ADViCE | **A**I Innovation for **D**ecarbonisation's **Vi**rtual **C**entre of **E**xcellence

# ADViCE: AI for Decarbonisation Challenges

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# Contents

# Executive Summary

As outlined in the ADViCE ecosystem report, many current applications of AI in high emissions sectors like energy and manufacturing largely focus on efficiency and cost reduction. However, there are applications of AI which could more directly accelerate decarbonisation in these sectors.

This report aims to accelerate the use of AI to drive decarbonisation in the UK by highlighting decarbonisation challenges that AI could help address. There are seven grand challenges:

# AI for Decarbonisation Grand Challenges


Unlocking domestic decarbonisation


Enabling net zero infrastructure


Maximising flexibility in energy networks


Decarbonising manufacturing inputs


Improving manufacturing process efficiency


Optimising soil management


Minimising methane in agriculture

## AI for Decarbonisation Challenges

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|---|---|
| **1. Unlocking Domestic Decarbonisation** | Decarbonising homes requires changes to both heating systems and consumer behaviours in every home in the UK. Engaging consumers in that process, financing it, and delivering it at pace are all major challenges. |
| **2. Enabling Net Zero Infrastructure** | Electrification of heating and transportation, combined with increased renewables mean the UK needs significant expansion of our electricity networks. Delivering at the required scale – and pace – is a real challenge, with lots of renewable generation being held up due to delays or uncertainty in network connections. |
| **3. Maximising Flexibility in Energy Networks:** | An electrified, high renewables future requires energy demand to flex, so users consume and store energy when the wind is blowing, and the sun is shining. This requires a radical change in how networks, markets and end users operate, which also requires an introduction of new technology, presenting a host of new challenges. |
| **4. Decarbonising Manufacturing Inputs** | Many manufacturing processes rely on carbon intensive fuels and/or raw materials. Decarbonising manufacturing requires a wholesale redesign of processes and products to use low carbon inputs, but this is complex and costly. |
| **5. Manufacturing Process Efficiency** | For processes that are extremely hard to fully decarbonise, improving their efficiency is important in reducing emissions. This shouldn't come at the expense of decarbonising inputs but may help accelerate decarbonisation in the short term for processes. |
| **6. Optimising Soil Management** | In agriculture, soil is a major source of emissions – as well as a potential route to carbon sequestration. Optimising the management of soil health from an emissions perspective is a key challenge. |
| **7. Minimising Methane in Agriculture** | Methane emissions from livestock are a major contributor to global emissions. Reducing these emissions is critical, whether through shifting to low-meat diets or more carbon-conscious livestock management. |

Within each grand challenge there are multiple individual sub challenges, each highlighting more specific area where AI could be beneficial. Each sub challenge may require different techniques and expertise, highlighting different ways to address the grand challenges.

Hopefully one or more of these challenges will capture your imagination and trigger ideas for how you might be able to apply AI to decarbonisation, the greatest challenge facing our generation. Talk to us about how we can help you make that happen!

You can join in the discussion of the challenges and how to solve them via the ADViCE working groups and webinars.

# Introduction

This report is part of Stream 1 of UK Government's Artificial Intelligence for Decarbonisation Innovation Programme, establishing the AI for Decarbonisation's Virtual Centre for Excellence (ADViCE) delivered by Digital Catapult, Energy Systems Catapult and The Alan Turing Institute. It describes the most important decarbonisation challenges where AI has the potential to make significant impact. It complements the Ecosystem report which identifies key organisations, project and trends in AI for decarbonisation. This report highlights areas where AI has not been extensively applied and consequently where there is significant potential for progress and innovation.

The report describes the context for the challenges and presents the seven key grand challenges across the sectors of Energy, Manufacturing, Built Environment and Agriculture.

This report is aimed at practitioners, decision makers, and researchers across the respective sectors. Tackling the grand challenges will require significant effort and resources from industry, academia, and government. For organisations in energy, agriculture, or manufacturing, solving the challenges here not only accelerates decarbonisation but also offers new business opportunities and areas for innovation. For practitioners and researchers, they offer new applications of AI, and opportunities for novel algorithm implementations. For private and public sector funders, the report highlights the areas which may require significant investment and attention.

This and the Ecosystem report provide the foundation for the continued activities of the ADViCE programme which will include engaging the AI and decarbonisation communities to tackle the challenges presented and help support those who are working on them.

# AI's role in Decarbonisation

This section briefly describes the importance of identifying major challenges for decarbonisation, the opportunities provided by AI, and the approach used to define the challenges.

The need to decarbonise has been laid in detail in the Ecosystem report. In summary, human-driven climate change, through the emission of greenhouse gases is forcing significant changes in the environment, leading to extremes in weather and climate, increased risk to people, nature, and food security. Many nations, and regions, have declared a climate emergency and are committed to minimising the most significant impacts of climate change.

Achieving this, will require a diverse range of political, social, and technological solutions, to both mitigate the effects and adapt to the inevitable changes that will occur to the economy and environment within which it sits.

AI is one tool which can help tackle challenges (or elements of challenges) which are difficult to address with other approaches. The rapid development of sensor technology and computational resources have created the opportunity for artificial intelligence to realise significant value in the everyday lives of people in the UK, and the wider world. The techniques and methods of AI, applied to increasing amounts of collected data, can provide insights and models of complex phenomenon and relationships which previously had been intractable. The ability to assimilate large quantities of data and turn them into actionable insights has enabled new innovations and business products ranging from drug pharmaceutical discoveries to image processing, and the prospect of a vast array of applications such as advanced chat bots, code development assistance and creative writing, that are unlocked by large language models (LLMs).

Despite the rapid progress in AI, the application of it to decarbonisation has lagged somewhat. As explored in the Ecosystem report, there are multiple reasons for this, including limited amounts of granular data, a lack of skills, culture, and uncertainty around the value of changing processes to incorporate data-driven methods. However, if the UK is to meet its Net Zero targets, urgency is required, and will necessitate the utilisation of all available tools to decarbonise these sectors.

There are now significant digitalisation efforts across the energy, built environment, agriculture and manufacturing sectors, which means more data is available for AI applications. There is clear value as it can enable more products and services, costs savings, but most importantly opportunities to decarbonise. For example, the roll out of smart meters and the development of new energy products for building owners is creating opportunities for consumers to modify their behaviours, reduce consumption and adopt low carbon technologies.

Although there is a range of possible applications which AI could be applied across these four sectors, their potential decarbonisation impact varies. In general, applications of AI in these sectors have often been focused primarily on efficiency and cost reduction, rather than decarbonisation specifically.

*Therefore, the aim of this report is to not only try and provide a list of challenges where AI can help support decarbonisation across energy, built environment, agriculture, and manufacturing, but highlight areas where AI can have the greatest impact and where there is still significant research and investigation required.*

We hope that this report can serve as inspiration and motivation to those in the AI community to apply their skills, techniques and insights to help to drive these decarbonisation challenges forward and make a real, impactful difference.

# Challenges Selection Methodology

This section describes the methodology for selecting challenges, including:

- the criteria used to score their potential impact
- the suitability of AI to help solve them
- the relative attention these challenges have received from the AI community to date

ADViCE

## Sectors

The focus of ADViCE is the following four main sectors:

- **Agriculture:** farming, livestock, supply chain and distribution.
- **Built Environment:** Residential, transport and commercial infrastructure.
- **Energy:** Renewables, network infrastructure and assets, and energy management.
- **Manufacturing:** Steel making, cement production, chemical processing, machines, and robotics.

More details about the specific industries can be found within the Ecosystem report. The choice of these industries is specifically due to the large contribution they make to greenhouse gas emissions in the UK, and the difficulty of decarbonising them.

## Identifying Challenges

For AI researchers and developers, a major barrier to identifying valuable opportunities for AI is understanding industry problems in sufficient detail. For this reason, a key approach to identifying challenges and systemic blockers to decarbonisations is to interview subject matter experts. Decarbonisation challenges where the exact application of AI is unclear have therefore sometimes been intentionally included to broaden perspectives and focus on major blockers, and not merely the ease with which AI can be applied.

This top-down, decarbonisation first approach was supplemented with a bottom-up approach looking at existing AI applications. The combination of these two approaches ensures that gaps and new opportunities have been identified thoroughly and effectively.

To gather the challenges in these areas, a combination of methods has been applied including interviews, surveys, and desktop research. For the top-down approach the focus was on interviewing experts in different areas of decarbonisation. For the bottom-up approach the focus was on desktop research, including identifying appropriate white papers on the topic; the use of databases on energy projects (including the UKRI gateway, ENA's Smarter Networks Portal and Energy System Catapult's CoPED Catalogue); and academic literature highlighting the research that has already been applied. A list of many of the resources used can be found in the Appendix.

## Phases

When categorising the challenges, they were typically related on one of the following phases of asset or product management:

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| **Design & Planning** | These are challenges focused on future, longer term solutions such as designing new products, or developing new technologies. They also focus on any planning applications, such as determining where to build new infrastructure, or what investments to make. |
| **Management & Operations** | These challenges focus on day-to-day operations for each sector. For example, this could be determining schedules for battery management, or logistics for manufacturing distribution. |
| **Maintenance & Anomaly Detection** | These challenges focus on maintaining equipment, but also are concerned with identifying and locating faults and making sure any machinery or infrastructure is working properly or with optimal energy efficiency. |
| **Incentives & Customer Support** | These challenges focus on incentives to drive decarbonisation behaviours in different stakeholders, as well as relationships with customers of the different sectors. |

These categories enable sector workers in relevant roles to quickly isolate applications that are relevant to them. They also allow AI practitioners to identify cross-sector opportunities where they have existing solutions in one of these phases, which could be applied to similar challenges in other sectors.

## Scoring Criteria

To isolate the most important and impactful challenges we developed a scoring system focused on three main criteria:

- Decarbonisation impact
- Suitability for AI
- Potential novel applications

These criteria were used to score the list of specific sub-challenges for each sector (which can be found in Appendix). Any challenge which scored zero in any of the three main scoring categories was not included.

The final grand challenges were selected by considering clusters of sub-challenges with common themes and which consistently scored relatively highly in each of the three scoring categories. The scoring for each sub challenge can be found on the ADViCE website here. Each of the scoring criteria are described in more detail below.

## Decarbonisation Impact

The most important criterion for the challenges is the potential decarbonisation impact. This includes consideration of the scale of emissions reduction that could arise from solving the challenge or how critical a blocker to decarbonisation this solution would address.

The levels used to qualitatively score this criterion are on a scale 0 to 3 (with 0 lowest) with the following high-level descriptions:

0. Negligible decarbonisation impact
1. Decarbonisation impact is well defined but relatively small scale OR decarbonisation impact is hard to define but potentially larger
2. Has the clear potential to reduce emissions at medium scale
3. Has the clear potential to reduce emissions at a large scale

Any challenge that scores zero in this area is not be considered and is not included in the long list of sub challenges in Appendix.

## Suitability for AI

This criterion determines whether the challenge can effectively be addressed with AI. It may be that only some components can, and others cannot, or in the best-case scenario, the entire challenge is purely solvable by AI. It may be that in some cases the challenge could potentially be solved, with AI, but there are other blockers which reduce its suitability. It could be that the data is simply not available in the short-term, or that it depends on other technologies, or perhaps updates to policies and regulations.

The levels used to score these criteria are on a scale 0 to 3 (with 0 lowest) with the following high-level descriptions:

0. AI is a very poor fit, the data is not available, and/or the challenge solution is more naturally aligned with other tools
1. Suitable data would be hard to obtain and/or AI could only address minor components of the challenge
2. AI could address key components of the challenge, and access to suitable data is probably possible
3. Most of the challenge could be addressed with AI, suitable data are available (and suitable algorithms may already exist?)

Any challenge that scores zero in this area is not considered and is not included in the long list of sub challenges in Appendix.

## Novel AI Applications

This criterion considers the novelty of AI applications in the specific challenge. It could be that the suitability of AI methods is very high, but research, development, and investment in this area is already well established and additional attention would have limited impact.

The levels used to score this area are on a scale 0 to 3 (with 0 lowest) with the following high-level descriptions:

0. Lots of attention on this challenge, with major investment flowing in and multiple forms of innovation occurring
1. Well understood area for research and funding, with some significant activity
2. Limited activity and funding trying to address this challenge with AI
3. Close to no activity trying to address this challenge with AI

Any challenge that scores zero in this area is not be considered and is not included in the long list of sub challenges in Appendix.

## AI Capabilities

We have also provided information on what AI capabilities are required for each challenge in the main grand challenges. These include:

- **Time Series:** Many sensors measure variables like energy, weather, and other values that vary over time. Analysing this requires a host of techniques and tools which are specific to this type of data, including time series analysis, forecasting methods and specific databases. AI for time series has yet to see the same transformational breakthroughs that vision and language have had in recent years.
- **Optimisation:** Many of the challenges require finding the optimal solution to a problem. Optimisation methods, whether conventional mathematical techniques or approaches like reinforcement learning, are therefore vital to find the best solution(s).
- **Geospatial:** Geospatial data is any data related to locations on earth and is therefore a key component of any mapping tool, or satellite imagery. This plays an important role in energy, built environment, and agricultural applications where the position of assets, machinery or planning is required. This will typically also involve using unique geospatial file types such as Hierarchical Data Formats (HDF).
- **Visual:** Visual data from satellites and cameras are increasingly important and are used in very specific AI applications such as image recognition. The challenges can be used to identify faults, for example, and are usually stored as tensor data, which has multiple attributes linked to each visual point, such as colour, or contrast.
- **Language:** Text mining and natural language processing can be used to extract information from text. Recent large language models (LLMs) such as ChatGPT have started to demonstrate the vast array of applications and possibilities from assimilating large amounts of data from text and documents.
- **Other Machine Learning:** There are a variety of other machine learning techniques that may be applicable to specific challenges, from regression and classification on tabular data through to physics-informed neural networks.

These specific capabilities are listed to help AI practitioners determine which challenges they could quickly provide some significant contribution based on their skill set.

# The Grand Challenges

**13%**

Residential heating is responsible for more than 13% of greenhouse gas emissions each year[1].

**18%**

Only 18% of all vehicles[4] purchased globally in 2023 are electric.

## Unlocking Domestic Decarbonisation (GC1)

**Summary:**

Without successfully decarbonising homes and domestic transport there is very little chance for successfully meeting the UK' s Net Zero targets. Residential heating is responsible for more than 13% of greenhouse gas emissions each year[1]. Decarbonising homes requires changes to both heating systems and consumer behaviours in every home in the UK. Engaging consumers in that process, financing it, and delivering it at pace are all major challenges.

**Sector:**

Built environment

**Detailed challenge description:**

One of the most promising strategies for domestic decarbonisation is to electrify our heating and transport, through heat pumps and electric vehicles (EVs) respectively. However, while uptake of these technologies is accelerating[2,3], they remain a small percentage of the overall stock. For example, only 18% of all vehicles purchased globally in 2023 are electric, and as of April 2023 the UK has only installed 380,000 heat pumps[5].

