on climate change, we can expect and need further massive movements in societal beliefs.

Global changes in food and manufacturing locations along with new methods of emissions accountancy and taxes are just some of the more distant hurdles to be considered. A key feature then must be the ability of the system, by design to be capable of adapting to unknown emergent issues, innovative technologies, and consumer services.

Whilst the need for a system that uses less energy must be top of the list of desirable outcomes, there must also be supply security and the benefits of national self-sufficiency or shared sufficiency, minimal exposure to fuel price volatility and beneficial improvements in health and welfare. The nation already faces supply challenges driven by the increased dependence on imported fuels. Investment in sustainable energy offers a route to develop an asset base that serves society with more predictable financial charges and reduced dependence on volatile international fuel markets. Unhitching the energy system from fossil fuels provides a real opportunity to think more freely about the characteristics of a truly sustainable future energy system, with less emphasis placed on what we have now. We have a chance to reshape our infrastructure and building stock to deliver the services that future generations will need in a way that also favours local economic wealth.

Technology already brings great benefits to society, and innovation will continue and thrive in this vital area. New consumer products and controls, smarter system management techniques and advances in system diagnostics and incident recovery will play a large part in a world where the services delivered by electricity are more vital to society than ever. Strong strategic direction and leadership is vital to design and deliver a level of efficient transition at the scale required, along with an essential ethos that embraces innovative developments as they arise.

[19] The Housing Stock of the United Kingdom Report BRE-Trust.pdf (bregroup.com).

# 8. About the IET

We are the IET – a charitable engineering institution with over **155,000 members in 148 countries** – working to engineer a better world.

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As a diverse home across engineering and technology, we share knowledge that helps make better sense of the world in order to solve the challenges that matter. It is why we are uniquely placed to champion engineering.

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We cover engineering across industry from design and production, digital and energy to healthcare, transport and the built environment. Passionate about energy, we bring together expert practitioners from the energy industry, academia and third sector.

We champion engineers and technicians working in the sector by offering networking, volunteering and thought leadership opportunities. Together, we campaign on issues of the day around energy and provide policy input to government.

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