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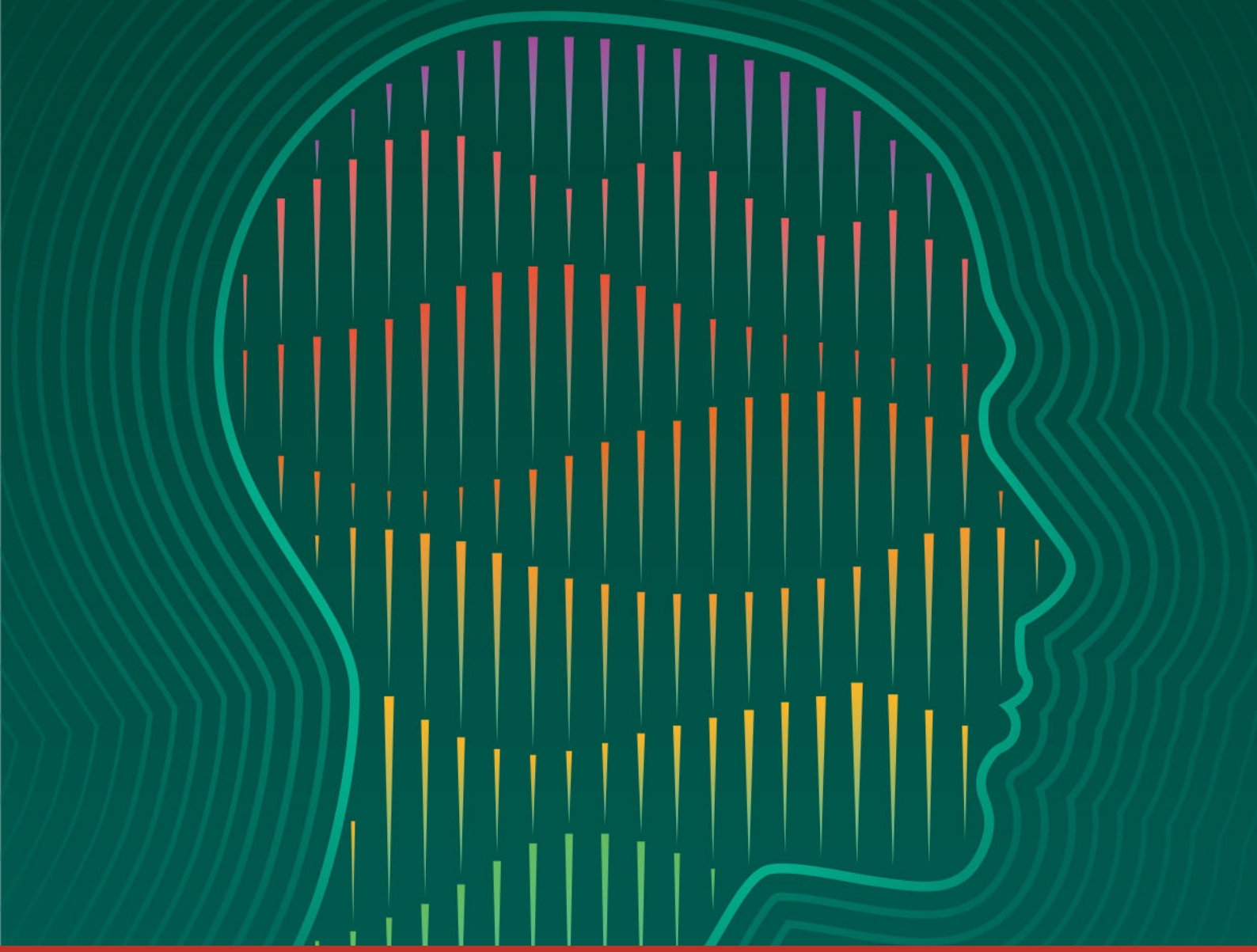

People, communities and climate technology

Public views on **climate technologies** and opportunities for future public dialogue

Contents

Disclaimer:

The views expressed in this report are not representitive of the views of UKRI.

Sciencewise, a public dialogue progamme delivered by UKRI, has conducted this research with a view to identifying areas of research and innovation and technologies where early public engagement would be useful, and welcomes further discussion with research funders, government departments, government agencies and other public bodies working on these issues.

Preface

The purpose of the report

This report aims to outline what is known about public views and values on emerging climate technologies, and to identify gaps and areas for further exploration through public dialogue.

The report has been produced by Sciencewise, a UKRI funded public dialogue programme that supports government departments and other public bodies to listen to and act on diverse voices, to shape policy and priorities. Sciencewise:

- **Helps decision makers to formulate policy with a deeper understanding of public views, concerns and aspirations;**
- **Ensures high quality, best practice public dialogue; and**
- **Supports transparency, credibility and independence.**

Since 2004, Sciencewise has supported almost 70 public dialogue projects on often controversial technologies and cross-cutting issues of societal change, from AI and gene editing to low-carbon energy and the future of food production.

The Sciencewise priority themes were updated in January 2022, drawing from key government and research council priorities, and the latest research and innovation trends:

- **Climate and Environment: How can society live sustainably?**
- **Data, AI and Robotics: How should society shape our digital world?**
- **Health, Ageing and Wellbeing: How should society live healthy lives?**
- **Life Sciences and Biotechnology: How should society shape the future of life?**

This report on public opinion about emerging climate technologies is intended to identify opportunities for public dialogues. We present results from analysing sources of public opinion on seven climate technologies. This provides a snapshot of public views at the time of writing, March 2023.

The report will be useful to those interested in public views on new and emerging areas of climate science and technology and is particularly targeted at those involved in science and technology policy.

Acknowledgements

The report was compiled by the British Science Association in its role as a member of the Sciencewise consortium between September 2022 and March 2023. Other consortium partners (Involve and the National Coordinating Centre for Public Engagement) and UK Research and Innovation provided input and quality assurance.

Comments on the technologies, themes, and sources were provided by the Department of Computer Science and Technology at the University of Cambridge, Tyndall Centre Manchester, and Science Policy Research Unit (SPRU) at the University of Sussex Business School.

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Executive summary

Significant global efforts are underway to advance the development and implementation of technologies with the potential to mitigate climate change.

These 'climate technologies' are a key part of any pathway to net zero emissions and researchers, innovators and entrepreneurs are working to make them cheaper and more accessible. Climate technologies will impact how people travel, heat their homes, what food they eat and what they buy, and it is vital that the public are involved in debates shaping emerging climate technology policy, development and usage. But the success of large-scale deployment of climate technologies depends not only on technical and economic factors, but also on public attitudes and values. In order for policymakers to create robust and supported net zero policies, it is essential to start an open discussion with the public to understand their views, hopes, concerns, and motivations for behaviour change.

Both existing and emerging climate technologies can play a role in reducing greenhouse gas emissions. But for the UK to respond to the threat of climate change and reach the UK Government target of net zero emissions by 2050, it is necessary that climate technologies are assisted by other interventions, including behaviour change. Individuals, communities, and organisations need support to reduce their own carbon footprint.

The report considers seven emerging climate technologies, identified through desk research and consultation with academics, policymakers, and technologists, and aims to highlight what is already known about public opinion towards these technologies. By analysing social intelligence sources such as surveys, opinion polls, social media, and social research, we identified key themes, possible concerns, and gaps in our knowledge around what the public think of each of the technologies and behaviours considered in this report.

Social and ethical issues in climate technologies

We found that several social and ethical issues appear repeatedly, regardless of which climate technology is being considered:

- **Trustworthy governance, regulation, security, and safety** - technology being thoroughly tested before being deployed, having regulation in place at an early stage, being secure, and having no adverse impact on human, animal, or planetary health are seen as a minimum requirement for acceptability.

- **Technology as an unknown quantity or "get out of jail card"** - people are concerned about climate change, and open to making changes in their lives and communities to adapt and mitigate changes. There is generally a low-level of awareness about how climate technology could fit into adaptation and mitigation measures, and there are signs that purely technology-driven solutions do not fit into people's ideas of what a sustainable future looks like. People also have doubts about whether breakthrough climate technologies will materialise and provide a "get out of jail card".

- **Just transition and community impact** - there is an appetite from the public to have a more active role in deciding which climate technologies are used and how. There is an awareness of the potential economic gains of climate technology, but also that the profits and power may be concentrated in inequitable ways. There is also an awareness of trade-offs and potential adverse impacts of climate technologies for certain communities.

Energy monitoring

Smart grids

Public engagement is key to the success of smart grids, since the technology relies heavily on household and community-level infrastructure changes, such as more localised energy system operation, or more flexible energy tariffs. Key social and ethical issues associated with the use of smart grids include privacy and data sharing, effectiveness, concern about being held responsible for energy usage, and initial cost.

Trends in social intelligence

- Most analyses of smart grids are technical in focus, and studies centre on stakeholder views of smart grid feasibility, environment, supply security, data security, governance, finance, user engagement, and equity.
- There is no single vision for smart grids in the UK. People are concerned about data privacy and security, but are positive about more local, decentralized, democratic energy systems.