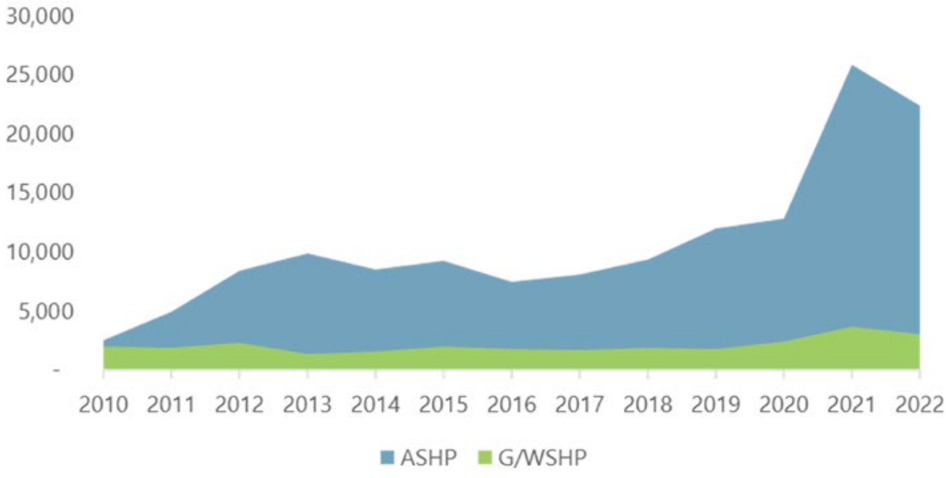


**Figure 1.** Installations of air source heat pumps (ASHP) and ground source or water source heat pumps (G/WSHP) in the UK from 2010 to 2022. Data from MCS database.

One of the main barriers to adoption of new technologies is the lack of trust, especially in contrast to conventional boilers and vehicles which have known reliability and understanding. This is a challenge both with consumers and heating installers, who have the largest influence over what gets installed.

[1] A Guide to Decarbonisation of Heat, Energy Systems Catapult, 2023.
[2] EV Market Stats 2023, Zapmap, 2023.
[3] Heat Pump Investment Roadmap, UK Government, 2023.
[4] Electric car statistics – EV market insights 2023, webuyanycar, 2023.
[5] Which Countries Are Winning the European Heat Pump Race? The Eco Experts, 2023.

**3,000**

recent figures show there are around 3,000 heat pump installers operating in the UK, but this needs to increase to at least 50,000.[6]

There is a significant shortage of skills - recent figures show there are around 3,000 heat pump installers operating in the UK, but this needs to increase to at least 50,000.[6] This is partly because existing heating installers are used to fitting oversized boilers which typically do not require a detailed design of the heating system – unlike heat pumps – and therefore haven't developed the required skills. This shortage results not only in delays to installation, but also the limited competition means feedback loops on cost and quality are weak and progress is slow. This also hinders public trust, and hence uptake, of the technology.

In addition, although most homes are suitable for heat pumps[7], energy efficiency improvements through retrofits, will significantly reduce running costs. The performance of retrofits can be very dependent on the quality of assessment, installation and commissioning, and there is often significant variation in quality and consumer outcomes.

Cost remains a barrier, in particular for heat pumps, although government initiatives have attempted to encourage uptake through incentives such as the recent Boiler Upgrade Scheme[8]. Installation costs typically make up a significant proportion of overall costs for heat pumps, demonstrating the need to find solutions that reduce this cost component.

In addition, several high demand technologies, including heat pumps and electric vehicle chargers, can require approval before connecting to the network to ensure they do not create network capacity issues. If numerous such connections are made, they risk outages on the network and may require expensive reinforcement (digging up the road and fitting new cables), network management technologies, or interventions such as storage or demand side response[9].

**AI Driven solutions:**

To accelerate uptake, AI can be used to improve planning, design and operation of low carbon homes.

At the planning stage, AI can be used to identify optimal retrofit pathways for different consumers and properties using data collected at scale or for individual properties. This can be combined with personalised information and guidance to consumers on retrofits to maximise uptake.

In the design stage, AI can automate key elements of the design process (e.g., calculating heat loss) and therefore simplify, standardise and accelerate the process, helping mitigate the skills shortage and improving quality.

[6] Decarbonisation requires a holistic approach to skills and regulation – Rob Hargraves. Energy Systems Catapult, 2023.
[7] All housing types are suitable for heat pumps, finds Electrification of Heat Project, Energy Systems Catapult, 2023.
[8] Boiler Upgrade Scheme, UK Government, 2023.
[9] Demand Side Response: Putting consumers in the driving seat, Energy Systems Catapult.

AI can also help optimise the operation and management of smart systems in homes. This can involve learning from smart meter data and other in-home sensors to understand behaviour patterns, optimising control of smart appliances to reduce cost and emissions, and tracking energy savings and building performance. Such energy management can expand to help support the wider local energy network and ensure the capacity of cables and assets are not exceeded.

**Related Sub-Challenges:**

Some of the core sub-challenges for this Grand challenge are as follows and are listed in the Appendix.

- **Challenge 15:** Customer information and guidance
- **Challenge 16:** Driving energy efficient behaviours
- **Challenge 17:** Abstracting away complexity for consumers
- **Challenge 18:** Supporting vulnerable customers
- **Challenge 62:** Identifying and targeting optimal retrofit measures
- **Challenge 63:** Retrofit design
- **Challenge 64:** Retrofit approvals
- **Challenge 65:** Retrofit installation and commissioning
- **Challenge 67:** Measuring retrofit impact
- **Challenge 68:** Standardised building performance ratings

**AI Capabilities:**

The AI solutions for this challenge will mainly require the following high-level capabilities to achieve (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Time Series:** In-home sensors and smart meter data are key to understanding energy usage and therefore the occupants' needs, and the impact of any retrofits.
- **Optimisation:** The aim of many solutions is to optimise the energy savings and identify the best technology or retrofit for the home. Visual: Visual data, such as infrared cameras for heat signatures, could help build an accurate picture of the options for a home. For example, arial photographs could identify the orientation of a house, identifying the suitability of a PV solar system.
- **Language:** Much of the data about the properties and occupant preferences will come from reports and surveys of the occupants. Utilising this information can help understand the best solutions for the individuals.
- **Geospatial:** The location of a home could be as important to the solutions as the energy usage. Isolated regions may be unsuitable for EVs which require long distance journeys. A location near an abandoned coal mine may indicate a heat network as the optimal domestic heating solution.

## Enabling Net Zero Infrastructure (GC2)

**Summary:**

Electrification of heating and transportation, combined with increased renewables mean we need both significant expansion of our electricity networks and ways to manage network constraints. Delivering at the required scale – and pace – is a real challenge, with lots of renewable generation being held up due to delays or uncertainty in network connections.

**Sector:**

Energy

**Detailed challenge description:**

Net Zero cannot be achieved without accelerating the installation of renewable generation. To decarbonise the power system, 180-220 GW of grid-connected capacity will be needed by 2035, requiring 6 to 9 GWs to be installed per year[10].

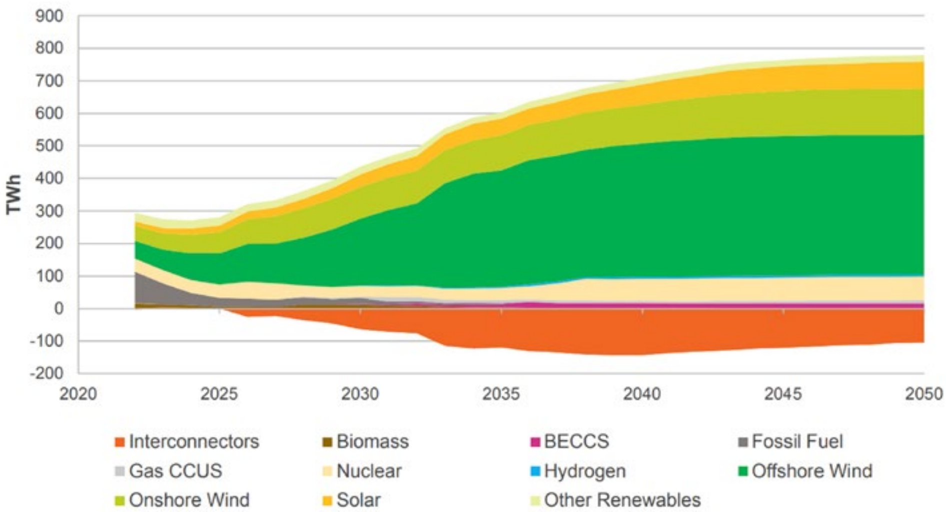


**Figure 2.** Total electricity generation output for the "Leading the Way" future energy scenario. From National Grid, Future Energy Scenarios, 2023.

Demand for electricity is expected to approximately double out to 2050[11,12], with the significant electrification of heating and transport. It will also increase the peak demand where some applications coincide (e.g., the use of electrified heating on cold days will coincide across many homes). In addition, decarbonising industry will require fuel shifts – probably to both hydrogen and electricity (see Grand Challenge 4) – and therefore significant network infrastructure will be required to enable this.

[10] Building a GB electricity network ready for net zero, Regen, 2023.
[11] The Sixth Carbon Budget: Electricity generation, Climate Change Committee, 2020.
[12] Innovating to Net Zero: UK Report, Energy Systems Catapult, 2021.

**15**

Queues for connecting renewables at distribution level can take up to 15 years.[13]

These factors combined mean that significant investment in infrastructure is required – not only building new renewable generation, but also new transmission and distribution networks to service new loads and connect new generation. However, queues for connecting renewables at distribution level can take up to 15 years[13], which means renewables take much longer than necessary to be available to consumers. Shortening this is critical to decarbonising our energy system by 2035.[14,15,16]

A key component of this challenge is the uncertainty about future network requirements. Both the choice of energy vector (electricity, hydrogen) and the pace of rollout have major implications for network planning – but what network capacity will be available in the future often determines the choice of energy vector and the pace of rollout. Ideally, new infrastructure should be optimised in such a way that every year the upgraded network has sufficient capacity and at locations where it is most needed. This is also important for ensuring energy security and grid stability. The connections for renewables and industry therefore require careful consideration of the network capacity, which makes determining optimal locations complex.

The planning and investment in network infrastructure is therefore a very challenging task which requires optimising a range of objectives (such as safety, risk, operational costs, and capital expenditure) across multiple timeframes and sectors, all in the face of significant uncertainty. With the additional requirements of ensuring the building of high levels of renewable generation, and the move to decentralised energy system, AI and data-driven techniques are going to be necessary to support and optimise decision making to enable infrastructure upgrades.

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**AI Driven solutions:**

Identifying the best industrial or renewable connection requires optimisation of networks to maximise opportunities whilst minimising the potential costs. This must take into several constraints including location, climate, weather, asset and cable ratings, consumer connections, renewable connections and network topology. Therefore, optimising new network connections is a difficult optimisation problem under uncertainty with limited data. AI can help accurately solve this problem efficiently and evaluate millions of different potential routes.

Evaluating these network options requires modelling detailed power flows, but this is nontrivial for very large networks with minimal monitoring. AI can be used to deal with missing or sparse data and accelerate the speed of simulations.

13 MPs call for grid improvements and affordable household loads so more can join the solar revolution, UK Parliament, Committees, 2023.
14 Decarbonisation of the power sector, House of Commons, Business, Energy and Industrial Strategy Committee, 2023.
15 Accelerating electricity transmission network deployment: Electricity Networks Commissioner's recommendations, Nick Winser, Department for Energy Security and Net Zero, 202.
16 Electricity Network Commissioner report, Energy Systems Catapult, 2023.

The future Distribution System Operators (DSOs) will need to know the supply and demand requirements for a local area. This requires understanding the likely network capacity and generation needs, and in particular the possible peak demand. This is not a simple task as it varies depending on the weather patterns, the uptake of Low Carbon Technologies (LCTs), and how those LCTs are to be used. AI can help both time series forecasting, and the generation of realistic demand profiles that can be aggregated together to model peak demand.

Similarly, electric vehicle charge points are likely to be a major disrupter of electricity networks since they have relatively high energy demand and are likely to be used at the similar times (i.e., all charging at home after work), creating new, possibly larger daily peak demands. However, network limits are not the only constraints and other impacts such as traffic, location and likely utilisation must also be accounted for. AI can help optimise charging locations given the combination of factors that need to be considered.

AI could also be used to manage electricity demand  and resolve network constraints, negating the need for some network infrastructure upgrades, this is considered in Grand Challenge 3.

**Related Sub-Challenges:**

Some of the core sub-challenges for this Grand challenge are as follows and are listed in the Appendix.

- **Challenge 6:** Designing Optimal Network Plans
- **Challenge 7:** Feasibility assessment for new renewable generation.
- **Challenge 8:** Routing new network infrastructure
- **Challenge 9:** Wind farm design
- **Challenge 10:** Deploying new EV charge points
- **Challenge 11:** Disaggregating network planning solutions
- **Challenge 12:** Multi-sector coordination
- **Challenge 13:** Connections Assessment and Approvals
- **Challenge 28:** Network Modelling with Missing and Sparse Data
- **Challenge 42:** Network Connections for Industrial Consumers

**AI Capabilities:**

Some of the core sub-challenges for this Grand challenge are as follows and are listed in the Appendix.

- **Geospatial:** Energy network problems often have a significant geospatial component due to geographical concentrations in demand and supply.
- **Optimisation:** By definition, many of the problems stated above are one of optimisation - finding the balance between the constraints of the energy system, the costs and the natural environment.
- **Time Series:** Energy demand and supply are hugely variable over time, and infrastructure needs to be designed to cope with all combinations (particularly peak demand and generation). This requires consideration of energy and weather time series.

## Maximising Flexibility in Energy Networks (GC3)

**Summary:**

A high renewables future requires energy demand to flex so we consume and store energy when the wind is blowing and the sun is shining. This is a radical change in network and market operation which also requires an underlying introduction of new technology and hence presents a host of new challenges. In addition to improving the energy efficiency of consumers (see Grand Challenge 1 and 5), energy demand and generation will need to be managed, curtailed, and shifted to meet Net Zero.

**Sector:**

Energy

**Detailed challenge description:**

Renewable generation is very weather dependent and tends towards decentralised and specific locations. Making the most of it (and balancing the system) therefore requires a combination of shifting demand to match generation and storing energy for future use.