Opportunities for new public engagement on smart grids

- The conversation around decentralization of energy control and supply could be scaled up. Public engagement could focus on community-level engagement in different areas of the UK, and explore which systems they would favour and why.
- Engagement should particularly focus on vulnerable consumers and communities – for example, people who are not connected to the electricity grid, or people who are dependent on consistent energy supply and so could not take advantage of 'off-peak times'.
- Few surveys look at data governance alongside smart grid governance, and it would be helpful to explore how people's views on data privacy apply in this context.

Household/ workplace monitoring

Sensor and data-driven technologies for energy monitoring are likely to become more advanced and more widespread, because they underpin many infrastructure changes that are required to meet net zero targets. Social and ethical issues around household and workplace monitoring include surveillance and cyber security, sensitive data sharing, empowerment as a result of reducing energy consumption, but also anxiety about energy usage and associated costs.

Trends in social intelligence

- In relation to cost and effectiveness, public attitudes to smart meters became more negative between 2005 and 2019.
- More recent studies report a positive shift in public attitudes towards monitoring technologies in the past three years.
- Key conditions required for support of monitoring technologies are free installation, reduced bills as a result of the technology, and privacy and data protection.
- Technology alone rarely motivates people to make behavioural changes, especially if its purpose is unclear to people.
- Research exploring workers' attitudes towards energy monitoring technologies in the workplace is scarce.

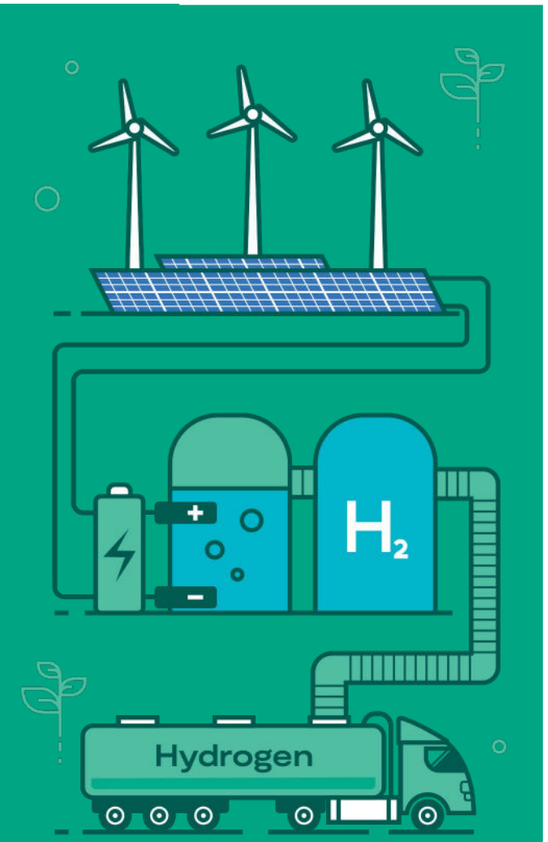
Opportunities for new public engagement on energy monitoring

- There should be continual monitoring of public attitudes towards specific monitoring technologies, and how it is impacted by the economic and political environment. Our analysis indicates that higher energy costs may have driven uptake of energy monitoring devices, however, some studies suggest that people feel a lack of choice or agency around monitoring technology, even when they recognize some of the benefits.
- There could be more studies that ask people about energy monitoring in the context of what they want their homes and workplaces environment to be like, and how technology supports that. There should be particular efforts to engage with disabled people, and people on lower incomes.
- Engagement could do more to explore to what extent technology supports behaviour change, especially among older age groups.

Energy generation technologies

Hydrogen

It is well understood that the public acceptability will play an important role in the successful deployment of hydrogen technologies, and there has been a wealth of research published on this topic in the last few years. We found that most of the studies focus on a specific use of hydrogen, for example, heating homes or fuelling cars. Evidence looking at the public's opinion about the full value chain, including production, transport, and storage, is currently missing.



Trends in social intelligence

- The general awareness of hydrogen as a fuel is relatively high, but understanding of different production methods and hydrogen technologies is low.
- Cost and safety are cited as the main reasons for opposition to deployment of hydrogen technologies.
- People are concerned about climate change and are fairly open to the idea of switching to low-carbon heating technologies but their understanding of how hydrogen technologies would reduce carbon emissions is low.
- Men, people with higher levels of education, younger people, and high-income groups are the most likely to be supportive of hydrogen technologies. However, home heating with hydrogen is generally not supported by experts.

Opportunities for new public engagement on hydrogen technologies

- New public engagement initiatives should consider how the environmental, economic and community benefits of hydrogen technologies should be explored with the public. Particular attention should be paid to opportunities to engage women, older people, people with lower levels of education and from lower income groups.
- There should be more studies looking at what can be done to prevent potential societal inequalities and distributional injustice caused by hydrogen technologies. How can we make sure that transition to hydrogen would not worsen the problem of energy poverty and that low-income households are supported?
- How does the merit of hydrogen compare with its alternatives, such as heat pumps?

Ocean thermal energy conversion (OTEC)

Although social research on the future of ocean thermal energy conversion highlights the importance of public acceptability in ensuring successful deployment of the technology, there are no surveys on the public's attitudes available yet. The existing literature suggests that social and ethical issues relevant to the widespread adoption of OTEC include:

- Environmental and visual impact – local communities might be resistant to large OTEC infrastructure being built in their areas based on their concerns about environmental and visual impacts.
- Spatial planning – OTEC projects might compete for space with other uses of the sea, such as fishing and tourism, which might have an impact on local communities.

Opportunities for new public engagement on OTEC

- Currently the public's opinion is absent in the conversations about OTEC. Consulting local communities about their concerns related to the deployment of the technology will help to avoid future disruptions.
- Existing literature on the future of OTEC focuses on technical issues and pathways to commercialisation. There is a need to produce non-technical information for stakeholders and potential end-users that will help to build a better understanding of the technology, so that the conversation can move beyond the small group of experts working on the scale-up of OTEC.

Fusion

Fusion energy has attracted a lot of research attention, and several recent studies looked at the public's views and their concerns about commercial-scale fusion. Due to radiation hazards being associated with nuclear energy, the main social issues around fusion are related to its environmental impact and safety, concern that the spread of nuclear technologies might contribute to the development of nuclear weapons, and worry about the feasibility of fusion technology as a source of energy.

Trends in social intelligence

- The UK public are aware of fusion energy and the level of awareness and support is increasing.
- Men and younger people are more likely to be aware of fusion energy.
- Once people are informed about the differences between nuclear fusion and fission, the support for fusion tends to increase.

Opportunities for new public engagement on fusion

- The conversation about the benefits and challenges around the deployment of fusion technology should be continued. Public engagement programmes should make sure that groups which currently feel less informed, such as women and older people, are included in the conversation.
- Most surveys and studies look at the general level of awareness and support for fusion among the public in the UK. To better understand the social issues around scale-up of fusion technology and place-based barriers, there is a need to engage local communities and ask them about the reasons for potential support and opposition, and what a UK energy strategy should look like.

Carbon Dioxide Removal (CDR)

Direct Air Capture

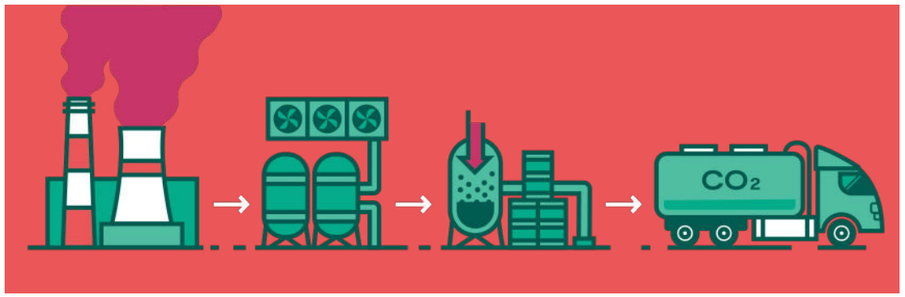
Direct Air Capture and Storage (DACS) has the potential to deliver economic and environmental benefits to the communities around it, however this would require ongoing engagement with those communities. Potential social and ethical considerations associated with DACS include safety and effectiveness, community impact, distant timescales, and concerns about its governance and cost.

Trends in social intelligence

- Different studies had different findings around people's "preferred" CDR technologies – some reported that people favoured BECCS over DACS, and some vice versa.
- People are concerned that the technology might be "too good to be true", may have high set-up costs, or be powered by fossil fuels.
- CDR technology is seen as too short-term (not addressing the underlying causes of climate change) and too long-term (not yet ready for deployment).
- Men are more likely to say they know about CCUS technologies than women.
- Public support for DACS is dependent on public confidence that it is deployed as part of a credible net-zero strategy built on accountability and transparency, rather than as a "quick fix."

Opportunities for new public engagement on DACS

- There are clear opportunities to work with the public to codesign the information they receive around DACS and other CDR technologies, and how they receive it. This engagement could provide a starting point for people to be more involved in decisions around it and how DACS is used, and should particularly focus on involving marginalized people and communities.
- Engagement should consider how DACS would fit into a much broader series of measures to mitigate climate change, and what mixture of natural and technological measures people would favour.



Speculative technologies

Solar Radiation Management

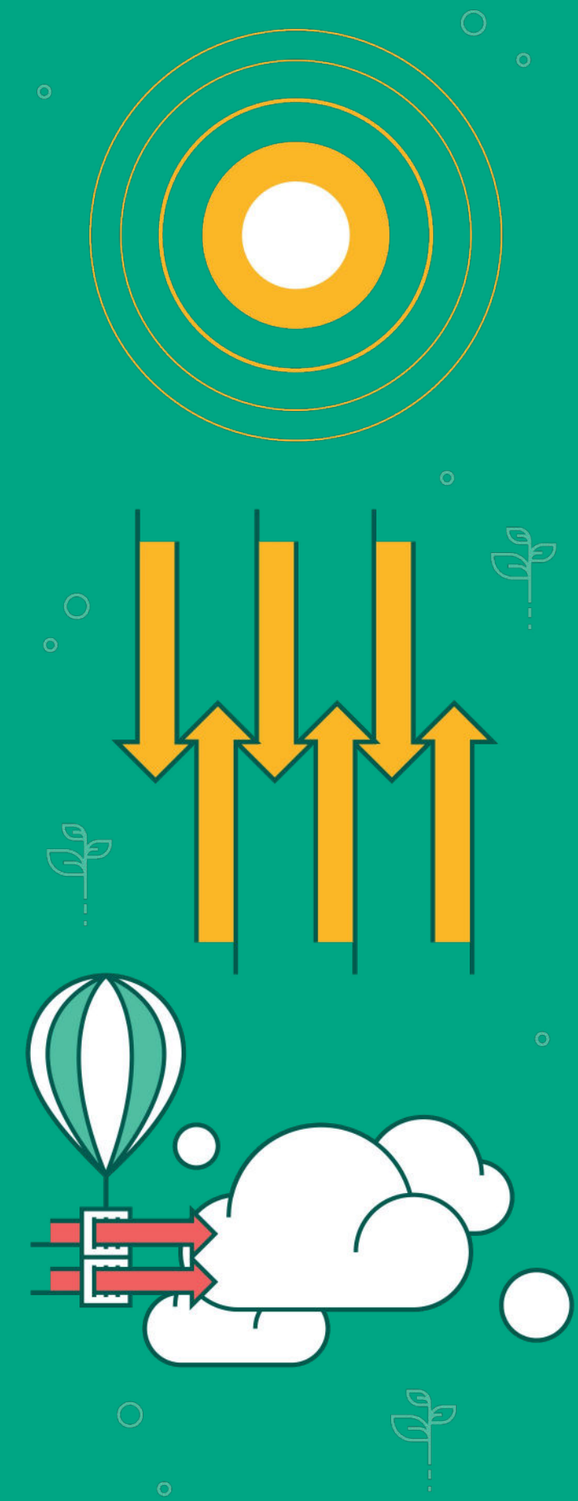
Solar Radiation Management (SRM) is an early-stage and already controversial idea. Potential social and ethical considerations associated with SRM include its effectiveness and the impact of research and testing on the planet, impact on vulnerable populations (especially those in the global south), its governance, and the fact that it does not address the cause of climate change.

Trends in social intelligence

- Very few public engagement initiatives on SRM and geoengineering have taken place in the UK in the last few years.
- Decisions around geoengineering should not be taken top-down, and people and communities should be given the information and power to participate.
- SRM is seen as a "last resort" and other adaptation and mitigation efforts should be scaled up.
- People's main concern about SRM is that the technology will be deployed without proper testing.

Opportunities for new public engagement on SRM

- There are risks with public engagement on SRM, as there are no immediate plans for policy decisions on its testing or use, so people may not feel their input is worthwhile. However, an engagement approach that develops principles could be a useful starting point, and could build upon studies from 2000 – 2014 to see if views and values have changed.



Cross-cutting findings

In this report, we have focused on four categories of climate technology, and examples within them, aiming to draw conclusions on public views and values about their implementation. We have aimed to set these technologies in context, and make clear that they are not the preferred options or the most likely options. Further information on how the technologies were identified can be found in the 'Introduction and methods' section.

Public attitudes about particular technologies do not exist in isolation from other views and values they hold, or from the social, economic, political, and cultural context at the time. The following section briefly summarises cross-cutting findings from this report, public views about topics related to climate technology, and other factors that may have influenced opinions over the period that the sources of public opinion included in this report took place.

Cross-cutting themes

We have identified three themes in public attitudes, which appear to apply across technologies. These themes are similarly found across a large body of scientific evidence on public attitudes to a wide range of technologies, both within the climate and energy sector and beyond:

Trustworthy governance, regulation, security, and safety – our analysis indicates that a technology being thoroughly tested before being deployed, having clear lines of accountability, regulation in place at an early-stage, being secure against physical and digital threats, and having no adverse impact on human, animal, or planetary health are seen as a minimum requirement for acceptability.

Technology as an unknown quantity or "get out of jail card" – our analysis indicates that people are concerned about climate change, and open to making changes in their lives, communities, and countries to adapt and mitigate changes. There is generally a low-level of awareness about how climate technology might sit alongside other adaptation and mitigation measures. There are signs that relying on what people perceive as "technical" solutions does not fit into their ideas of what a sustainable future looks like. This is a common finding across other areas of science and technology such as health, or food production – people tend to favour solutions that they perceive as "natural", or those that use existing well-known technologies. A 2021 Government survey found that 50% of people would support "an equal mix of technological and lifestyle changes" to reduce carbon emissions[1]. There are also doubts about whether these technologies will materialise and provide a "get out of jail card" – backed up by a 2022 Ipsos survey, in which less than 20% of UK adults agree that "There will be a breakthrough technology developed which will halt climate change" in 2023[2]. In some cases, higher awareness of a technology led to higher levels of concern about its deployment.

Just transition and community impact – our analysis indicates that there is an appetite from the public to have a more active role in deciding which climate technologies are used and how. There is an awareness of the potential economic gains of climate technology, but also that the profits and power gained may be distributed in inequitable ways. Crucially, there is also an awareness of trade-offs and potential adverse impacts of climate technologies for certain communities. Generally, people are more enthusiastic about technologies when there is a concrete plan in place to share the benefits with communities. We also note demographic trends about climate technology. Men, higher-income groups, and people with higher levels of qualifications tend to have more positive attitudes towards technology.

[1] HM Government. (2021). Climate Change and Net Zero: Public Awareness and Perceptions.

[2] Ipsos MORI. (2022). Global predictions for 2023.

How the UK population feel about climate change

In 2021, the Office for National Statistics included questions on people's worries about climate change, and anxiety about the future of the environment in their Opinions and Lifestyle Survey (OPN)[3]. They found that 75% of UK adults report feeling worried about climate change, and 43% feel anxious about the future of the environment. Women were more likely than men to report these feelings of worry and anxiety. Themes regarding people's worries included: impacts of climate on future generations and family; feelings of powerlessness and that the issue was out of their control; and concern about the cost of lifestyle changes that may help to address climate change. A 2022 poll by Ipsos put public concern at 84%[4].

A 2022 Axa Future Risks report finds that climate change is the top risk identified by individuals and experts[5], ranking higher than geopolitical instability, despite Russia's invasion of Ukraine. The biggest risks that respondents associated with climate were physical risks of extreme weather such as floods, drought, and wildfire. The report also finds that, compared to 2021, people report lower levels of trust in scientists (from 75% to 66%), international institutions, national authorities, civic institutions, and private companies to limit the impacts of global crises. However, generalised trust in scientists remains consistently high[6].

A regular YouGov poll asking people what they think are the "most important issues facing the country today", finds that since April 2020 at least 20% of people have listed it as a top concern[7]. Similarly, another regular YouGov poll finds that around 30% list the environment as an area that the government should spend more money on (with about 15 – 20% saying the government should spend less)[8]. A 2022 report on climate messaging and policies found that people supported measures to spend public money on preparing the UK for the impact of climate change, subsidising renewable energy, and supporting insulation and heating improvements[9].

In 2021, a Government survey on climate change and net zero found that 54% of UK adults felt that their local area was experiencing the effects of climate change "at least to some extent"[10]. In the same study, 78% said they supported the Government net zero target. A 2022 Ipsos Mori study found that 39% of people felt the Government had a clear plan to tackle climate change[11].

People see tackling climate change as a shared responsibility between governments, businesses, and individuals[12]. People are aware of particular sectors including car manufacturing, fashion, energy, and aviation needing to reduce their emissions. The ONS survey found that 33% of people think that large corporations should make changes before individuals.

[3] Office for National Statistics. (2021). Three-quarters of adults in Great Britain worry about climate change.

[4] Ipsos MORI. (2022). 8 in 10 Britons concerned about climate change – half think net zero target should be brought forward.

[5] AXA. (2022). Future Risks Report.

[6] Ipsos MORI. (2022). Ipsos Veracity Index 2022.

[7] YouGov. (2022). The most important issues facing the country.

[8] YouGov. (2022). What sector should the government spend more on?

[9] Raikes, L., & Cooper, B. (2022). Talking green: the UK survey.