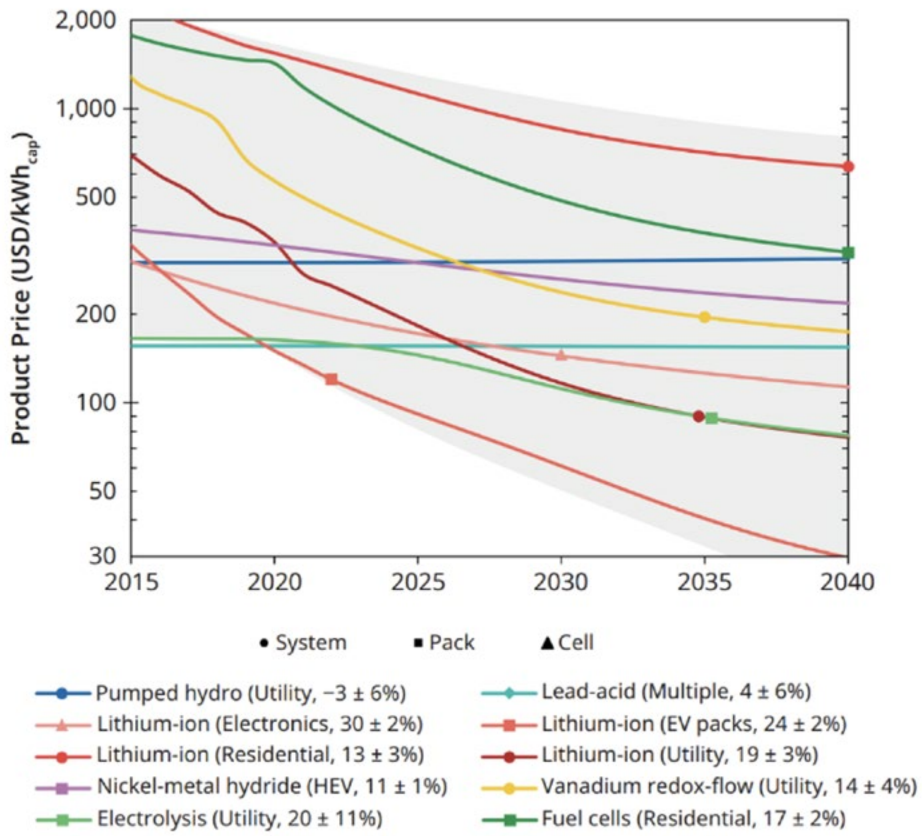



**Figure 3.** Cost projections for different storage technologies over time. Taken from "Monetizing Energy Storage", Oliver Schmidt and Iain Staffell, OUP, 2023, used under license CC BY-NC-ND 4.0.

In addition, electrification of heating and transportation means new, extremely large peaks in demand will occur. By default, these will both significantly exceed the capacity of the electricity network and occur at a different time to peak renewable generation. It is therefore important to introduce flexibility into the system to align demand with supply.

Storage has typically been expensive, but the costs are rapidly reducing and expected to keep reducing, e.g., see the storage costs of batteries (Figure 2), which means local storage will be increasingly viable as a way to control the energy networks.

In addition, more devices, such as heat pumps and electric vehicles are installed with communications and controllable technology meaning they could be utilised to help support the network. However, optimally controlling these devices is a non-trivial task, especially since there is a need to optimise for multiple factors – consumer needs, local and national network constraints, local and national generation. Many of these factors (e.g., renewable generation) are volatile and uncertain. Similarly, at low voltage and building level energy usage can be irregular and therefore more difficult to predict accurately.

Achieving a flexible energy system will also require modifications to energy markets to provide the incentives for consumers to shift their demand and provide mechanisms for this to occur. In some cases, more decentralised energy markets and Locational Marginal Pricing (LMP)[17], are being considered as a way to help utilise the distributed energy resources and help balance the network.

[17] Locational pricing can be the foundation of a Net Zero electricity system, finds new study, Energy Systems Catapult, 2022.

**The AI Driven solutions:**

The future operation of electricity networks will be highly complex, dependent on many nonlinear constraints and volatile data. Yet the network must be balanced across the entire hierarchy from household to transmission level. AI is a natural solution for these challenges since it can better capture the highly stochastic nature of low voltage demand and generation and produce more accurate forecasts. AI can further be used to take these inputs and utilise them in advanced optimal control strategies which can help balance the network, and manage smart control systems to reduce peaks, better utilise renewable energy on the network and reduce costs.

Where the calculations that underpin optimisation problems are computationally intensive (for example with optimal power flows), AI can be used to learn the characteristics of optimal outputs and reduce the need to run so many simulations, therefore accelerating the identification of optimal outputs.

AI is particularly suitable for the real time, distributed control of multiple assets such as the batteries within electric vehicles. As low carbon technologies increase the strain in localised areas of the network, the batteries across connected EVs can be coordinated to help support the network, creating incentives for users, whilst not disrupting their utilisation of the car, or their journeys. In time, many more solutions may become available through the increased prevalence of smart appliances, enabling large turn-down from demand side response and thus reducing peak demand issues.

Forecasting is an important input for all these systems to enable the estimation of the uncertainty of demand and generation produced. Used as inputs, these forecasts allow control algorithms for storage devices to better anticipate and prepare for peaks or troughs on the systems. AI is able to develop the necessary advanced forecasts which can provide granular information on the expected ranges of demand or generation, and therefore the risk to the network. This is particularly important when utilised within smart building control systems, where the demands are relatively volatile and therefore cannot be captured by traditional forecasting methods.

**Related Sub-Challenges:**

Some of the core sub-challenges for this Grand challenge are as follows and are listed in the Appendix.

- **Challenge 19:** Estimating Flexibility
- **Challenge 20:** Implementing Network Flexibility
- **Challenge 21:** Coordinated Community Control
- **Challenge 22:** Smart Electric Vehicle Management
- **Challenge 23:** Advanced Network Control
- **Challenge 25:** Weather Forecasting for improved system operation
- **Challenge 26:** Optimal Trading for Storage
- **Challenge 27:** Optimal Power Flow Calculations
- **Challenge 30:** Renewable Energy Forecasting
- **Challenge 31:** Forecasting for Network Management
- **Challenge 32:** Decentralised Market Solutions
- **Challenge 66:** Smart Building Control Systems

**AI Capabilities:**

The AI solutions for this challenge will mainly require the following high-level capabilities (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Time Series:** Flexibility is entirely dependent on the time series data for demand, generation and weather. This data is required to produce forecasts and the past behaviour must be utilised to help schedule any storage or other flexibility applications.
- **Optimisation:** Flexibility is concerned with optimising the energy demand on the network according to network constraints, demand, generation, costs and other exogenous variables such as weather and network topology.
- **Geospatial:** Flexibility is strongly dependent on the topology on the networks. It must be understood what is connected, the potential effect of the weather or climate, and what other nearby assets could be used to provide flexibility.

**40%**

Heavy industry is responsible for nearly 40% of global $CO_2$ emissions.[18]

# Decarbonising Manufacturing Inputs (GC4)

**Summary:**

Many manufacturing processes rely on carbon intensive fuels or raw materials. Decarbonising manufacturing requires a wholesale redesign of processes and products to use low carbon inputs, but this is complex and costly.

**Sector:**

Manufacturing

**Detailed challenge description:**

Manufacturing process are one of the main causes of greenhouse gas emissions worldwide. Heavy industry is responsible for nearly 40% of global $CO_2$ emissions[18] with the iron and steel industry alone responsible for 11% of global $CO_2$[19] with 70% produced by using coal. The emissions are caused by two main inputs: fuel sources required for the production process (e.g. see Figure 3, for fuel split for cement kiln heating), and feedstocks (i.e., raw materials) used to create the manufactured outputs.

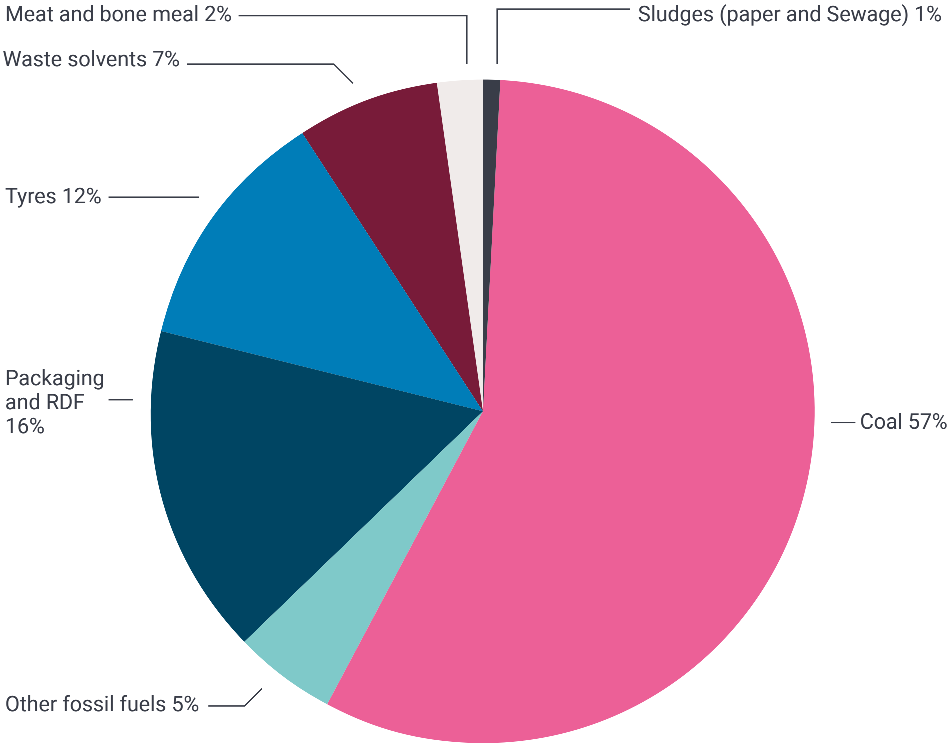



**Figure 4.** Fuel split for heating of UK cement kilns in 2010. Adapted from Industrial energy use and carbon emissions reduction: a UK perspective, by P. Griffin, G. Hammond, and J. Norman, shared under CC BY 4.0 license.

[18] The challenge of decarbonizing heavy industry, Brookings, 2021.
[19] These 553 steel plants are responsible for 9% of global $CO_2$ emissions, Carbon Brief, 2021.

Switching fuels is an obvious way to decarbonise, but many products require high temperatures (several hundred degrees C), which can be costly or difficult to achieve with electricity. However, for medium-to-low temperature processes and space heating, electricity is often a cost-effective option (particularly with waste heat recovery[20]. Redesigning processes to use lower temperatures to enable cost-effective electrification is a potential route to decarbonisation.

An alternative option for processes where electrification is less viable is to utilise hydrogen. Zero carbon green hydrogen can be generated using electrolysers powered by renewables (or nuclear). This would require the location of new hydrogen production plants to be chosen to optimise green hydrogen production. Adaptation of existing processes to use hydrogen would also be require[21].

A disadvantage of fuel switching is the significant capital expenditure and disruption required to transition to the new fuel source. Some of the equipment will need to be retrofitted or completely rebuilt[22].

There are a few options available to manufacturers to cut the costs of this transition. Onsite renewable generation could lower costs by reducing electricity imported from the grid and avoiding network costs. This could be used directly or to help produce green hydrogen. Alternative market solutions, such as private wires, virtual power plants, or different energy procurement strategies can also help lower costs[23].

*There is another challenge with fuel switching, and that is the new network connections that will be required. Many methane gas pipes are hard to repurpose for the use of hydrogen and switching fuels will be dependent on where the connections are planned and when they will be complete[24].*

The other main contributor to manufacturing emissions is feedstock. Some processes, such as steel making, use high carbon materials such as coal. Others require materials which release lots of $CO_2$ when processed, for example, limestone must be heated in cement production, and this releases lots of $CO_2$. So decarbonising these manufacturing inputs requires either changing to lower (or zero) emission alternatives, or implementing carbon capture, utilisation and storage (CCUS) to remove the emissions produced. For example, coal is used as a reducing agent in steelmaking but hydrogen could also be used[25] (in this case to use direct reduced iron, and the only output is water[26]). Once again to decarbonise feedstock requires finding alternatives, in many cases hydrogen, which must be generated, with the manufacturing equipment upgraded or retrofitted to deal with the changing processes.

[20] Decarbonising Manufacturing: Challenges and Opportunities, Make UK, 2022.
[21] Project to decarbonise cement production with nuclear hydrogen receives funding boost, New Civil Engineer, 2023.
[22] Decarbonization challenge for steel, McKinsey, 2020.
[23] Decarbonizing primary steel production: Techno-economic assessment of a hydrogen based green steel production plant in Norway, Bhaskar et al., Journal of Cleaner Production, 2022.
[24] Britain's Hydrogen Network Plan, ENA, 2021.
[25] Hydrogen sparks change for the future of green steel production, ING, 2023.
[26] Hydrogen (H2)-based ironmaking, World Steel Association, 2022.

## AI Driven solutions:

Many of the solutions for decarbonising the inputs to manufacturing are expensive and require significant upgrades to equipment or even a completely new redesigned plant. AI can play a role in reducing costs for this transformation.

One of the main ways that AI can support is through the design of new low carbon feedstock alternatives. Instead of expensive physical experiments and testing, AI can produce designer molecules and chemicals with particular desirable properties or suggest synthetic processes. Simulation-based testing of thousands or even millions of alternatives can be performed before any real laboratory environment production is required. The utilisation of AI in the design can be extended to the full manufacturing process, considering alternative methods, new equipment, or even an entirely new plant to enable different fuels, or reduce waste.

AI can also optimise and manage the production of green hydrogen, controlling the electrolyser to make the most efficient use of the intermittent renewable generation[27] This could also be integrated with storage systems to increase flexibility (See Grand Challenge 3).

Finally, AI could be used to improve carbon accounting and modelling. Better carbon accounting would strengthen incentives for manufacturers to decarbonise. Although direct measurements are often missing, AI can help infer and track the sources of emissions, potentially at more granular levels than are currently monitored.

[27] How AI can accelerate the transition to Green hydrogen, Schneider Electric, 2023.

**Related Sub-Challenges:**

- **Challenge 13:** Connections Assessment and Approvals
- **Challenge 37:** Design of Low Carbon Feedstock Alternatives
- **Challenge 38:** Design of Low Carbon Manufacturing Processes
- **Challenge 43:** Installing Onsite Renewables and Storage
- **Challenge 44:** Supporting the Generation of Green Hydrogen
- **Challenge 50:** Carbon Accounting and Modelling

**AI Capabilities required:**

The AI solutions to tackle this challenge will require the following high-level capabilities (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Optimisation:** Since design of optimal feedstock and processes is a core element of the challenge, optimisation is clearly a capability that is required.
- **Time Series:** Time series processing is a major input to the optimisation, especially for the renewable energy generation and weather data required to understand green hydrogen production.
- **Visual:** Visual data may be useful in carbon accounting, as well as for chemical process and manufacturing process design.
- **Other Machine Learning:** Regression and classification approaches can be important for carbon accounting.

**47%**

A survey of manufacturers[20] showed that 47% saw energy efficiency as one of the key ways to reduce emissions.

## Manufacturing Process Efficiency (GC5)

**Summary:**

For processes that are extremely hard to fully decarbonise, improving their efficiency is important in reducing emissions. This should not come at the expense of decarbonising inputs but may also help accelerate decarbonisation in the short term for processes that will eventually be fully decarbonised.

**Sector:**

Manufacturing

**Detailed challenge description:**

Manufacturers have obvious incentives to improve process and energy efficiency, and this will be required to help decarbonise the sector. However, it is important that this does not divert attention and investment away from decarbonising inputs (which is often harder and more expensive, but important for full decarbonisation). This is often the case - a survey of manufacturers[20] showed that 47% saw energy efficiency as one of the key ways to reduce emissions. In contrast only 9% focused on fuel switching for electrified production and 8% focused on fuel switching to hydrogen.