[10] HM Government. (2021). Climate Change and Net Zero: Public Awareness and Perceptions.

[11] Ipsos MORI. (2022). Earth Day 2022. Public opinion on climate change: GB and the world.

[12] HM Government. (2021). Climate Change and Net Zero: Public Awareness and Perceptions.

The UK Climate Assembly, conducted in 2020, was a major public engagement process initiated by six UK House of Commons Select Committees[13], in order to give parliamentarians and policymakers access to evidence of public preferences on climate and the net zero target. A representative group of 108 members of the UK public took part in the Assembly over six weekends. The Assembly considered ten topics relating to climate and net zero:

- Underpinning principles for the path to net zero;
- How we travel on land;
- How we travel by air;
- Heat and energy use in the home;
- What we eat and how we use the land;
- What we buy;
- Where our electricity comes from;
- Greenhouse gas removals;
- The changed context created by COVID-19;
- Additional recommendations.

The Assembly showed high levels of public interest and support for policymaking to address climate change. Assembly members identified five themes that recurred across the topics[14]: education and information, fairness, freedom and choice, co-benefits, and nature.

In 2022, the Committee on Climate Change published a report which identified seven ways in which deliberative approaches could contribute to better climate policy-making[15]:

- Increasing trust in the policy process;
- Generating action;
- Ensuring representation;
- Defusing conflicts;
- Testing policy arguments;
- Assessing the full policy mix;
- Governance of new technologies.

Outside of formal public engagement or public opinion research, there have been many examples of informal or "uninvited" forms of engagement on climate change[16]. Activism has grown in prominence in the past five years, and often uses direct action tactics for engaging people with climate change issues and the associated policy decisions. Groups such as Extinction Rebellion (XR) and Just Stop Oil have brought public and policy attention, and have influenced change. For example, prior to the XR protests in 2019, the UK Government climate target was an 80% reduction in emissions by 2050, rather than the net zero target recommended by the Climate Change Committee, and there had been no commitment to run a Climate Assembly. We have not included analysis of climate activism in this report, since we focus on more formal and structured forms of public engagement.

[13] Climate Assembly UK. (2020). The path to net zero.

[14] Climate Assembly UK. (2020). The path to net zero.

[15] University of Lancaster (2022) The role of deliberative public engagement in climate policy development.

[16] Chilvers, J., Pallet, H., Hargreaves, T., Stephanides, P., Waller, L. (2022). An Observatory for Public Engagement with Energy and Climate Change. A briefing note introducing the UKERC Public Engagement Observatory.

Contexts for this research

A high proportion of the data included in this report was collected during periods of social and economic disruption (2018 – 2022). We have identified several factors that may have influenced people's views on climate technology, or may lead to future shifts in values and priorities.

The cost of energy and energy security have been major topics of public conversation and policy debate in 2021-23. Rising inflation and Russia's invasion of Ukraine have resulted in record increases in household energy and fuel bills[17], alongside reports of record profits for energy companies. As a result, 88% of adults report feeling worried about energy bills[18], and young people list "the future of renewable energy" as one of the top three issues they want governments to be working collaboratively to solve[19].

In 2021, the UK hosted the 26th United Nations Conference of the Parties (COP26), welcoming thousands of delegates from governments and communities around the world to discuss climate change and its impacts. There were many public engagement initiatives coinciding with COP26, including surveys on people's climate policy preferences and the UK's role in combatting climate change[20]. Whilst people are generally supportive of climate policies and aware of some behaviour changes that may be required, 55% say they are not confident that the UK Government will take the action required over the next few years.

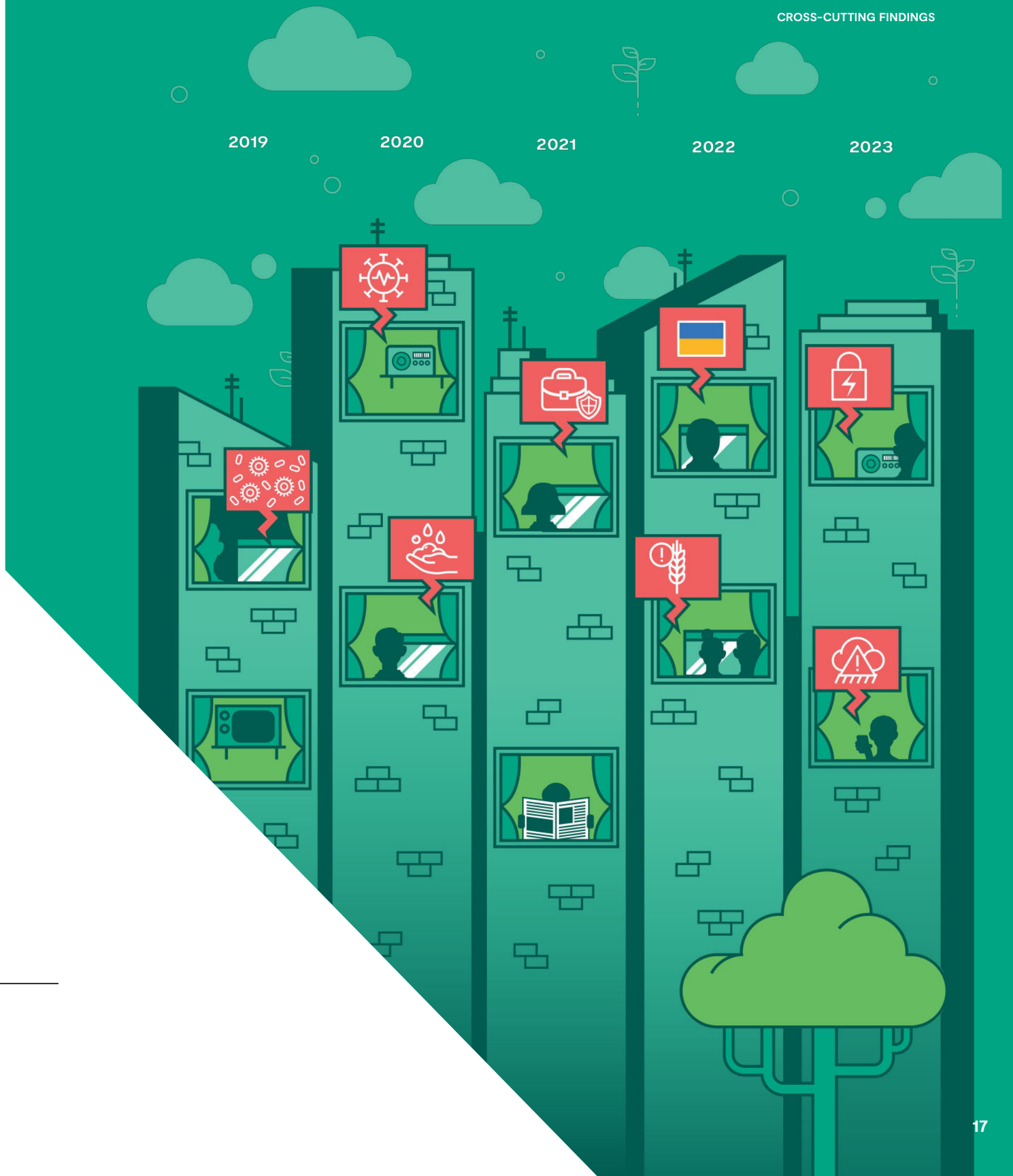
In 2022, the UK experienced several periods of extreme weather, including drought and heatwaves. In 2022, an Office for National Statistics survey found that 47% of UK adults expected to be impacted by extreme weather, and 51% thought they might be affected by food shortages.

[17] Environmental Audit Committee. (2022). Accelerating the transition from fossil fuels and securing energy supplies.

[18] Clarke, J. (2022). Almost nine in 10 UK adults worried about energy prices - survey. The Evening Standard.

[19] British Science Association. (2022). Future Forum. Creativity in STEM: young people's views on using collective collaboration to build a better future.

[20] Ipsos MORI. (2021). UK public highly supportive of COP26 goals but few expect the government to take the steps needed.



Introduction and methods

What is climate technology?

'Climate technology' is any technology that is designed to reduce greenhouse gas emissions and mitigate the consequences of climate change. The term is broad, and it incorporates a range of physical and digital technologies applied across different industries to remove emissions, help us to adapt to the impacts of climate change, and improve our understanding of the climate[21].

Climate technologies are often seen as a key element in the decarbonisation and management of the climate crisis. Increasing their uptake and making them cheaper and more accessible around the world is critical to slow down climate change and achieve the net zero emissions target. Different countries will have different pathways to net zero, depending on their existing energy mix, infrastructure, and economic position. Therefore, in this report, we aim to limit our analysis to UK-based examples and statistics.

This report focuses on early-stage or emerging climate technologies that are new or rapidly developing. Some of the technologies such as solar radiation management are speculative, and may never reach maturity or deployment. Nonetheless, each of the technologies are likely to require engagement and dialogue with the public: in many cases they might bring potential public benefit, but they can also pose social risks.

Significant investments and efforts by researchers, innovators, and entrepreneurs are underway to advance the technologies and better understand the role they could play in society's pathway to net zero, but, as with any emerging technologies, it is impossible to predict when they will be ready and how much of a socio-economic impact they are going to have.

[21] PwC. (2021). State of climate tech 2021. Scaling breakthroughs for net zero.

How were technologies chosen for this report?

There is a wide range of developing climate technologies which have the potential to address the impacts of global warming and to decarbonise industry. Different technologies offer possible solutions to the challenges of energy supply, transportation, built environment, agriculture and manufacturing.

To identify climate technologies to include in this report, we followed a three-step process:

- **Indexing** – we scanned multiple lists of early-stage and emerging climate technologies that have been compiled by government departments and relevant research groups (for example, Government Office for Science[22], Grantham Institute at Imperial College London[23], and Stanford Social Innovation Review[24]) and identified technologies that appeared across several lists;
- **Consultation** – we consulted with experts in climate technologies, science and technology policy, and social impacts of science and technology;
- **Prioritisation** – we conducted initial research to find out which technologies have been covered by recent opinion polls and surveys, and short-listed technologies with different applications and at different maturity levels to showcase the breadth of climate technologies being developed and the different stages of their readiness.

By including technologies in the report, we do not intend to suggest that they are the most promising or most likely to reach widespread use. Among the technologies considered for inclusion in the report were two-way charging electric vehicles, organic solar voltaics, vertical and urban farming, sustainable aviation fuels, and low greenhouse gas proteins. During 2021 and 2022, there has been significant investment in energy supply technologies, in part due to economic and geopolitical changes[25]. Reflecting this, two of the three categories we selected for the report are related to energy supply.

During the consultation phase, we continually heard that "the technologies which will accelerate our progress towards net zero already exist, they just aren't being deployed". This view was particularly relevant to addressing the short-term challenge of energy security, where new technologies have been positioned by policy makers as a "silver bullet" solution, despite existing energy sources and behavioural changes being a cheaper and quicker measure to implement. Experts cited onshore renewables and reductions and demand-side changes (such as reductions in heat and transport use) as examples. There is a breadth of public dialogue and engagement about these existing technologies, which we briefly summarise in 'Detailed findings'.

[22] Government Office for Science. (2021). Research at GO-Science - Government Office for Science - GOV.UK.

[23] Grantham Institute. (2022) Next generation climate mitigation technologies.

[24] Green Biz. (2020). This is climate tech.

[25] UK Tech News. (2022). UK must invest in green tech to 'future-proof' economy, says Kemi Badenoch.

What public opinion sources were used in this report?

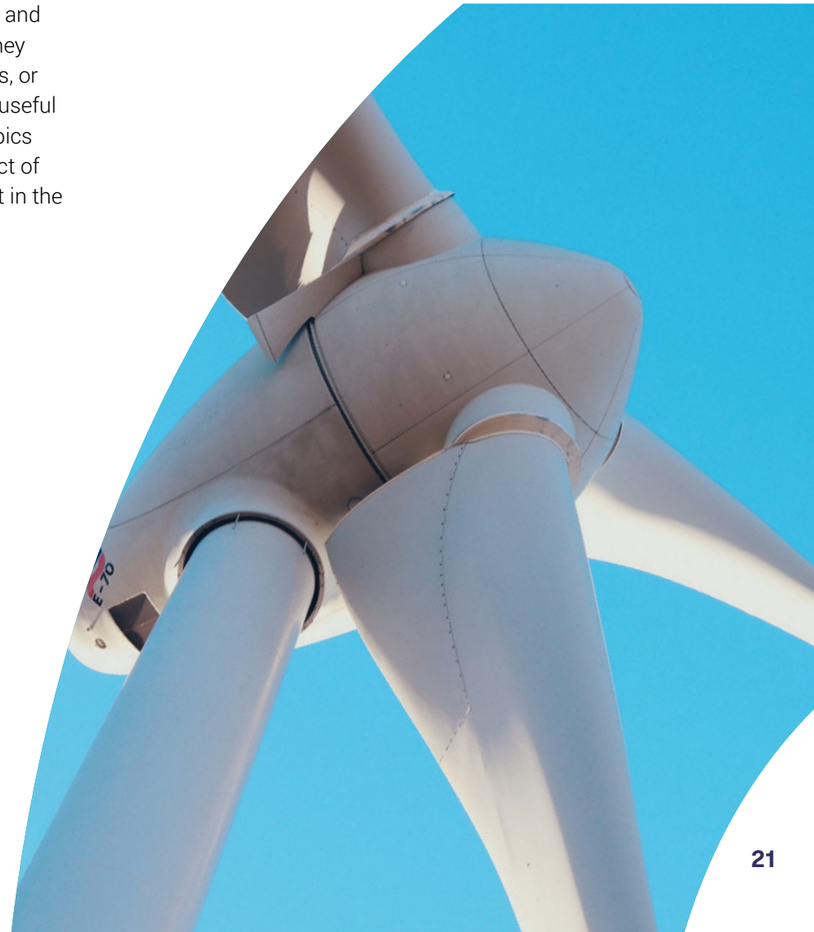
To learn about the public opinion on climate technologies, we analysed recent surveys, reports, polls, and social research on the seven climate technologies. We did not commission any new research as part of this process.

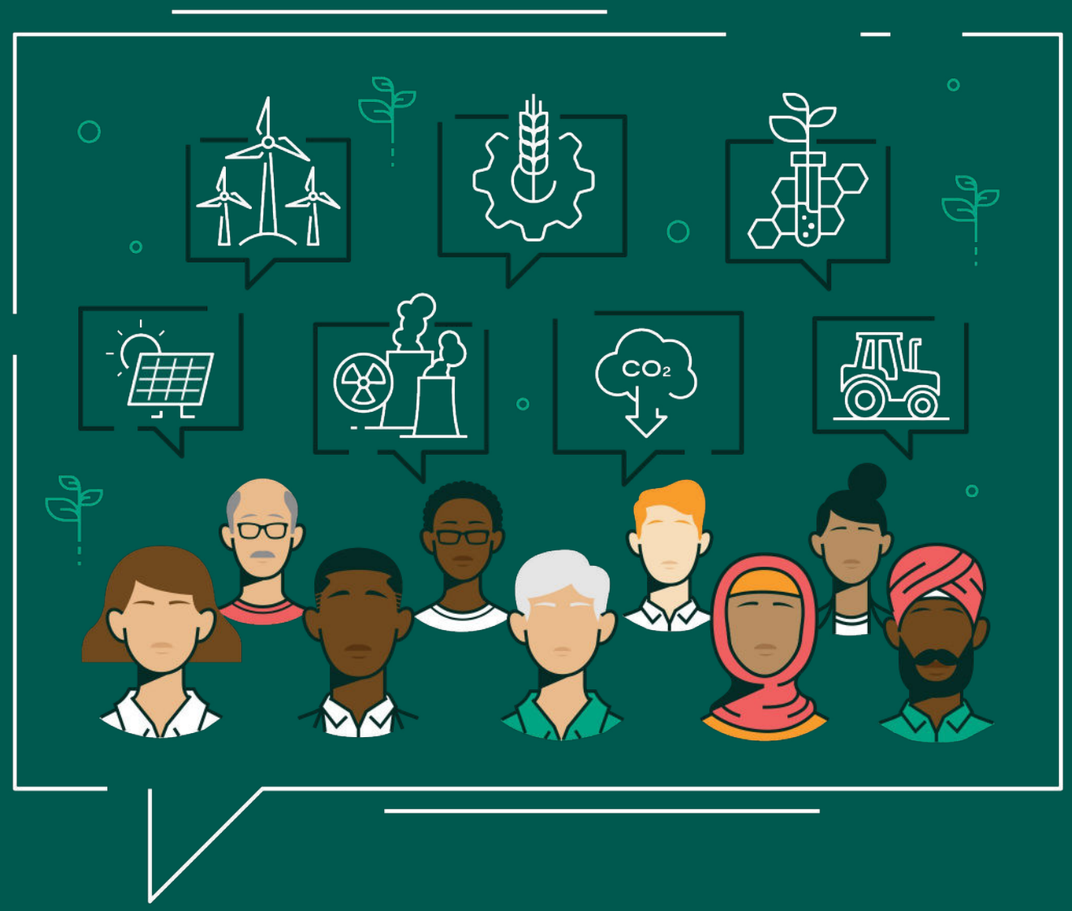
Our inclusion criteria were:

- Publicly available data;
- UK-focused, or demonstrably transferrable to UK;
- Transparent about its sampling procedure and methods;
- Analysed since 2018.

Most of the research we included in this report is in the form or surveys, or small focus groups and case studies. Surveys, which involve standardised questions and responses, are limited in how much they can tell us about public values, actions, or experiences. However, they provide a useful starting point for identifying which topics and technologies should be the subject of more in-depth qualitative engagement in the form of deliberative dialogue.

For less mature technologies which have not been covered by sources in the UK yet, we analysed international sources and highlighted it in the specific chapter. However, it is important to note that the challenge of transferability between contexts and communities limits the conclusions that we were able to draw from international research, or specific user-group data. As climate technology infrastructure is more likely to be built in certain areas, it is important to include geography in reporting and analyse the impact the technology might have on local communities. Another limitation we encountered while compiling this report is the sample sizes which are often not large enough to understand the opinions of traditionally marginalised groups, such as racially minoritized groups or disabled people.