Processes can be optimised for energy usage and emissions through automation and advanced control of devices. However energy usage and emissions is often not sufficiently monitored - the above survey found that only 59% measure their electricity consumption and only 41% measure their outright emissions. It is likely that very few individual components of the manufacturing process are monitored in detail. This creates several limitations: energy usage is likely to be poorly understood; condition monitoring will be restricted; energy management solutions are likely to be suboptimal; and energy inefficiencies cannot be identified. This is particularly likely for SME manufacturers.

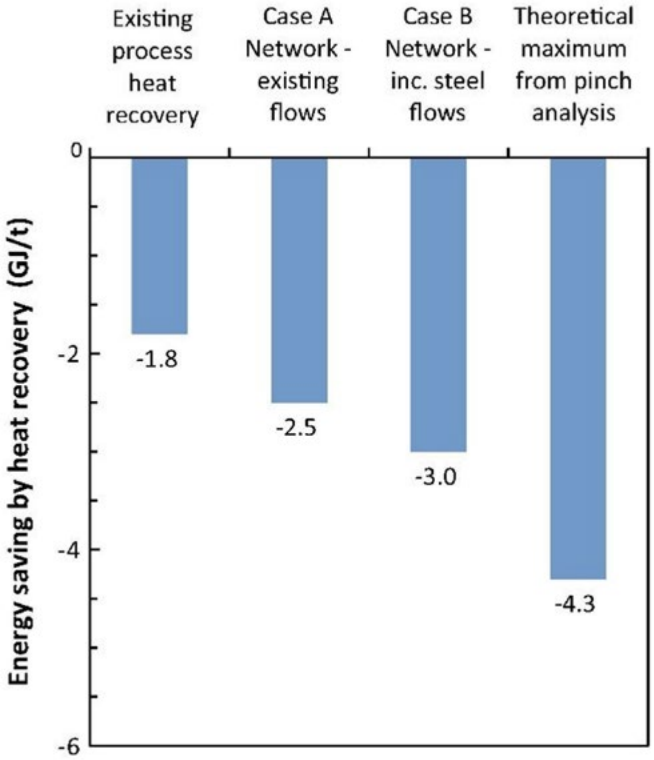



**Figure 5.** Example of possible energy savings estimates (gigajoules per tonne) in the steel production supply chain based on different heat recovery scenarios. Taken from Potential for energy savings by heat recovery in an integrated steel supply chain by McBrien et al. shared under license CC BY 4.0.

Another drawback to limited monitoring is the difficulty with estimating and understanding emissions. Without this information it will be difficult to know how to reduce them, or which components provide the biggest contribution or opportunity.

Reducing emissions (and energy costs) without impacting operations can sometimes benefit from demand flexibility and energy storage. Shifting production times to align with clean, cheap energy can be effective – and storage can be used to smooth that out and reduce disruption (although the upfront capital costs can be large).

Another source of emissions for manufacturers is distribution and logistics. Although it is relatively simple to decarbonise domestic vehicles, it is much more difficult to do the same for heavy goods vehicles which could potentially be replaced with ones which can use biofuels or hydrogen. Adapting transport logistics can also enable more efficient fuel utilisations, either through optimal route planning, or modifying the distribution chain.

**AI Driven solutions:**

AI is well suited to optimising complex energy management objectives. AI can handle a variety of inputs and can be adapted to take into account different constraints. Therefore, whether the management is through optimisation of production schedules, demand side response, or battery storage scheduling, AI algorithms can be used to help identify the best way to shift or turn-down demand, reducing emissions and maximising savings. In many cases multi-objective optimisation algorithms could be deployed to find the optimal solution when there are several (possibly competing) objectives.

***Demand forecasting is another major application for manufacturing energy management and is well suited to artificial intelligence methods. AI can learn past behaviour through analysis of historical observations and can infer the future expected demand for products and the corresponding uncertainty. This therefore helps with scheduling of devices and processes but also allows an assessment of the risks.***

AI can also be used to identify process inefficiencies. Combined with high resolution monitoring, machine learning methods could isolate inefficiencies and areas for optimisation. Assessing which processes may need to be targeted with additional efficiency measures or energy management solutions requires accurate carbon accounting and modelling. AI can be particularly useful to estimate, track and reduce emissions, and identify the contributions from the various components.

As shown above many AI algorithms are dependent on some degree of historical training data and monitoring to be accurate. However, AI can also be used to help solve missing data issues. Firstly, they can be used to identify the optimal location and amount of monitoring needed to develop accurate models and algorithms. This can be balanced with the potential costs and computational requirements. This is particularly important for manufacturing systems since they require specialist measuring equipment such as probes for very high temperature areas.

AI can also be used to generate accurate and useful estimates of unmonitored systems. Transfer learning is a popular method for simulating equipment or devices from a similar family (e.g., boilers). This means monitoring can be kept to a minimum, and data from other sites can add value. There is also a recent explosion in generative AI, and such methods could be applied to meta-learn the behaviour of unmonitored sites, even when there is limited monitoring of similar sites.

**Related Sub-Challenges:**

- **Challenge 39:** Manufacturing Process Efficiency
- **Challenge 45:** Energy Management in Manufacturing
- **Challenge 46:** Demand Forecasting for Manufacturing
- **Challenge 47:** Manufacturing Logistics and Distribution
- **Challenge 48:** Maximising Data Utility in Manufacturing Plants
- **Challenge 49:** Defect Identification in Manufacturing Products

**AI Capabilities required:**

The AI solutions for this challenge will mainly require the following high-level capabilities (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Optimisation:** Optimisation techniques are key to managing competing objectives and optimising processes.
- **Time Series:** Analysis of energy time series, production trends and sensor data can identify opportunities for improved efficiency.
- **Visual:** Image processing may be used to detect equipment defects and process anomalies early and thus reduce wastage.

**31%**

Nitrous oxide ($N_2O$) emissions from soil are responsible for 31% of all agricultural greenhouse gas emissions.[28]

**70%**

Agriculture forms 70% of all nitrous oxide emissions.[29]

## Optimising Soil Management (GC6)

**Summary:**

In agriculture, soil is a major source of emissions – as well as a potential route to carbon sequestration. Optimising the management of soil heath from an emissions perspective is a key challenge.

**Sector:**

Agriculture

**Detailed challenge description:**

Nitrous oxide ($N_2O$) emissions from soil are responsible for 31% of all agricultural greenhouse gas emissions, behind only enteric fermentation (48%)[28] which will be considered in challenge 7 (GC7). In fact, agriculture forms 70% of all nitrous oxide emissions[29], which pound-for-pound has about 265 times the impact on global warming than carbon dioxide and stays in the atmosphere for over 100 years[30]. In agriculture these emissions primarily come from applying nitrogen fertilizers to soil where the microbes convert the nitrogen into $N_2O$. However, they are also produced from organic fertilizers like animal manure[31].

Nitrogen fertilisers are necessary for soil health, plant growth and development, controlling respiration, and photosynthesis. Artificial fertilisers can help increase nitrogen levels and improve yields, but their long-term use or over-fertilization can damage the soil healt[32].

Emissions are generated by microbial reactions and depend on weather conditions, physicochemical reactions, and proper soil management practices[32]. This includes adjusting the time and method of applying fertilisers, tillage and irrigation practices, use of biochar (materials carbonised over high temperatures), nutrient management and different crop rotations[32,33].

[28] Greenhouse gas emissions from agriculture in Europe, European Environment Agency, 2023.
[29] Pollutant Information: Nitrous Oxide, National Atmospheric Emissions Inventory, 2021.
[30] Overview of Greenhouse Gases, United States Environmental Protection Agency, 2023.
[31] Greenhouse gas emissions, Our World in Data, 2020.
[32] Addressing nitrogenous gases from croplands toward low-emission agriculture, Nature, climate and atmospheric science, S.-Y. Pan et al., 2022.
[33] Management Strategies to Mitigate N20 Emissions in Agriculture, M.U. Hassan et al., 2022.

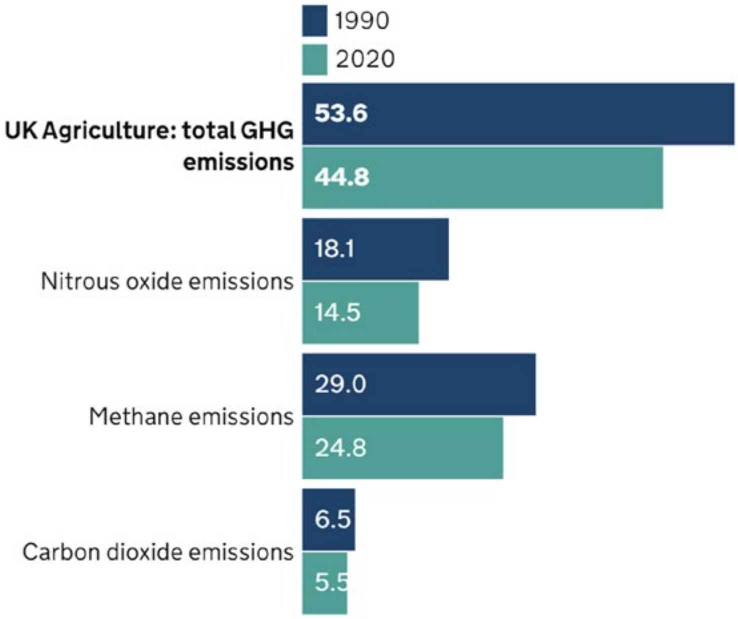



**Figure 6.** Breakdown of total greenhouse gas emissions (in metric tons of carbon dioxide equivalent) from agriculture and comparison of 1990 to 2020. From Agri-climate report 2022, Department for Environment Foord & Rural Affairs, used under Open Government Licence v3.0.

Different crops generate different emissions and therefore adjusting crop production can also be an effective strategy. It should be noted that these different practices have to be carefully balanced, and relationships and effects are not necessarily easy to model due to many interdependencies between complex variables, behaviour dependencies, climate effects and soil composition. Many empirical models of nitrous oxide emissions are relatively inaccurate and unable to predict daily and monthly emission[34].

Soil can also play an important role in providing negative emissions under the right conditions and management. Carbon could be sequestered in agricultural soil, although there is still uncertainty about the amount of potential sequestration[35].

Farming and land management can help to improve carbon storage through reducing soil disturbance, adapting planting schedules, manging livestock grazing, and composting with crop residuals (remains of crops after harvesting)[36].

However, sequestration has potential complications. If the soil is distributed then the captured carbon can be released and it is difficult to monitor and verify how much carbon has been sequestered[36]. The soil sequestration potential also varies according to environmental factors, anthropogenic effects, and soil types but is still not fully understood[37].

[34] Machine Learning improves predictions of agricultural nitrous oxide ($N_2O$) emissions from intensively managed cropping systems, Saha, Basso & Robertson, 2021.
[35] How does uncertainty of soil organic carbon stock affect the calculation of carbon budgets and soil carbon credits for croplands in the U.S. Midwest? W. Zhou, et al., 2023.
[36] What is Soil Carbon Sequestration? American University, Washington, 2020.
[37] The knowns, known unknowns and unknowns of sequestration of soil organic carbon, Agriculture, Ecosystems & Environment, U. Stockmann, 2013.

### The AI Driven solutions

Overuse of fertilisers is one of the causes of higher nitrous oxide emissions. Rather than using slow and more expensive methods to measure properties of the soil, AI can help to accurately and quickly understand the amount of fertiliser required, thus limiting emissions.

Another way to reduce emissions is through the development of optimal soil management strategies which could reduce $N_2O$ whilst not reducing the crop yields. There are many different factors which effect the emissions from soil (e.g., changing the amount and timing of tillage, which crops to grow, irrigation-drainage management, crop rotation, etc.) and thus there is a need for further investigation to identify the core drivers, or combination of drivers. AI is a potential solution since it can assimilate these various inputs and their complex relationships, understand the key processes and identify optimal solutions.

***AI could also be used to help identify and predict the distribution of greenhouse gas emissions from agricultural systems. This could enable targeted interventions for specific sites where emissions are concentrated to improve soil health. Alternatively, AI could identify the root causes of high emissions and therefore find suitable sites or techniques with properties that are more likely to produce lower emissions.***

For soil sequestration, AI could also be used to improve estimation of carbon storage levels, since it is often difficult to monitor and verify the health and carbon stored in the soil. By taking data from soil monitors, weather, and satellite data, these algorithms can help farmers understand particular attributes of their soil such as the carbon stored, or the nutrient levels. These techniques could also be used to try and improve the amount of possible sequestration through the identification of optimal conditions and attributes. Targeted monitoring and sampling could also help improve estimates or could be used to reduce the amount of data required and enable streamlined operations and management.

AI techniques could be used to predict changes in soil health and carbon storage potential from future weather events, climate change or changes to the surrounding environment. They can model how the soil attributes change to these different events, and even help to plan future, more resilient sites.


**Sub-Challenges and related challenge numbers:**

- **Challenge 51:** Soil-Based Carbon Sequestration
- **Challenge 53:** Fertiliser Design and Recommendations
- **Challenge 55:** Prediction for Agricultural Resource Planning
- **Challenge 59:** Soil Health Monitoring and Management
- **Challenge 60:** Crop Monitoring and Management

**AI Capabilities required:**

The AI solutions for this challenge will mainly require the following high-level capabilities (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Optimisation:** Optimisation techniques may be required to balance competing factors and make recommendations around optimal management
- **Visual:** Analysis of images of crops and land can be essential in optimising soil and crop management
- **Geospatial:** Analysing geospatial factors including weather, drainage and climate are essential to understanding factors influencing soil and crop health.

**41%**

Livestock are responsible for 41% of agricultural greenhouse gas emissions.[28]

## Minimising Methane in Agriculture (GC7)

**Summary:**

Methane emissions from livestock are a major contributor to global emissions. Reducing these emissions is critical, whether through shifting to low-meat diets or more carbon-conscious livestock management.

**Sector:**

Agriculture

**Detailed challenge description:**

Livestock are responsible for 41% of agricultural greenhouse gas emissions[28]. This comes from emissions of methane (CH4) from enteric fermentation (digestive processes) but also from manure. Unfortunately, methane is a very potent greenhouse gas, with a pound for pound impact 28 times greater than $CO_2$[30]. As the population grows, methane emissions are set to get worse without radical interventions[38].

There are several ways that methane emissions from agriculture could be reduced but they can be broadly categorised into lower carbon diets and reducing the emissions from animals and their manure.

Reductions in meat and dairy farming not only can reduce emissions but could help improve food security and health, especially by reducing red meat consumption. A reduction in the required livestock would reduce the amount of land use for feed[39]. Despite the increased awareness of the positive impacts of moving to a non-meat based diet there is still significant inertia and resistance. Some of the main challenges include the need for healthy and similar plant-based meat and dairy alternatives, but also making it easier to adopt a non-meat diet without losing any nutritional benefit[40].

[38] Methane emissions are driving climate change. Here's how to reduce them. UN environment programme, 2021.
[39] Taking action on hot air: Why agriculture is the key to reducing the UK methane emissions, Ian Plewis, University of Manchester, 2022.
[40] Foods for Plant-Based Diets: Challenges and Innovations, Alcorta et al., Foods, 2021.