Detailed findings

Public opinion about existing climate technologies

In this report, we analyse public opinion on climate technologies that are likely to be the topic of UK policy discussions and decisions in future. However, there are several climate technologies that are already at the implementation stage, or are the current "best available option". Moreover, during our expert consultation phase, we heard that existing technologies could be cheaper, faster, and just as effective as emerging options.

Analysis of public views and values around existing technologies may give indications of how people will feel about future climate technologies and the social and ethical issues that accompany them.

Here we briefly summarise views on four existing climate change adaptation and mitigation technologies, and the themes that have appeared regularly during public dialogues on climate technology.

Renewable energy

Some technologies are more likely to be seen as "natural solutions" and are usually viewed positively – renewable energy is one example of this. Many surveys show that there is broad public support for existing renewable energy, with 79% of survey respondents saying they support renewable energy in a 2021 Government study[26]. This support carries to specific types of renewable energy, with 84% supporting solar energy, 76% supporting offshore wind, 70% supporting onshore wind, 75% supporting tidal power, and 67% supporting biomass.

Food production and biotechnology

A Food Standards Agency scoping study around public attitudes to food technologies such as GM, bioengineering, meat from cloned animals, and cultured meat, shows that there is no single picture of people's views, and that attitudes vary depending on the application and context of the technology[27]. Factors that influenced opinion included cost, regulation, safety, past experience, knowledge of the technology, and framing of information. Similarly, the 2019 Public Attitudes to Science survey found that technologies that involve minimal intervention such as making dietary changes, or using satellite data to improve crop yields were more likely to be supported than editing genes across species or cultivating meat[28]. However, views can change once tangible and clear examples of gene editing and other biotechnologies are presented to people.

[26] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Energy Infrastructure, and Energy Sources, Spring 2022, UK.

[27] Food Standards Agency. (2020). Consumer Attitudes Towards Emerging Technologies.

[28] Department for Business, Energy & Industrial Strategy. (2020). Public Attitudes to Science 2019.

Biodiversity and land use

A 2019 Government study on engagement with the natural world found that 90% of respondents were concerned about damage to the environment, and that awareness of biodiversity loss had risen from 49% in 2014 to 62% in 2019[29]. People generally see the natural environment as something to be protected, enjoyed, and managed holistically so that ecosystems remain in balance.

Social and ethical themes in public opinion

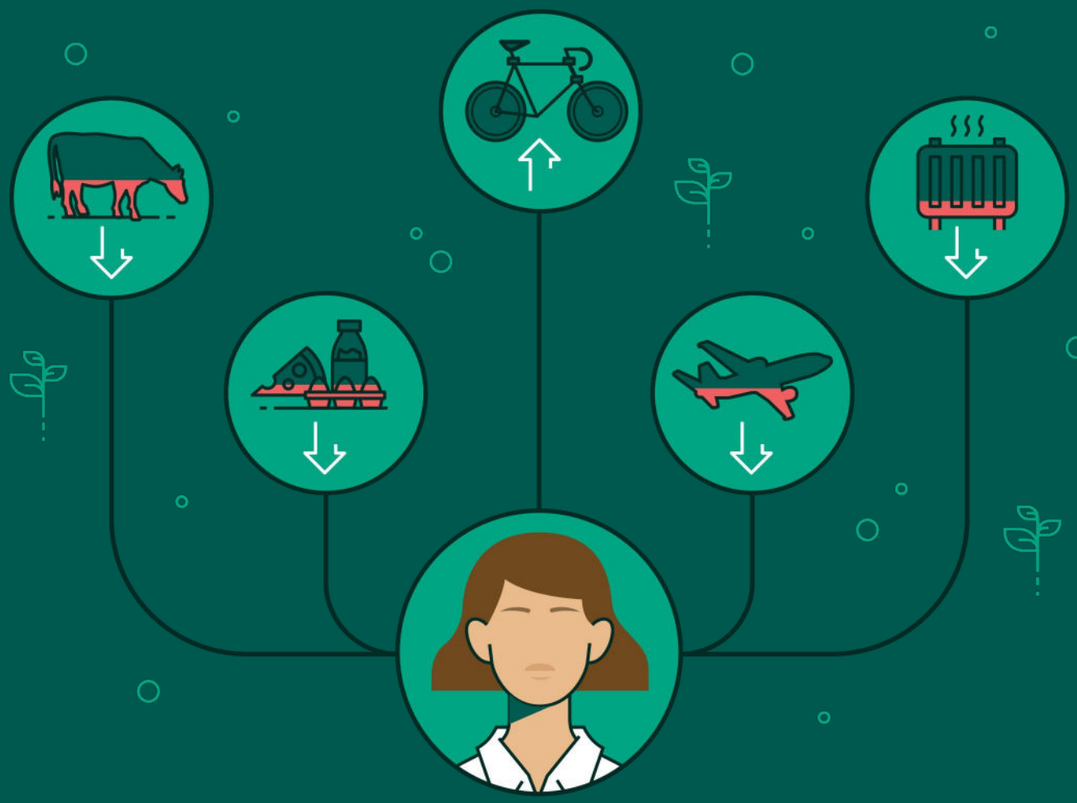
Analysis of 24 Sciencewise public dialogues on climate technologies such as low-carbon heating, nuclear power, and renewable energy identifies four key themes[30].

1. Solutions which the public perceive of as 'natural' are often preferable to solutions which are seen as higher technology and sometimes unproven;
2. Citizens see a role for climate technologies in achieving what nature can't;
3. Citizens are more accepting of climate technologies where clear benefits for local communities (e.g. jobs) are identified;
4. Consumers need to be supported by government to help reach net zero.

We noted similar themes in public attitudes to emerging climate technology as for existing climate technology. In addition to the above, cost, safety, and regulation were key considerations for people.

[29] Natural England. (2019). Monitor of Engagement with the Natural Environment – The national survey on people and the natural environment.

[30] Sciencewise. (2023). How can society live sustainably?



The role of behaviour change

Both existing and emerging climate technologies have an important role to play in reducing carbon emissions, but to address climate change and achieve net zero targets by 2050, deployment of technologies needs to be supported by behaviour change. Although this report focuses on emerging climate technologies and what is known about the public attitudes towards them, it is important to note that this does not mean that technologies alone can deliver net zero emissions. This section explores the role of behaviour change in achieving net zero targets, and what is known about the public's views on their own responsibility to address climate change.

What is behaviour change and how does it impact net zero targets?

In the context of net zero, behaviour change refers to lifestyle changes, and technology adoption and use, which result in reducing carbon emissions[31]. Examples include reducing the number of flights taken, turning down heating, or reducing the amount of red meat and dairy products in one's diet. Various experts and organisations who studied the UK's potential pathways to net zero have argued that the role of behaviour change is a key element in reducing emissions and delivering net zero[32]. The Climate Change Committee (CCC) in their 2021 report to Parliament on progress in reducing emissions stated that the public must be brought along with the transition to net zero and supported in making low-carbon choices[33].

Drawing on the assessment by the CCC, in October 2022 the House of Lords Environment and Climate Change Committee published a report on behaviour change for climate and environmental goals where they identified that 32% of emissions reductions up to 2035 required actions by individuals to adopt to low-carbon technologies, choose low-carbon products, and reduce carbon-intensive consumption[34]. The International Energy Agency's estimation of the role of behaviour change in achieving net zero is even greater. In their roadmap to net zero by 2050 for the global energy sector, the IEA suggests that 55% of emissions reductions require a combination of the deployment of low-carbon technologies and active involvement of citizens and consumers[35].

The importance of sustainable choices by individuals, households and businesses is also acknowledged in the government's Net Zero Strategy published in 2021[36]. The strategy sets out the government's approach to encouraging behaviour change and explains that it is underpinned by six principles:

- Minimise the 'ask' by sending clear regulatory signals,
- Make the green choice the easiest,
- Make the green choice affordable,
- Empower people and businesses to make their own choice,
- Motivate and build public acceptability for major changes,
- Present a clear vision of how we will get to net zero and what the role of people and business will be.

More recently, the Independent Review of Net Zero published in January 2023 presented public engagement on net zero as the missing piece of the puzzle[37]. The review points out that almost half of the measures proposed in the Net Zero Strategy require actions from individuals and calls for greater action on supporting people to make green choices.

[31] Ipsos MORI. (2022). Net Zero Living.

[32] For example, Nelson, S., Allwood, J. (2021). Technology or Behaviour? Balanced Disruption in the Race to Net Zero. Energy Research and Social Science. , Climate Change Committee. (2021). Progress in reducing emissions.

[33] Climate Change Commitee. (2021). Progress in reducing emissions.

[34] House of Lords Library. (2022). Net zero and behaviour change.

[35] Intenational Energy Agency. (2021). Net Zero by 2050. A Roadmap for the Global Energy Sector.

[36] HM Government. (2021). Net Zero Strategy: Build Back Greener.

[37] Skidmore, C. (2023). Mission Zero. Independent Review of Net Zero.

What do we know about public opinion on behaviour change?

Existing surveys suggest that the public are concerned about climate change, and they recognise that they have a role to play in addressing it[38]. The BEIS Public Attitudes Tracker from Autumn 2022 found that 85% of respondents agree that climate change effects can be reduced if everyone does their bit, and 76% agree that they personally could make changes that would help to reduce climate change[39].

However, a study of public attitudes to net zero policies by Ipsos Mori found that although the public are concerned about climate change, this alone is not sufficient to inspire significant behaviour change[40]. The study reports that the public are generally in favour of net zero policies, but when potential lifestyle and cost implications are presented, the support drops sharply. This suggests that further engagement with the public on the importance of societal changes required to reach net zero, and the potential risks associated with inaction, is needed.

The study also found that when co-benefits of net zero policies, such as job creation or enhanced air quality, are identified, public support tends to increase. Drawing on insights from behavioural science, the report highlights the importance of engaging the public in the decision-making on net zero early on, as it helps provide context for specific behaviour changes and create a sense of ownership.

Transport

With transport being responsible for around one fifth of global carbon emissions[41], it is one of the most polluting sectors and requires significant behaviour changes from the public to reach net zero targets. Main actions associated with decarbonisation of the transport sector are:

- Walking, cycling, or travelling by public transport instead of driving,
- Purchasing and using zero-emission vehicles,
- Reducing the number of international and domestic flights.

Evidence suggests that there is an increasing number of people who claim to travel less for climate change[42]. BEIS Public Attitudes Tracker found that in Summer 2022 53% of respondents choose to walk or cycle instead of using a car, 34% choose to use public transport instead using a car, and 10% drive an electric or hybrid car[43]. When asked about support for net zero policies related to travel and mobility, Ipsos Mori found that 68 % supported frequent flyer levies, 62% supported electric vehicle subsidies, and 53% supported creating low traffic neighbourhoods[44]. However, when financial implications of the policies were introduced, for example, paying more for flights, paying more to drive their petrol or diesel car, or paying more council tax, the support for these policies fell to 32%, 34%, and 18% respectively.

Energy

Long-term and sustainable changes in behaviour are needed to reduce energy consumption and associated carbon footprint. To reach net zero, it is essential that individuals and households:

- Use low-carbon heating,
- Use energy efficiency measures,
- Purchase and use energy efficient appliances.

Although people are aware that the way they heat homes will need to change in order to reach net zero targets, data suggests that only a minority of people are willing to install low-carbon heating[45]. Concerns about cost of installation, a preference to wait to see how the technology develops in time, and a perception that it might not be possible to install in their home are cited as the main reasons for being unlikely to install low-carbon heating. Other barriers include supply chain issues with low-carbon heating[46], availability and skills of contractors to install the systems.

When asked about their support for phasing out the sale of coal and gas boilers through a complete ban, 62% of the public supported the policy. However, if the policy meant that they personally wouldn't be able to install a new gas boiler in their home, or that they would have to pay more for installing an alternative heating system, the support decreased to 42% and 31% respectively.

[38] Ipsos MORI. (2021). Net Zero policies. Ahead of COP26, how do the UK public view net zero policies?

[39] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Net Zero and Climate Change, Autumn 2022, UK.

[40] Ipsos MORI. (2022). Net Zero Living.

[41] Our World in Data. (2020). Cars, planes, trains: where do CO2 emissions from transport come from?

[42] Tony Blair Institute for Global Change. (2021). Planes, Homes, and Automobiles: The Role of Behaviour Change in Delivering Net Zero.

[43] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Net Zero and Climate Change, Autumn 2022, UK.

[44] Ipsos MORI. (2022). Net Zero Living.

[45] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Heat and Energy in the Home, Summer 2022, UK.

[46] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Heat and Energy in the Home, Summer 2022, UK.

Food

Because animal-sourced foods, such as meat, fish, and dairy, use much more land and water, they are responsible for much more greenhouse emissions than plant-based foods[47]. The main behaviour changes associated with sustainable diets are:

- Reducing meat and dairy consumption, and
- Reducing food waste.

Research suggests that the link between dietary choices and climate change is less clear to the public than link between transport or energy and climate change[48]. When asked about lifestyle changes that have the biggest impact on tackling climate change, people usually list walking, cycling, and using public transport[49]. Fewer respondents are aware that eating less red meat and reducing food waste are effective ways of reducing greenhouse gas emissions[50].

In their study of attitudes to net zero policies, Ipsos Mori found that 56% support increasing vegan and vegetarian options in public sector food provisioning, but the support falls to 26% if the policy meant that the public would have to pay higher taxes to fund the policy[51]. Another food-related policy explored in the study was higher taxes on red meat and dairy products. The policy was supported by 47% of respondents and opposed by 32%, which was the highest level of opposition of all the policies tested in the study. Once the lifestyle and financial implications of the policy were introduced (e.g. not being able to eat as many meat and dairy products and paying more for them), the support fell to 34% and the opposition increased to 43%.

Material consumption

To achieve environmental goals, it is essential that individuals and households change their behaviours related to material consumption. Extraction, processing and transport of materials are depleting physical resources and producing significant carbon emissions[52]. Behaviour changes needed to accelerate the transition to circular economy include:

- Reducing overall consumption,
- Increasing recycling and upcycling, and
- Purchasing products with a low carbon footprint.

When asked about their support for changing product pricing to reflect how environmentally friendly the products are, 62% of the respondents supported the policy[53]. The support increased to 69% when lifestyle implications, such as not being able to buy as many products as currently, were introduced. This might suggest that the public are aware of waste-related challenges and willing to support sustainable consumption.

[47] Marteau, T. M., Chater, N., Garnett, E., E. (2021) Changing behviour for net zero 2050. BMJ.

[48] Centre for Climate Change and Social Transformations. (2021). Public perceptions of climate change and policy action in the UK, China, Sweden and Brazil.

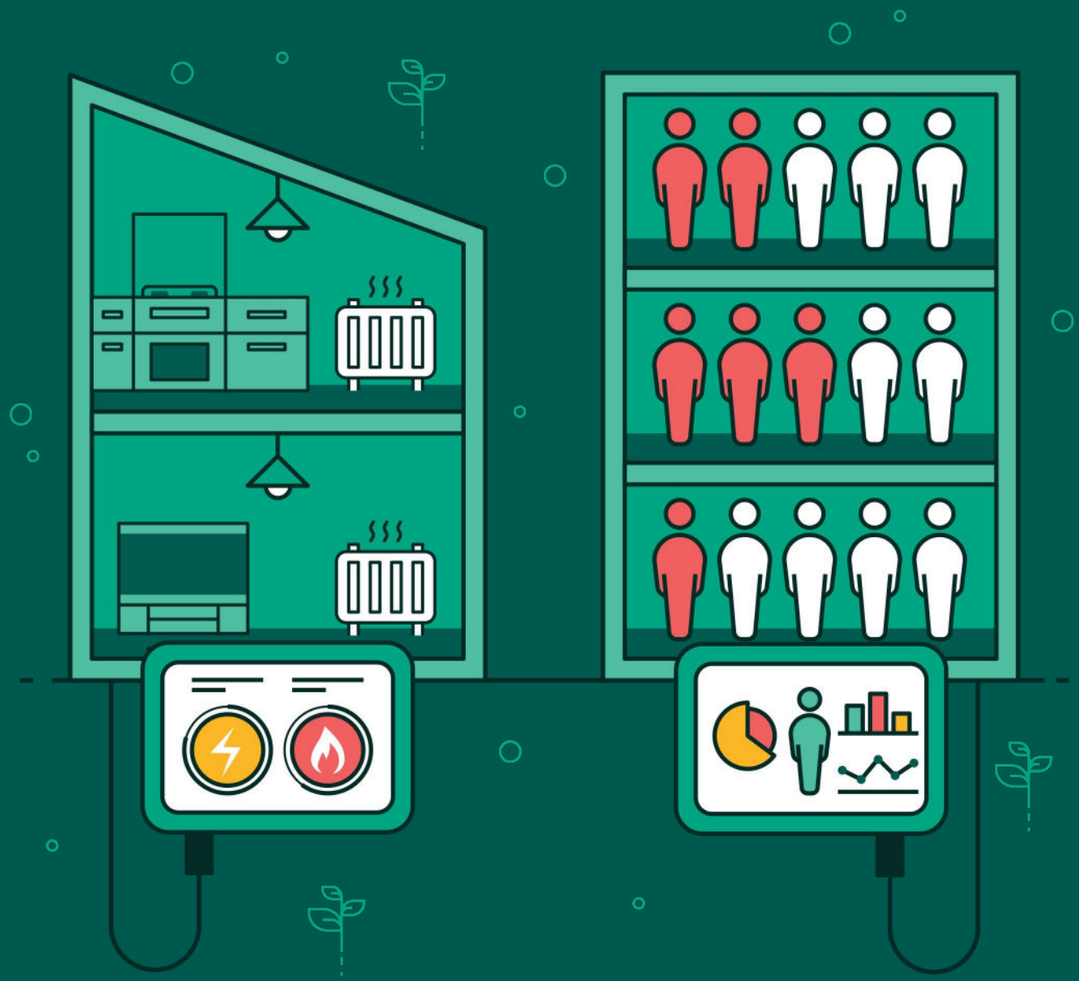
[49] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Net Zero and Climate Change, Autumn 2022, UK.