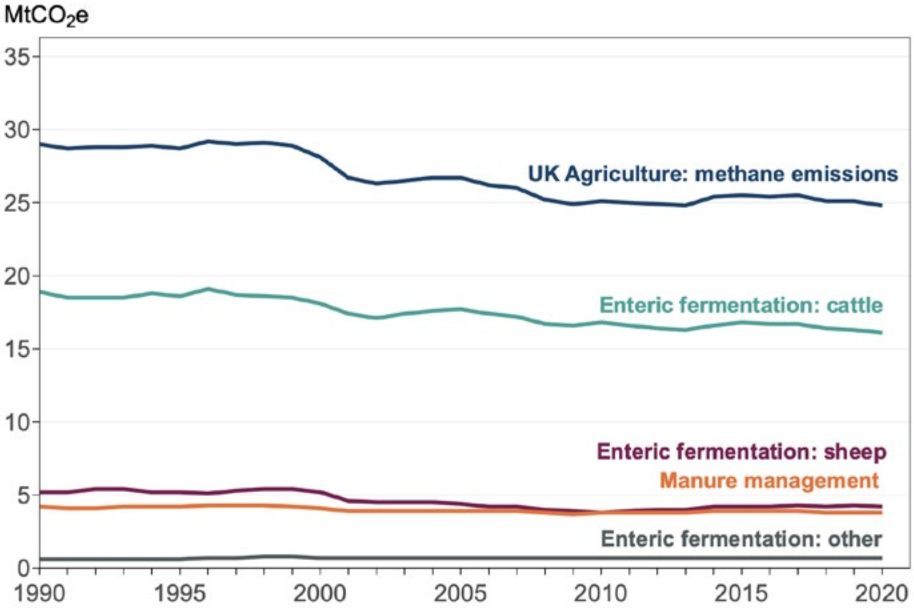



**Figure 7.** Total and breakdown of methane gas emissions from UK agriculture. From Agri-climate report 2022, Department for Environment Foord & Rural Affairs, used under Open Government Licence v3.0.

To reduce emissions from animals involves reducing the methane levels from enteric fermentation and manure. The intensity of emissions varies across different regions and production systems and is dependent on environmental factors, nutrition, animal types and properties, and farming practices[41]. The main animal source of methane is from ruminants such as cows, sheep and goats, who gain nutrients through a plant-based diet which is fertilised through multiple stomachs before digestion[42] which then creates belching, releasing gas. Some farming produces more emissions than others, for example cattle breeding and production creates much more methane than sheep due to their size and numbers[42].

[41] Enteric fermentation, Climate & Clean Air Coalition, 2014.
[42] Strategies to Mitigate Enteric Methane Emissions in Ruminants: A Review, V. Palangi et al., Sustainability, 2022

Different properties of animals alter the levels of emissions including growth rate, animal size, energy consumption, animal health, etc.[41,42] Given many traits of the animals are heritable, this suggests reproduction management may help slightly reduce emissions by focusing on breeding offspring with features that reduce emissions (e.g., enhanced fecundity, reduced stress response, and better immunity)[43].

Emissions can also be reduced for enteric fermentation by changing animal feeding practices and types[30]. Evidence shows that the genome and stomach microbiome can play important contribution to the methane emissions, and they can be reduced by, for example, reducing forage diet levels, and adding fat, biochar, and potassium nitrate[42].

Methane is also produced from manure when it decomposes under aerobic conditions. One way to reduce these emissions is through better manure management, through shortening storage, compositing, aeration, and manure acidification[38,43]. Methane can also be used as a renewable energy source as a component of anaerobic co-digestion where the application of microorganism converts the manure into a biogas[44].

**AI Driven solutions:**

AI can play a key role in estimating and monitoring of methane emissions. Data from sensors, satellite data, buildings and the animals themselves can be used to derive models of emissions, identify key drivers and inefficiencies, and understand ways to help improve management of the farm and their outputs.

AI can also be used to reduce the emissions from animals. Firstly, AI can help to develop feed and feed additives so that the gas emissions are reduced. Data driven techniques can analyse the outputs from different animals under different conditions and feeding regimes to understand what causes the greatest methane outputs. Alternatively similar effects could also be estimated by directly studying and modelling the reactions of gut microbiome to understand the underlying chemical processes and predict the likely effects on emissions. This research could further be used to develop designer feed which provides the optimal emissions reduction.

Lower emission traits in livestock can be produced by selected breeding practices. AI can support this through identifying microbial properties and genetics which are best suited for lower CH4 emissions. Genetic differences and similarities across livestock can be isolated and then used to determine the optimal breeding management practices to reduce overall herd emissions.

[43] Tackling Climate Change Through Livestock, FAO, 2013.
[44] Applications of artificial intelligence in anaerobic co-digestion: Recent advances and prospects, M. Khan et al., Bioresource Technology, 2023.

AI is also well suited to help optimise and model different manure treatments and practices. The main way is through supporting anaerobic digestors. AI can be used to help select which combination or proportion of materials is best use in them, but it can also be used to help optimally manage, model and understand the different processes. This can drive improvements in efficiencies and increase yields.

Finally, AI can be used to help drive low carbon diets and the development of plant-based meat alternatives. Applications for consumers could use AI to help understand the carbon footprint of the food that is consumed, but also suggest low-carbon or non-meat alternatives. Analysis of low carbon diets can also be used to help understand behaviour aspects of moving to vegan and vegetarian diets and therefore help promote and support healthier and environmentally friendly lifestyles. One barrier to moving to vegetarian diets is the potential loss of enjoyment from meat which is difficult to replicate. AI can help support this by designing plant-based meat, by helping to recreate the taste, texture and other properties from real meat.

**Sub-Challenges and related challenge numbers:**

- **Challenge 50:** Carbon Accounting and Modelling
- **Challenge 52:** Designing Low Emission Food Alternatives
- **Challenge 54:** Designing Feed and Feed-Additives for Livestock
- **Challenge 57:** Livestock Breeding Programmes
- **Challenge 58:** Manure Treatment
- **Challenge 61:** Low Carbon Diets

**AI Capabilities required:**

The AI solutions for this challenge will mainly require the following high-level capabilities (although note there may be other less obvious solutions and approaches which could use other capabilities):

- **Optimisation:** The challenges are mainly concerned with finding optimal feedstock, breeding practices or manure treatments. Therefore, optimisation is a natural fit for reducing methane emissions from agriculture.
- **Other Machine Learning:** Understanding the drivers of high emissions, whether through animal gases or manure will require supervised learning methods on tabular data. This also will be required to create suggestion engines for low diet alternatives.
- **Time Series:** Many of the data that are used are naturally dynamic in time, and therefore time series skills are necessary for solving the agricultural methane emission issues. This includes, weather data, and carbon emissions.
- **Visual:** Visualisation tools are necessary for recipe analysis and helping with low carbon diets as well as identifying alternatives.
- **Language:** To better understand why people move to low carbon and vegetarian diets will need to analyse the behaviour of those who have made the switch. Analysing the data from social media or surveys could provide insights and develop products which could help others.
- **Geospatial:** This is important in tracking and understanding methane emissions. These can vary widely depending on the location and climate of the farmland.

# Next Steps


This report has presented grand challenges where artificial intelligence methods can support decarbonisation in the sectors of Energy, Built environment, Agriculture and Manufacturing. Solving any of the grand challenges, and their related sub-challenges, would have a significant effect on our progress in meeting our Net Zero targets. There are three main next steps:

## Go and do

Hopefully one of more of these challenges will have captured your imagination and triggered ideas for how you might be able to apply AI to decarbonisation. Go and make that happen!

ADViCE exists to help connect you to the people, organisations and data you need to succeed, so engage with us through our website, webinars or directly via email. Have a look at the ecosystem report to better understand how you might engage.

## Input and improve

This report represents a snapshot of decarbonisation challenges that AI can help to address. Many of the aspects of the challenges have not been explored in detail, yet that detail may be critical for developing AI solutions that accelerate decarbonisation. We want these challenges to be continuously updated and added to over time.

Join one of our AI for Decarbonisation working groups by registering interest here or visit our AI for Decarbonisation knowledge base (coming soon) to add more detail to a challenge or propose a new challenge. Sign up for updates and news from ADViCE.

If you are involved in cutting edge developments in AI and can see new potential applications, add those to the knowledge base as well.

If you want to organise a detailed discussion of a particular challenge, let us know and we can facilitate that and get relevant people together.

## Enable others

Access to data is critical in developing AI solutions. If you hold data that could be used in developing AI solutions to one of these challenges, publish that data openly, or publicise the fact you have that data and develop mechanisms for innovators to work with you on it. Tell us that you have data for a challenge and we can connect you to people who might use it.

If you are an investor or funder, ensure that you consider the decarbonisation impact of any AI investments in these sectors. Do what you can to shift attention from purely cost-reduction applications of AI to decarbonisation-focused applications. Incentivise people to explore areas of the grand challenges that are likely to address systemic blockers to decarbonisation.

# Appendix: Challenges Longlist

This appendix describes a longlist of sub-challenges from each of the sectors, Agriculture, Manufacturing, Energy and Built Environment according to the four phases described on page 13. These sub-challenges can make contributions to the grand challenges found in the main text. There is an interactive online list of these sub challenges which has further information on the scoring in terms of impact, AI suitability and novelty and can be found here.

# Energy Challenges Longlist

## Design and Planning

As the energy system moves to low carbon world there is significant need for designing and planning suitable technology and networks to help support decarbonisation. This includes helping to design new technologies which are more energy efficient or help increase renewable generation yields, supporting the connection of low carbon technologies, and helping to prepare and design a resilient energy ecosystem.

AI has been particularly powerful at helping with design process. For example, in pharmaceuticals it can be used to design new drugs. However, they can also be used to design everything from new processes to new policies and regulation. This section considers design sub challenges within the energy sector which can be help with decarbonisation.

**Technology and Assets:**

AI has been used to help design everything from new drugs to new machines. This may be particularly important as industrial technologies have to adjust to use different low carbon fuel sources. Some examples include:

1. **Designing Assets for Improved Performance:** Improving design processes (e.g., by accelerating physics-based simulation with ML-based proxies) can help to ensure that designs for infrastructure are optimal for performance and costs. For example, alternative wind turbines designs could enable them to operate at higher wind speeds and thus reduce curtailment. It can also help ensure that they are resilient to extreme environmental conditions.
2. **Nuclear Fusion:** In the longer-term, nuclear fusion offers the potential for abundant clean power, but still requires considerable development to be practical. Given the vast quantities of data involved, AI can play a critical role in processing data, analysing experiments, and potentially even optimising control strategies.

**Materials and Chemicals:**

3. **New materials for renewables and storage:** Performance of both renewables and batteries are often dependent on the properties of their components' materials. Improvements in the materials available can potentially increase the effectiveness of these technologies. Examples include changing the chemical properties for individual solar cells, or new chemical compositions for batteries. For solar panels, minerals such as perovskite can produce much more efficient solar cells and thus increase PV solar outputs. AI can accelerate the discovery and evaluation of different materials.

**Processes**

4. **Scaling up Manufacturing of renewables:** In some cases the technology exists but scaling up the manufacturing and supply chain is a significant blocker. For example, with higher performing solar cells, there is a need to upscale the manufacturing process, taking the small lab level development and optimising the conditions to allow higher quality and faster levels of production.

Helping to plan new networks and new connections is essential to decarbonise the energy system. For example, electrified transport and heating will increase demand on the network, and in some cases may exceed the headroom of the cables. Further, to decarbonise supply will rely on connecting renewable generation where it is needed and where the network can handle it. The challenges below will focus on planning, especially the what, where and how. What new assets and connections, where they will go, and how they will be connected.

### Anticipating Future Network Needs

To optimally plan a network requires understanding what the future network needs will be, what potential technologies are going to be connected and what their impact is likely to be. Therefore, realistic scenarios must be generated to be able to properly plan the network. This can be short term (a few years ahead) or may require anticipating decades in advance. An example of this is the future energy scenarios (FES) produced by the National Grid.

5. **Prediction of local generation and capacity needs:** A future DSO will need to know the supply and demand requirements for a local area. This requires understand the likely capacity and generation needs, and in particular peak demand. This is not a simple task as it varies depending on the changing weather patterns, the likely uptake of LCTs, as well as how those LCTs are likely to be used. AI can help both with time series forecasting, but also with the generation of realistic usage profiles that can be aggregated together to model peak demand. Since LCT uptake is an important driver for demand the follow subtask to this challenge is highlighted:

    - **Low Carbon technologies:** LCTs will have the biggest impact on the network due to the aggregated effect of heat pumps, electric vehicles and solar panels. How people and businesses will likely use and buy these technologies will affect the size and rate of this impact and therefore drive planning schedules. AI can help identify factors influencing the uptake of LCTs, and forecast their rollout on a granular basis.

6. **Designing Optimal Network Plans:** Both energy supply and demand are going to change significantly in coming years but the location, timing and nature of these changes is uncertain. Energy networks need to be planned to be robust and close to optimal for a range of possible futures, but this is incredible computationally complex. AI can help quickly generate scenarios and identify optimal and resilient solutions.

### New Networks and Connections

Network planners need to know how to support decarbonisation and enable connections of renewables and low carbon technologies. This is supported by understanding the future needs and requirements (above). Some of these challenges are as follows:

7. Feasibility assessment for new renewable generation: There are many different factors that need to be taken into account when assessing locations for renewable generation including: weather, power network capacity, geological features, shipping routes, and impact on the environment and local communities. AI can help combine these factors to accelerate optimal feasibility assessments. Issues include:
   - **Renewable cost estimates:** Levelized Cost of Energy, Annual energy output, connection costs, etc. All need to be taken into account to help estimate costs which will enable assessment and viability of investments.
   - **Estimating Shipping Impacts:** Offshore renewables such as wave and wind farms can have significant effects on ship movements, impacting trade and travel.
   - **Tidal array optimisation:** To choose and construct suitable tidal arrays the sites must be assessed according to the suitability for energy production, in addition to their impact on the environment.
8. **Routing New Network Infrastructure:** Defining the routes that transmission infrastructure will take is a long process and needs input from multiple organisations and data from multiple sources (e.g., land use, flood risks, other infrastructure). This occurs both at early on with "route corridors" and then with a detailed route design. AI can help by automating the combination of different data sources and assessment of potential routes.
9. **Wind farm design:** Wind farms must be constructed so as to minimise the disruption caused by adjacent wind turbines. In particular, the wake caused by one wind turbine can reduce the wind generated by a nearby one. AI can help develop optimal layouts to minimise these effects and maximise outputs.
10. **Deploying New EV Charge Points:** EVs are one of the major disrupters of electricity networks since it is likely many charging stations will be used at the same time, creating new peaks in demand. However, network constraints are not the only factor and other objectives must be accounted for such as traffic, location and likely utilisation. AI can help optimise charging locations given the combination of factors that need to be considered.

11. **Disaggregating Network Planning Solutions:** Local area network planning solutions are typically defined for a zonal level. If the outputs could be disaggregated to smaller areas, it could help produce more informative delivery strategies. For example, disaggregation could be used to help understand the targeted rollout of a particular technology. AI could enable automatic disaggregation to more granular levels.
12. **Multi-sector coordination:** Extending network planning and operation across to multiple sectors and vectors (transport, water utilities, telecommunications, etc.) is increasingly important given electrification and digitalisation. This could also extend to include environmental and air quality data and models to help inform and motivate decision making. High fidelity digital twins can be difficult to build, maintain, and integrate (as well as computationally intensive). AI could help enable the modelling of interdependencies across vectors and sectors and reduce planning disruptions and improve resilience.

### Implementing and approvals

Network planners need to know how to support decarbonisation and enable connections of renewables and low carbon technologies. This is supported by understanding the future needs and requirements (above). Some of these challenges are as follows:

13. **Connection Assessments and Approvals:** One of the biggest challenges with new network connections is the lack of certainty for what connections are available for key infrastructure such as renewables, and heavy industry, and the time it takes to connect. AI can help by automating the combination of data sources, extracting information from technical documents, and automating some elements of the decision-making process to speed up the process.
14. **Testing new policies and market models:** Changes to policy and regulation are likely to be critical to accelerating decarbonisation. This will likely include the introduction of new markets. AI can help in a number of ways including extracting information from across the sector to inform new policies, comparing and summarising policy changes to improve accessibility for different stakeholders, and simulating the effects of new policies or market structures (e.g., using agent-based modelling).

## Incentives and Support

To move to Net zero will require enabling and incentivising all users but especially consumers to decarbonise. In particular, domestic consumers will need to become more energy efficient and switch to low carbon technologies such as heat pump and electric vehicles. At the same time, it is important that no consumer is left behind and that the most vulnerable are also supported. For industrial and commercial consumers, this will mainly be achieved by designing the right policies, markets and regulation, making it as easy as possible for them to connect their own onsite renewables (see Design and Planning Challenges), and to incentivise their own decarbonisation strategies. The following are some of the challenges around supporting consumers in their own net zero journeys:

15. **Consumer Information and Guidance:** The plethora of new technologies and services can be confusing to consumers. Misunderstanding and misinformation are also rife, and a lack of trust can make households wary of taking up new products and services – e.g. heat pumps. AI-assisted understanding of consumer behaviour and preferences would allow information and marketing to be more effectively personalised for different consumers to support them on their decarbonisation journey.

16. **Driving energy efficient behaviours:** Explaining to consumers how they should change their behaviours to reduce or decarbonise their energy usage is dependent on understanding what current behaviours are. AI-based non-intrusive load monitoring breaks energy usage down into different appliances without requiring each appliance to be separately monitored. This can enable more tailored energy efficiency advice without the need for new sensors.

17. **Abstracting away complexity for consumers:** From a consumer perspective, complexity in energy management is going to increase: homes are going to have an increasing number of smart devices, flexibility in demand will become increasingly important, and energy pricing is likely to become more complex. Automation with AI can play a vital role in allowing consumers achieve their desired outcomes without having to manually manage all those components.

18. **Supporting vulnerable consumers:** Vulnerable consumers have potentially complex needs and may need more (or different) support in the energy transition. Through analysing behaviours, energy data and building data, AI can potentially help identify consumers who are vulnerable (or at risk of vulnerability) to enable better targeted support. This is not a simple task since there is no single definition of vulnerability and measuring it is nontrivial. AI could also be used to better optimise energy usage, taking into account the multiple factors that are important to specific vulnerable consumers. Note that for consumer-facing AI applications targeting the broader population, there is an ethical challenge to ensure these don't cause poor outcomes for vulnerable consumers.

## Management and Operations

### Grid Management and Flexibility

Underlying future energy networks will be flexibility services and grid management. New markets will facilitate energy trading at more local levels, and distributed energy resources such as storage and demand side response will help to manage the grid. This will also be supported through the management of buildings and distributed networks (See above). Some of the challenges in this area are as follows:

19. **Estimating Flexibility:** Flexibility is going to be a key to the future low carbon networks, but estimating the available flexibility is not straightforward. For example, in a domestic context the available flexibility might be influenced by a combination of the maximum energy usage, householder preferences and awareness, and the presence of automated controls. These are seldom fully known, and AI can be used to model them.

20. **Implementing Network Flexibility:** Flexibility is key to managing the future energy networks. Buildings, local generation, and network assets can have their outputs controlled to help relieve stress on the network and help maximise the use of renewables. Some of the challenges include:

    - **Managing Flexibility:** As the network moves towards smart grid, DNOs may have to operate and manage several products (DSR, batteries, etc.) and controllable loads to secure the network. This also requires accurate short-term forecasts and demand and generation.

    - **Virtual Power Plants:** Distributed generation could be aggregated to help support the networks, but this involves monitoring and/or coordinating hundreds or possibly thousands of devices.

    - **Managing Rebound Effects:** New flexibility operations and grid management strategies may reduce energy demand and increase renewable utilisation, but they could also have unintended consequences. For example, often demand side reduction can result in an increased delayed demand.

21. **Coordinated Community Control:** To avoid creating negative impacts on the local electricity grid, it is important to manage demand across communities (whether they are commercial or residential, or a mix) to reduce network strain, help save building owners money and reduce energy. Connected devices such as batteries, heat pumps etc. could be controlled in a coordinated way to reduce their aggregated effects on the network and save consumers money. Expanding smart control through federated learning algorithms or similar can ensure that privacy and security is retained for households.

22. **Smart Electric Vehicle Management:** One of the major challenges in transport will be to facilitate electric vehicles. In addition to requirements for better planning of the EV charging infrastructure, will be the management and control of connected vehicles. The following is some of the major challenges:

    - **Distributed Control of Residential Electric Vehicles:** A potentially viable resource will be large numbers of electric vehicles connected on the same local feeder. Although simultaneous charging of several domestic EVs can cause a strain on the network, coordinated control of their storage devices could support the network, help utilise local PV, and help save money.
    - **Smart Charging for HGV.** There are specific needs for HGV and coaches due to high prices and constraints in terms of location of chargers. Upfront investment is expensive for depot infrastructure.
    - **Charging for Car rentals.** Car rentals can not only optimise their own charging schedules to reduce costs and peak demand, but they can also potentially incentivise users to smartly charge their car.
    - **Autonomous Vehicle integration.** Autonomous vehicles may enable lower traffic levels and individual EV requirements. This reduces some material and energy needs whilst not reducing necessary travelling for business or leisure. The charging of autonomous vehicles has an impact on the overall energy network, and AI could help optimise this. They could even potentially be used as mobile demand and storage for grid balancing.

23. **Advanced Network Control:** With increasing renewable generation on the network the system is much more complicated to balance. In addition, as the energy system moves to more distributed operation there will be a need to balance the network at more local level. Some of the challenges in future network control are as follows:

- **TSO-DSO coordination:** As energy usage moves from supply centric to demand centric the role of the DSO will be important in ensuring a local energy supply. However, national level demand-supply balance will still be important. Automation will be needed to ensure that the local and national level are kept in balance and suitably coordinated to support each other.
- **Smart Transformers:** Flexibly adapt to ensure power is directed when and where needed.
- **Optimal Volt/Var Control:** Voltage must be controlled to ensure safe operation of distribution networks, but also increases life of mechanisms such as tap control.
- **Automated System Stability:** Automated power system stability could enable additional renewable connections and increase network reliability.
- **Estimating/Predicting Network Losses:** Energy is lost due to usage, and resistance through assets. Some losses can also be reduced by replacing equipment, others are unavoidable.

### Grid Management and Flexibility

Although energy systems are now focused on the demand side, renewable energy generation is key to a Net Zero future. As well as increasing the number of renewable generation sources, proper management and operations of renewable generation can help improve yields. Some of the main challenges in this area include:

24. **Mechanical Control to Optimise yields:** Some renewables can be controlled by adjusting the asset to increase the amount of renewable energy they generate. Examples include:
    - Wake steering is a particular application in wind power, where the yaw is controlled to maximise the downwind power output by reducing wake deficits. Physics-based models are computationally complex, so AI optimisation can significantly improve efficiency.
    - Controlling the position of solar panels to point towards the greatest irradiance potential.
25. **Weather forecasting for improved system operation:** More accurate and granular weather forecasts can drive decarbonisation through reducing uncertainty around renewable generation and therefore reducing the amount of fossil fuel generation held in reserve. Since weather forecasting is computationally intensive, AI can help by including data sources (e.g., cloud locations) with spatial or temporal resolutions that numerical weather prediction cannot. Applications and scenarios include:
    - Better wind speed and irradiance forecasts can improve the estimates of wind and solar power outputs respectively, allowing better informed bidding on generation markets.
    - Learning tidal currents more accurately can increase the yields from tidal energy.
    - Predicting storm damage and allowing faster restoration of power after storms
26. **Optimal trading for storage:** Energy storage is increasingly important given intermittent renewable generation. Storage can provide multiple services to the grid (e.g., frequency response) and most business cases require stacking of multiple revenue streams, so determining the optimal charging and discharging strategies is complex and highly dependent on forecasting. AI can be used to both provide forecasts and develop optimal strategies.

### Modelling and Simulation

Proper operation of current and future energy networks is very dependent on data and digitalisation. Models of the network (including power systems models) play a critical role in decision making, and AI can help with these.

27. **Optimal Power Flow Calculations:** Balancing electrical supply and demand in an economically optimal way whilst respecting the physical constraints of the system requires very computationally intensive Optimal Power Flow calculations. These often need to be simplified to obtain solutions in the required timeframes, which results in suboptimal (and hence more expensive) power generation. AI can learn the characteristics of optimal solutions and therefore allow much faster identification of the optimal solutions. They must also deal with challenges such as:
    - **Low Observability State Estimation:** Power flow modelling requires significant amounts of data to create accurate state estimates. The question is what level of monitoring can provide sufficiently accurate estimates, and/or what can be achieved through other techniques using the limited data available.
    - **Extrapolating from low resolution data:** A related problem to low observability, is the resolution of the available data. Increased resolution for monitoring can be computationally expensive. What is the best possible trade-off between increased resolution vs computational costs?
28. **Network Modelling with Missing and Sparse Data:** Many of the simulations or models require data to produce useful or realistic outputs. However, not all sites are monitored (or are available), and obviously sensor data can suffer malfunctions or communications issues. The solution thus requires models which are adapted to data with gaps, or to model the missing data itself. Generative AI has become very popular of late due to large language models, but there is also huge potential for time series data. Some of the challenges in this area include:
    - **Estimating demand for unmonitored sites:** If monitoring from other buildings can be used as a proxy for unmonitored sites this can reduce costs whilst still providing insights which can improve energy efficiencies. Meta-learning and transfer learning are common in other sectors for simulating demand for similar applications where no data exists.
    - **Demand Disaggregation.** Most monitoring only records the aggregated demand at the business level and provides no information of the underlying process and appliances. This hides valuable insights into where efficiencies could be gained, or energy demand could be reduced. If accurate estimates of disaggregated demand can be produced then this can provide new solutions but also reduce the need for additional submetering.

- **Network Mapping:** In addition to telemetry data, another important dataset is the network GIS topology data. One challenge is that many network maps have not been digitalised and often network maps are inaccurate. Further, there may be gaps in data and these must be accurately completed. Improved mapping, through AI or otherwise, can be used to help add new connections or improve maintenance.
- **Identifying optimal monitoring location:** When there are constraints on the amount of monitoring that is available, it is important to be highly selective in where monitoring is placed to ensure maximum effectiveness.

29. **Carbon intensity modelling:** Understanding the carbon intensity of the energy utilised in the network at different times can help ensure strong incentives to reduce demand when carbon intensity is high. National and regional carbon intensity can be currently modelled reasonably accurately, but it is more complicated to model at a very granular level. AI can help model the complex and dynamic flows required to estimate granular carbon intensity.

### Forecasting

Forecasting is a vital component to operating the energy networks. Historically, national energy and price forecasts have helped to balance the networks and ensure a reliable energy supply. However, as the networks becomes more demand centric there is a need for advanced forecasts for a whole range of variables and applications. Some of the major prediction challenges are as follows:

30. **Renewable Energy Forecasting:** Predicting energy generated from renewable sources is vital. Since most renewable sources are dependent on weather their outputs can have high levels of uncertainty – for example a solar power forecast has a high degree of uncertainty since it is difficult to predict the movement of clouds. Different applications require different forecast horizons, from very short term to reduce amounts of spinning reserve, to medium term to help with planning. AI can help both with the underlying weather forecasts and the direct forecasting of renewables.

31. **Forecasting for Network Management:** Forecasting has always been integral to balancing the networks but there are additional complications with the increase in distributed renewables and low carbon technologies. Balancing may have to be done at a more local level where the demand is much more volatile and uncertain. Some of the main challenges are as follows:

    - **Operating Costs Forecasts:** Balancing Services use of System costs are required to ensure security of supply. Other operating cost models will require forecasts to ensure sufficient pots of money are available especially with the move to localised energy system.
    - **Dynamic Reserve Setting:** Day ahead estimates which can accurately estimate the amount of back-up power needed can help better utilise resources. Traditionally reserve setting has been part of the ESOs role but may be part of a future DSOs requirements.
    - **Congestion Prediction:** Interconnections between DSO regions or countries can help maximise renewable utilisation, however this requires accurate forecasting of the risk of cable congestion.
    - **Short term Distribution level forecasts:** As DNOs move to a distribution system operator, there is a requirement to have accurate forecasts at the low voltage level which are coherent across the entire network hierarchy. This has some additional complications not present at the national level such as large network switching effects, and much higher volatility. Hence new operational systems will need to be produced to handle network balancing at the distribution level.

### Energy Markets

Energy Markets are already quite complicated with a plethora of products and exchanges for various services, from wholesale, balancing, capacity etc. Things will likely become more complicated as energy markets become more decentralised and many more consumers become prosumers. Some of the energy challenges are as follows:

32. **Decentralised Market Solutions:** Energy is moving from supply to demand centric with the increase in distributed renewable energy resources, and higher uptakes of low carbon technologies. The following are some of the challenges with such markets:
    - **Local ancillary services:** Future DSOs will have to ensure security of supply in local regions. This has unique challenges compared to the national level since the demand is at much lower aggregations and therefore relatively more volatile and irregular.
    - **Defining Local Market Regions:** Different areas of the network have different resources and renewable generation potential (sunnier areas are typical in the south of UK, and the windier areas in the north). The demand is also irregular and driven by population densities, and the location of industries and businesses, with varying network headroom. This makes planning a sustainable, and fair local area market a nontrivial task.
    - **Energy Trading Strategies:** The move to more localised energy markets will require advanced trading strategies which can better respond to the local demand and generation. Since the focus is on smaller regions these will be much more volatile than national level, and therefore may need to be embedded with data driven models which can better process and learn from the real time data. Solutions such as block chain may also be required to look at how to enable a peer-to-peer market in a timely and secure way.

## Maintenance and Anomaly Detection

Networks need continual maintenance to ensure that they are working as efficiently as possible. Similarly, quickly fixing faults will ensure that supply is uninterrupted for as long as possible. The use of AI for asset maintenance is a very well-funded field with strong existing incentives, and in general, cost effectively, maintaining existing assets has limited value for decarbonisation. An exception to that might be using it to improve the economic viability of offshore renewables, because maintenance costs make up a significant proportion of the lifetime costs.

33. **Asset Health and monitoring:** Sensors and monitoring can help ensure that an asset or piece of equipment is operating as expected. However, since assets can fail in several ways the quantity being measured by a sensor may not be directly linked to a component or process which has failed. In such case inference may be required by analysing the subtleties in the data. Some challenges in asset health and monitoring are as follows:

    - **Remote inspection:** For hard-to-reach infrastructure (tidal power and wind turbines for example), remote inspection methods such as through drones, or imaging technology can be used to inspect equipment. This requires accurately identifying the asset or important features. There are also applications to jobs assessments such as gas pipe coatings inspections.

    - **Condition Monitoring:** Sensors or other monitoring technology can help to assess the performance and condition of a device or infrastructure and help identify when maintenance is required. It can also identify faults. This can include overhead line steelwork corrosion assessments, thermal condition monitoring of transmission assets, or even wood pole asset condition. Condition monitoring can also be used for gas governors to manage the flow of gas.

    - **Real time thermal ratings** involve using AI to adjust the maximum current allowed through an electrical cable based on asset health and weather conditions, which allows existing infrastructure to be better utilised without compromising safety.

34. **Detecting and Locating Faults:** Faults on the system can put an asset out of action and disrupt the supply of energy or reduce the outputs from renewable generation. Therefore, identifying a fault and locating where it is on the system is vital for quickly repairing them. AI can help by accelerating the process of identification and diagnosis. Some of the main challenges in this area are:

- **Remote inspection:** For hard-to-reach infrastructure (tidal power and wind turbines for example), remote inspection methods such as through drones, or imaging technology can be used to inspect equipment. This requires accurately identifying the asset or important features. There are also applications to jobs assessments such as gas pipe coatings inspections.
- **Identifying Gas Pipe Leaks:** More automated and data-driven techniques could help reduce the losses and reduce emissions by reducing the number of leaks and fixing them quicker.
- **Fault Detection and Prediction:** Through condition monitoring or otherwise, quickly detecting faults can help to limit disruption to the grid and consumers. This could be on any device, from detecting tap changer failures, to cables damaged from falling trees. This can be particularly important after storms, to enable quick restoration of power. To further reduce network down time, prediction of when an asset may become faulty can be helpful. For example, real time thermal ratings are monitoring devices which ensure electrical cables are operating within safe limits.
- **Alarm and Event Transparency:** Although alarms are necessary to highlight problems on the network, very frequent alarms can distract from normal network management. Improved understanding of alarms and links to root causes can help reduce the number and frequency of alarms. Large language models could potentially be able to help with interpretations and improve the response times.

35. **Maintenance and Repairing Faults:** Once a fault has been detected and isolated the aim is to fix it as quickly as possible especially if is affecting energy supply. Fixing faults varies in complexity due to the varied types of assets. For example, offshore renewables can be inaccessible if the weather is not favourable. Effective preventative maintenance can ensure an asset breaks as infrequently as possible. Some challenges in maintenance and fault repair are as follows:

    - **Remote inspection:** For hard-to-reach infrastructure (tidal power and wind turbines for example), remote inspection methods such as through drones, or imaging technology can be used to inspect equipment. This requires accurately
    - **Maintaining offshore assets:** For offshore assets, a major issue is how to plan maintenance since the conditions are often not favourable for sending workers to fix any faults or upgrade the equipment. Related, it is also useful to estimate the remaining useful life of these assets which will enable better preparation for replacements.
    - **Maintaining Solar:** Solar will often be affected by vegetation and trees which may grow around and block the panels, wind and solar assets connections can cause negative oscillatory behaviour on the network.
    - **AI-enabled robots:** This is particularly important for infrastructure which is less easily reached such as offshore energy, or subsea cables. They can also be used in circumstances where the job may be less safe, such as in gas mains excavations. In some cases, robots can also provide the required maintenance.
    - **Estimated Time to restoration:** Improved estimates of time to restoration can help customers by giving them more confidence in service updates and help them plan their energy usage. This is particularly useful for vulnerable customers.
    - **Service Engineer Support:** New digital products, such as augmented reality, could help engineers fix faults and provide maintenance. There could also be data-driven digital tools and decision trees which could help e.g., through tablets or smart glasses.

36. **Cyber Security:** The digitalisation of energy systems and data increases the risk of cyber-attacks, particularly as the system is decentralised. AI can assist in detecting and responding to cyber threats. Active security controls will be needed to improve resilience and robustness and feed into security decisions.

## Manufacturing Challenges

This section details some of the decarbonisation challenges in the manufacturing sector. These challenges also have planning, operational and maintenance categorisations and we have included only one consumer incentive and support challenge since others are similar to the ones listed in the energy challenges longlist.

### Design & Planning

Proper design and planning within manufacturing can help reduce emissions in several ways. This can be related to the producing a final product which allows much more energy efficiency for the final application. In addition, of course manufacturers can decarbonise by utilising renewable energy, but this is tied up with the much more general problem of renewable connections as seen in the Design & Planning section of the Energy Challenges. Some of the manufacturing specific challenges are as follows:

37. **Design of low carbon feedstock alternatives:** High emission materials are used in many heavy industries. For example, coal is used as a reducing agent in steelmaking. However, there are alternatives such as hydrogen (in the case of steelmaking hydrogen can be used to create direct reduced iron, and the only output is water). AI could be used to help investigate other alternatives and processes which could decarbonise the feedstock of our major manufacturing processes.

38. **Design of low carbon manufacturing processes:** Many manufacturing processes require high temperatures which means it is difficult to replace the traditional coal and methane fuel sources with low carbon alternatives. Investigation of new process designs could therefore help to design new plants (or adapt old ones) which can incorporate hydrogen alternatives, or to enable the use of electrification which could be fuelled by renewable sources.

39. **Manufacturing process efficiency:** Although industrial and manufacturing processes are typically very efficient, in order to reduce costs, additional high-resolution monitoring, combined with machine learning methods could isolate additional inefficiencies, which can be further optimised.

40. **Design of more Efficient Products:** Refining the design on products and materials is essential to lower emissions. Examples include:

    - **Aerodynamic design optimization:** AI algorithms can analyse and optimize aircraft designs to reduce drag and improve fuel efficiency, leading to lower emissions during flight.
    - **Designing new materials:** AI can help select materials that have a lower environmental impact, such as lightweight composites that reduce aircraft weight and fuel consumption.

41. **Improvements in Recycling Materials:** Recycling reduces the need from sourcing and extracting new materials and hence reduces overall emissions. Further AI could identify environmentally friendly waste disposal options, including separating different materials, identifying the best disposal route.

42. **Network Connections for Industrial Consumers:** Existing industrial consumers are one of the more difficult to decarbonise because they are very dependent on the available network connections and the capacity of the nearby energy networks. For example, for a manufacturer who utilises gas, for them to switch fuels they will depend on the likelihood of the construction of a new hydrogen network and its available capacity. These can help decision makers identify the best investment options and give planning confidence to industrial consumers. The building of new networks can be supported by AI, by optimising the design of networks so they can maximise opportunities while minimising the potential costs.

43. **Installing onsite renewables and storage:** Onsite renewables and energy storage can help reduce electricity import costs, enable reduction in emissions, as well potentially enable the manufacturer to save further costs by participating in electricity markets. However, there are several potential roadblocks: high upfront capital costs, slow payback periods, finding suitable locations, potential upgrade costs (say to a roof to support the new solar panels), and maintenance costs. AI can be used to explore and identify viable options by optimising the location, cost and operation of the renewables, and potentially optimising according to alternative business opportunities, e.g., engaging in the wholesale market or capacity market. This provides a potential income stream.

44. **Supporting the generation of Green Hydrogen:** Generating green hydrogen is through utilising electrolysers which are powered through renewables. Since it is dependent on intermittent renewables, the production can have high levels of uncertainty, but this could be supported by AI to manage the operation or optimise the location of new hydrogen production plants which are favourable to renewables.

## Management and Operations

Many businesses can reduce their energy usage, emissions and costs by refining their operations and implementing energy management schemes. The following are manufacturing specific challenges which can help them decarbonise:

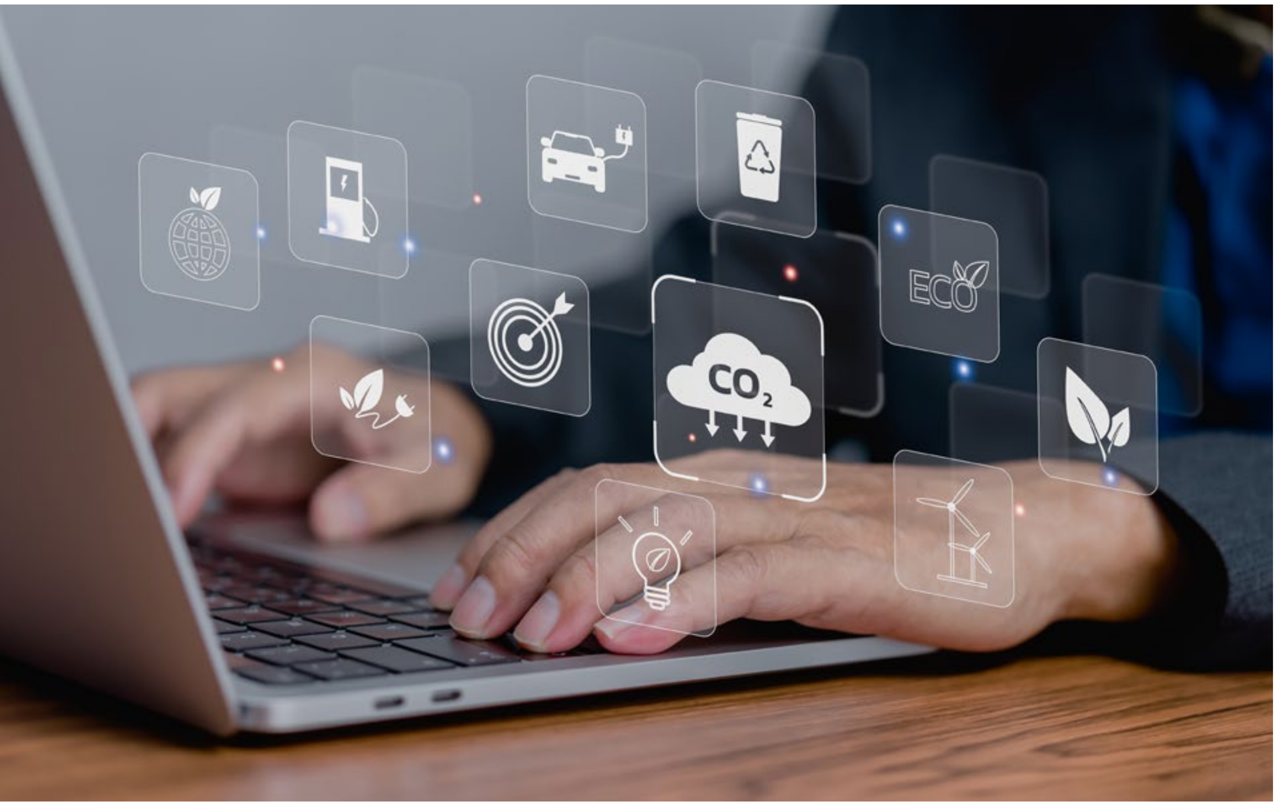
45. **Energy Management in Manufacturing:** Understanding the scheduling of processes and optimising management of less essential systems can help reduce energy usage and also utilise energy when demand is lower and cheaper. Some energy management challenges include:
    - **Optimising energy efficiency:** Since energy efficiency provides cost savings, the low-hanging improvements are usually already implemented. However, increased monitoring and machine learning could find other areas to refine.
    - **HVAC Systems management:** Many manufacturers utilise heating and ventilation systems which are major contributors to their emissions. These could be more optimally managed to take into account when they are needed to help reduce their demand.
    - **Optimise production schedules:** Different tariffs are available which can take advantage of off-peak price reductions and lower costs from renewable generation. Production schedules could be adapted to take advantage of these opportunities. Further, coupled with renewable energy certificates or on-site renewables manufactures could take advantage of cheap self-generation to reduce costs and emissions.
    - **Equipment Control:** AI could be used to adjust machinery settings for maximum energy efficiency based on things like material characteristics, job duration, number of components, etc. AI can optimize manufacturing processes such as machining, welding, and assembly to reduce energy consumption and emissions.
46. **Demand Forecasting for Manufacturing:** Demand forecast can help manufacturers anticipate loads and costs. For manufacturers this could also enable smart inventory management where AI could optimise inventory levels to reduce excess production. It could also provide more control over scheduling of major production runs to coincide with high renewable energy.

47. **Manufacturing Logistics and Distribution:** Products made by manufacturers need to be distributed to those that use them. Some of the challenges are:

- **Decarbonising transport:** Installing infrastructure to support either electric or hydrogen transport is one way to help support decarbonisation. However, it may increase overall costs.
- **Efficient Fuel Utilisation through Journey Planning:** The route taken and the type of journey (e.g., stop-start driving) can change the utilisation of fuel within a mode of transport. Better journey planning can help improve the energy efficiency. This will be particularly useful for heavy goods vehicles used in manufacturing applications which are more difficult to electrify than domestic vehicles.
- **Supply Chain Optimisation:** Better planning of transport routes and utilisation of vehicles can remove or reduce some transport inefficiencies and reduce waste.

48. **Maximising Data Utility in Manufacturing Plants:** Data issues are a major obstruction to manufacturers understanding their energy usage and areas of efficiency improvements. When there is limited or no data there are many opportunities to install new monitoring, or better utilise existing data to help model and operate plants:

- **Non-energy Data Sources:** Some data sources, such as weather data, are vital for the optimal operation of the energy networks. However, feature extraction or improvements in old data sources, or new, previously unused data sources can add value to network management, operation and planning. This could be as simple as increased resolution of weather forecast data.
- **Optimising Monitoring utilisation:** Monitoring can help support management and operations since it can help with condition monitoring, understanding energy usage and emissions, and can also help with maintenance. AI can be used to identify the optimal location and amount of specialised monitoring required to reduce the costs whilst minimising computational requirements and not reducing the operational efficiency.
- **Simulating Realistic Data:** Data is required for the efficient running and understanding the energy usage and emissions of a manufacturing plant. However, instead of installing expensive monitoring to understand a processes, generated data could be used to replace some of the sensors to reduce costs. AI can be used to generate realistic data which has the features and complexity expected in the processes. If there is data available from other plants or machines then transfer learning could also be used to simulate the bespoke, unmonitored system.




## Maintenance and Anomaly Detection

Condition monitoring, maintenance and anomaly detection are common for any major asset and therefore these challenges encompass many of the those within the energy challenges. The following is one specific challenges in the area of maintenance which can help decarbonisation:

49. **Defect Identification in Manufacturing Products:** Machine imaging techniques could be used recognise early defects and alter production to reduce corrective rework and maintenance.

## Incentives and Consumer Support

50. **Carbon Accounting and Modelling:** Carbon accounting can provide a foundation for key incentives for manufacturers to reduce emissions. However, tracking the carbon emissions associated with inputs (including embodied carbon) and processes is nontrivial. There is generally insufficient direct measurement to create an accurate picture of carbon emissions. AI can support this through processing and combining alternative data sources to estimate, track and reduce emissions and the contributions from the various components.

## Agriculture Challenges Longlist

This section details some of the decarbonisation challenges in the agriculture sector. These challenges also have planning, operational and maintenance categorisations but only a few consumer incentives and support challenges as there are not many that are significantly different to those already listed in the energy challenges

### Design & Planning

Design and planning are very important for the agriculture sector. Chemicals must be designed to help yields, and the produce from agriculture can be used to replace less sustainable practices. The following are some of the main design and planning challenges in agriculture:

51. **Carbon Accounting and Modelling:** Carbon accounting can provide a foundation for key incentives for manufacturers to reduce emissions. However, tracking the carbon emissions associated with inputs (including embodied carbon) and processes is nontrivial. There is generally insufficient direct measurement to create an accurate picture of carbon emissions. AI can support this through processing and combining alternative data sources to estimate, track and reduce emissions and the contributions from the various components.
52. **Designing low emission food alternatives:** AI could be used to develop new alternatives to some of the higher carbon outputs in agriculture. AI can improve efficiency in plant-based products but also help support lab-grown meat production, thus reducing the high carbon outputs from the meat industry.
53. **Fertiliser design and recommendations:** Excessive or inappropriate use of fertilisers contributes significantly to agricultural emissions. AI can –assist the design and selection of sustainable fertilisers, as well as optimisation of their manufacturing processes (which are often carbon intensive).
54. **Designing Feed and Feed-Additives for Livestock:** The diet, feed quality, and supplements given to livestock can improve their health, increase productivity, and help reduce the amount of methane emissions they produce through enteric fermentation.
55. **Prediction for Agricultural Resource Planning:** Longer term forecasts can help plan processes and use of resources. In particular the following are two planning applications which can help decarbonisation:
    - **Crop prediction:** Predicting crop yields to optimize harvest planning and reduce waste.
    - **Drought prediction and mitigation** - AI for early drought prediction and water-saving practices

## Management and Operations:

Day to day operations for agriculture provide many opportunities to improve energy efficiency. Some of the major challenges are as follows:

56. **Optimising Farming Resources:** AI can be used to help optimise resources used in agriculture applications such as crop production and irrigation such as water, fertiliser and pesticides. Efficiency can also be improved by utilising solar power (for example for pumps) instead of diesel driven generators.

57. **Livestock Breeding Programmes:** The methane emissions from livestock can be affected by numerous factors such as animal size, feed conversion efficiency, and growth rate, which are driven by genetic factors, and therefore breeding programmes can select those animals which are likely to have lowest future greenhouse gas emissions. AI can be used to identify the traits which can produce lower emission offspring.

58. **Manure Treatment:** Manure is another major contributor to methane emissions. However, there are several treatment approaches that can help reduce these including acidification, and aeration. Manure can also be used to generate bio energy when mixed with substances such as grass and feedstock through the application of microorganisms which digest the mixture to produce biogas. Adjusting operation practices, such as the temperature, and optimal substrate mixtures are needed to help increase the efficiency of the outputs. AI can be used to identify optimal operating conditions.

## Maintenance and Anomaly Detection

Maintaining the health of crops and soil in agriculture also ensures better land use and the capturing of carbon. Below are some of the maintenance and health management challenges in agriculture:

59. **Soil Health Monitoring and Management:** Monitoring of soil health can help enhance crop productivity and sequester carbon. Monitoring soil health can reduce fertiliser requirements and hence emissions. AI can help both automate monitoring and recommend optimal actions.

60. **Crop Monitoring and Management:** Optimal crop rotations can help support soil health & emissions reduction and enable more efficient utilisation of resources. AI can be used to recommend and monitor crop rotation schedules. Image processing, satellites and drone-based AI can also help support the early detection of crop diseases, reducing the losses of crops and ensuring optimal land use.

### Incentives and Consumer Support

61. **Low carbon diets:** Shifting to lower carbon diets could play a significant role in helping decarbonise agriculture. AI-assisted understanding of consumer behaviour and preferences would allow information and marketing to be more effectively personalised for different consumers to help them transition to a lower carbon diet.

## Built Environment Challenges

This section details some of the decarbonisation challenges in the built environment sector. Many of these overlap significantly with the Energy sector.

### Design & Planning

62. **Identifying and targeting optimal retrofit measures:** Different consumers have different building characteristics, energy usage and appliances, and therefore it is not trivial to understand the most suitable retrofit pathway for a household or business based on their requirements. Analysis and modelling of different interventions could be utilised to help identify and recommend the most suitable interventions (and forecast energy savings). This could be done for individual properties, or at scale to enable appropriate targeting of retrofit offers.

63. **Retrofit design:** Some retrofits, such as heat pumps, must be sized to ensure they can achieve the desired temperatures for the home, and the design process for these is lengthy and inconsistent, making it harder for consumers to decarbonise their homes. AI could support this process through automated data collection (e.g., building layout or heat loss) and system design optimisation/recommendations.

64. **Retrofit approvals:** High demand devices (e.g., heat pumps and EVs) often require approval before connection to the electricity network, which can be a lengthy process. AI can be used to help speed up and improve the approval process by automating modelling of these connections and enabling automatic approval of the majority of them.

65. **Retrofit installation and commissioning:** The performance of some retrofits can be very dependent on the quality of installation and commissioning, and there is often significant variation in installation quality. For example, a well designed and installed heat pump can have 50% higher efficiency than a poorly installed equivalent. This may be down to a shortage of skilled installers. AI could help improve this by accelerating training, augmenting the installation process, and automating improved quality assurance.

## Management and Operations

With the increase in monitoring and controllable devices, the energy system is moving from its traditional supply side focus to the demand side. Demand management can help better match demand to renewable generation, shave peaks, save consumers money, and help support the network. The following is the main challenge in this area:

66. **Smart Building Control systems:** More connected devices and increased monitoring, e.g., through smart meters, opens up many more opportunities and products and services for consumers to save money on their energy usage. Multiple smart homes could be connected in smart grids which can then help support the network. Some of the main challenges in these areas include:

    - **Building management Systems:** Connected devices within a home or commercial building can help consumers and companies save money and take advantage of smart tariffs by controlling IoT devices and low carbon technologies. This could focus on heating or lighting and can be automated by learning the occupant's energy behaviour to ensure that comfort or utility is not lost whilst still saving energy. Installation of onsite renewables and storage could also be included in such systems to further decarbonise and reduce costs.
    - **Building Demand Forecasts:** Building management systems can be optimised by forecasting their energy usage and responding by appropriately scheduling their appliances and applications. Forecasting at an individual level is very difficult due to their spikey nature, unpredictable occupant behaviour, and high volatility.  AI is well suited to creating estimates from complicated historical demand profile patterns.
    - **Demand Side response:** Demand side response involves turning off or on devices to help control demand. For example, heating or refrigeration systems could be turned off briefly to reduce demand during peak hours. As long as the time period is short the system will not affect the heating or cooling significantly but will reduce the overall energy used. DSR is an enabler for a flexible grid and can help manage grid instability. AI can both help measure the impact of DSR (which is non-trivial) and automate DSR.


## Incentives and Consumer Support

67. **Measuring retrofit impact.** It is impossible to precisely calculate the effect of a retrofit on energy consumption since there is no way to compare to the unmodified energy usage had the retrofit not been applied. AI provides an alternative by estimating the savings modelling of the demand. This can become more difficult to do accurately for volatile demands such as household energy usage. Such modelling would increase consumer confidence in retrofits, but also unlock new funding models (as funding could be tied to long term savings).

68. **Standardised building performance reporting:** Currently building energy performance is reported via EPCs, but these are based on major assumptions (e.g., 'typical' occupancy profiles) and have been shown to have significant limitations. AI could be used to provide better measures of building performance (e.g., energy efficiency, heat transfer, effects of weather) via analysis of actual energy demand.

## General Challenges

There were several reoccurring challenges which covered problems within more than one individual challenge or were more general than any specific application. Regardless they have important implications for the application of AI and the decarbonisation impact that they could make. The following where the most common general challenges which we identified.

A. **Explainable AI:** Adoption of AI in engineering heavy sectors such as energy and manufacturing can be hindered by lack of understanding and trust in the outputs. In addition, the increased use of black box algorithms not only reduces the transparency of what operations are being performed but also risks cascade effects in complex systems like energy networks. Further, the sectors considered in this report must have clear understanding of the techniques they are applying if they are to be able to reduce risk and maximise the implementations. Advances in explainable AI are therefore important in supporting applications of AI to decarbonisation.

B. **Privacy and Ethics:** The utilisation of more granular data such as smart meter readings from individual homes and consumers may be very valuable for applications such as network operation. However, they also increase privacy risks and create ethical challenges when services are derived from this type of personal data. This poses a dilemma since banning use of this data also removes opportunities for consumers to better control their energy and potentially reduce costs. Privacy preserving techniques such as differential privacy need to be developed which can balance between utility and privacy. There also need thorough testing and reporting to ensure that they cause no harms and help others apply them safely.

C. **Sustainable AI:** More computationally expensive algorithms bring with them their own increased energy usage and greenhouse gas emissions. Deploying AI at scale whilst minimising its own negative impacts on the environment remains a challenge. Utilising AI workloads as flexible demand within the energy systems is likely one component of this.

D. **Estimating unobserved data:** Most potential applications of AI for decarbonisation suffer from lack of granular enough data – from agricultural emissions to electricity network layouts. Techniques that are robust to this are important, but generative AI or meta-learning could also play a key role in helping to fill in the gaps for simulation and modelling purposes.

# Appendix: Challenge Cards

ADViCE

## Challenges cards

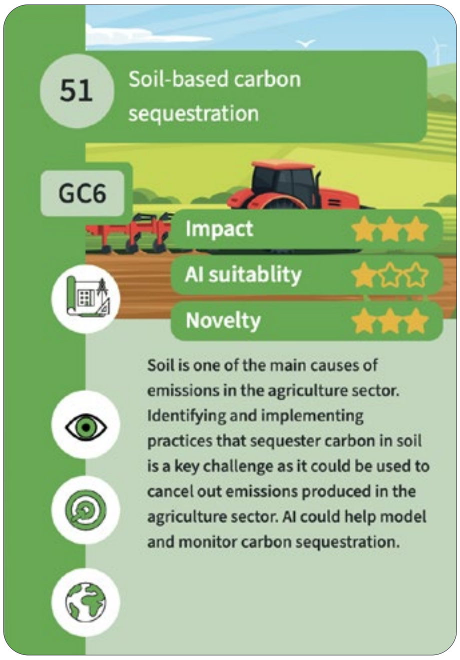
Decarbonisation challenges can be explored more visually using the challenge cards (and their virtual equivalents which can be found here. Examples of the cards are shown below.

### Symbols on the cards correspond to:

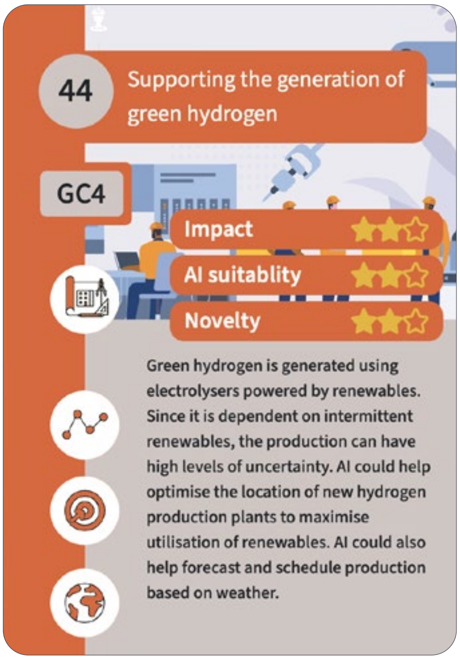
| Symbol | Phase |
|---|---|
| | Design and Planning |
| | Management and Operation |
| | Maintenance and Anomaly Detection |
| | Incentives and Consumer Support |

| Symbol | AI capability |
|---|---|
| | Visual |
| | Time series |
| | Geospatial |
| | Optimisation |
| | Language |
| | Other Machine Learning |

### A - AGRICULTURE




### B - MANUFACTURING




### C - ENERGY


### D – BUILT ENVIRONMENT

# Appendix: Challenge Selection Resources

## Challenge Selection Resources

The following databases, white papers and reports were used to identify and find challenges for the energy sector.

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**Databases**

The following databases and lists where used to source projects from previous innovation projects. These helped to develop the long list of challenges and supported the bottom-up approach since they highlighted areas where AI has already been applied:

- UKRI Gateway to Research. This is the UKRI portal onto publicly funded research, and hence includes all projects from Innovate UK, EPSRC etc. This is not energy specific and hence was used in conjunction with the CoPED catalogue (see below) which filters the UKRI Gateway with energy specific keywords.
- CoPED Catalogue Energy System Catapult's platform for Energy Project Metadata. This currently is a filtered version of UKRI projects from the Gateway to Research with energy key words used to identify relevant decarbonisation projects.
- ENA's Smarter Networks Portal. The Energy Networks Association database collects projects from Industry based innovation projects including the Network Innovation Competition projects, and Strategic Innovation Fund.
- CORDIS is the European portal which contains projects on EU Research & Development projects.
- U.S. Department of Energy SBIR/STTR awards. Awards for small business innovation research and technology transfer.
- Previous Data Science Competitions: Energy Systems Catapult have previously collected distribution network operator related projects as part of data science competitions we developed.
- AI for Decarbonisation Innovation Programme Stream 2 Projects. The list of projects of stream 2 projects funded as part of the AI for Decarbonisation programme were also included to ensure completeness.

### White papers and Reports

There are several reports that we considered in the areas of built environment, energy, manufacturing and agriculture which highlighted the major challenges, and areas where AI could be applied. There are also academic papers and review articles which collate various challenges. These helped to develop the long list of challenges and supported both the bottom up and top-down approaches.


- AI Insights: Rising to the challenge across the UK energy System, DNV, 2023. Last Accessed 28/11/2023. Available here.
- AI and Data for Decarbonising the Built Environment, University of Cambridge, Decarbonisation Network, 2023. Accessed 28/11/2023. Available here.
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- Tackling Climate Change with Machine Learning, D. Rolnick et al., ACM Computing Surveys, 2022. Last Accessed 28/11/2023. Available here.
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- AI and Climate Change: How they're connected and what we can do about it, AI Now Institute, 2019. Last Accessed 28/11/2023. Available here.
- How AI is Helping the Energy Sector Improve the Customer Experience, BizTech, 2023. Last Accessed 28/11/2023. Available here.
- How a utility giant is using data analytics, machine learning to benefit customers, VentureBeat, 2023. Last Accessed 28/11/2023. Available here.
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- AI Techniques for Electrical Technologies, MathWorks. Last Accessed 28/11/2023. Available here.


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