[50] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Net Zero and Climate Change, Autumn 2022, UK, and Centre for Climate Change and Social Transformations. (2021). Public perceptions of climate change and policy action in the UK, China, Sweden and Brazil.

[51] Ipsos MORI. (2022). Net Zero Living.

[52] Whitmarsh, L., Capstick, S., Nash, N. (2017). Who is reducing their material consumption and why? A cross-cultural analysis of dematerialization behaviours. Phil. Trans. R. Soc. A.

[53] Ipsos MORI. (2022). Net Zero Living.



Energy monitoring

Energy monitoring technology aims to mitigate the impact of climate change by reducing energy usage, increasing energy efficiency, and supporting the introduction of low- or zero-carbon energy sources.

The following section explores what is known about public views and values around energy monitoring. We focus on two interrelated scales of monitoring:

- Smart grids, where data from households is centralised and analysed so that the energy system can respond to and drive supply and demand;
- Household and workplace monitoring technologies, where data collection and analysis is related to individual buildings or settings.

Smart grids

What are 'smart grid' technologies?

Note that this section covers energy infrastructure, and that household monitoring such as smart meters is covered elsewhere in this report.

Smart grids are based on the traditional model of the electricity grid which delivers power to millions of homes and businesses. In a smart grid, the electricity grid is fitted with automatic control and monitoring systems, so that is responds "intelligently" to supply and demand[54]. Smart grids are expected to play a key role in enabling the UK to meet its 2050 Net Zero target, by reducing emissions released by energy and improving the efficiency of energy systems. Over the coming years, there are plans to introduce a network of technologies that monitor and control the supply of power across the UK electricity grid in response to the usage and behaviours of users[55]. As electric appliances (e.g. refrigerators, dishwashers, ovens, and washing machines) will become smarter, it will be possible to connect them to a smart grid. This means that the automated control of the smart appliance energy consumption will be provided by the service.

[54] Majeed Butt, O., Zulqarnain, M., Majeed Butt, T. (2021). Recent advancement in smart grid technology: Future prospects in the electrical power network. Ain Shams Engineering Journal.

[55] Department of Energy & Climate Change. (2014). Smart Grid Vision and Routemap, and Connor, P. M., Baker, P.E., Xenias, D., Balta-Ozkan, N., Axon, C.J. & Cipcigan, L. (2014). Policy and Regulation for Smart Grids in the United Kingdom. Renewable & Sustainable Energy Reviews.

Smart grids aim to support the take-up of low-carbon technologies such as electric vehicles and heat pumps, which are increasing demand on the electricity network. Similarly, smart grids can be used to introduce low-carbon or renewable energy generation such as solar photovoltaics and onshore wind, which cannot always be quickly ramped up to balance demand in the grid and face challenges of intermittency of supply which can be (partially) addressed through grid flexibility.

The key components and changes that are required for smart grids are:

- Installing smart gas and electricity meters in millions of homes and businesses to monitor people's usage;
- Connecting the meters to the Data Communications Company (DCC) to transmit and receive data;
- Ensuring distribution network operators (DNOs) are prepared to manage energy supply and demand at a local level;
- Transitioning DNOs to distribution system operators (DSOs);
- Connecting across the whole system[56].

The different components and technologies used in a smart grid are at different stages of technological readiness. The main challenges to installing and maintaining a smart grid are related to synchronisation, interoperability, and cybersecurity, rather than technology development[57].

The UK Smart Grid Routemap identifies some potential benefits of smart grids:

- For individuals:
  - Opportunities to save money on energy bills e.g. making energy cheaper at times when it is more abundant to encourage people to use more high energy appliances like washing machines at these times;
  - More control over how energy is managed;
  - Better integration across products and services;
- For local communities:
  - Employment opportunities in creating and managing smart grid infrastructure;
  - Improved infrastructure for low-carbon technologies;
- For the UK:
  - Improved energy reliability and security;
  - Ability to target initiatives to reduce emissions.

In 2014, the UK Government published a Smart Grid Vision and Routemap[58]. This was followed up by an 'Energy White Paper'[59] and 'Energy digitalization strategy'[60] in 2021. The UK's progress towards implementing smart grids was slowed by the COVID-19 pandemic in 2020-21. It is estimated that innovation in power grids (infrastructure, transmission, and distribution) and flexible power (such batteries and demand side response) will require £10.6bn funding per annum up to 2030[61] and that the smart grid market will witness 3% annual growth over the next five years[62].

[56] UK Power Networks. (2022). Placing customers and communities at the heart of net zero. Business plan 2023-2028.

[57] Thales. (2021). Smart grid technology: benefits and security challenges.

[58] Department of Energy & Climate Change. (2014). Smart Grid Vision and Routemap.

[59] HM Government. (2020). Powering Our Net Zero Future. Energy White Paper.

[60] Department for Business, Energy, and Industrial Strategy. (2021). Digitalising our energy system for net zero. Strategy and Action Plan 2021.

[61] PwC. (2020). Unlocking capital for net zero infrastructure.

[62] Mordor Intelligence. (2022). United Kingdom Smart Grid Market - Growth, Trends, Covid-19 Impact, and Forecasts (2023-2028).

Social and ethical issues in smart grids

Public engagement is key to the success of smart grids, since the technology relies heavily on community transformation, new models for energy systems in which people may have a larger role, and on people installing, understanding, and using smart meters in their homes. Potential social and ethical risks associated with smart grids include[63]:

- **Personalisation, privacy, monitoring and data usage** – data-driven systems are more effective the more data they have access to. It is possible that governments or energy companies will use smart grids to justify collecting more data on citizens, which they may not share back with users. However, increased data sharing and collection could lead to a much more effective system. Public views on, for example, the trade-offs between data privacy and sharing, and an effective system would be valuable.

- **Effectiveness and personal responsibility** – as the system is introduced, consumers may have worries about consistency of energy supply, and whether the new system is better than the current grid. Although they could enable users to have more flexibility and control of their energy usage, it is possible that smart grids will have little effect on consumer behaviour. Alternatively, users may feel like they are being held responsible for their energy usage.

- **Initial cost** – customers may fear that they will bear most of the initial costs of smart grids (for example, installing power outlets for electric vehicles), and that the promised cost-savings will not outweigh them. However, a more decentralised system could enable smaller energy companies to reenter the market.

- **A just transition** – although smart grids will potentially enable a much more active role for people, certain communities may benefit more than others (or more quickly than others). Examples include community-led systems often being associated with affluent communities[64], or users with more experience or access to IT systems (usually younger, more affluent people) seeing more benefit from smart grid technologies.

[63] Milchram, C., Van de Kaa, G., Doorn, N., Künneke, R. (2018). Moral Values as Factors for Social Acceptance of Smart Grid Technologies. Sustainability.

[64] Johnson, V., Hall, S. (2014). Community energy and equity: The distributional implications of a transition to a decentralised electricity system. People, Place and Policy.

Findings

Despite the growing investment and rollout of smart grids and associated technologies in the UK, we found no major UK-based public engagement initiatives have taken place over the past five years. **Most analyses of smart grids are technical in focus, and studies centre on stakeholder views of smart grid feasibility, environment, supply security, data security, governance, finance, user engagement, and equity.**

A 2022 UK study[65] conducted in-depth interviews with industry experts alongside nine 'interested citizen' participants. The research presented interviewees with up to eight options for potential smart grid operating models, each requiring different social, technical, and political choices. The study showed that **no single future vision for smart grids was favoured by all actors and all sectors of their study. Participants raised concerns about data privacy, security, and the feasibility of large-scale citizen engagement** (which they felt may in reality be limited to a small cohort of active citizens); but **participants were positive about more local, decentralised, democratic energy systems.** The research did not attempt to engage with people who had not encountered or formed views of smart grids, and noted that future engagement must be ongoing, and involve a more diverse range of viewpoints.

A 2023 literature review on social science and smart grids[66] found **a lack of studies** on energy democracy, tensions between centralization and decentralisation, vulnerable consumers, reasons for non-participation, and geographies of smart grids.

We found two studies which explored **energy storage technologies**, which are designed to optimise the energy grid and support electrification. One study looks at media coverage of storage technologies in the UK and Canada[67]. Another study led by researchers at Cardiff University involves four workshops which ask groups of the public to explore the acceptability of storage technologies[68]. They report that participants in the workshops were **largely unaware of the future role of storage technologies or the need for energy flexibility.** The researchers found that **acceptability is highly context-specific**, that no technologies were seen as totally acceptable or unacceptable, and that participants organised the perceived risks and benefits of storage technology around six themes: aesthetic and spatial impacts, efficiency, environment and sustainability, reliability, safety and technological progress. Separate to the technological risks and benefits, participants were concerned with fairness and governance.

The following insights are mostly based on international research, or UK-based engagement pre-2018.

Survey data from a community in upstate New York (USA) compared social acceptance of smart grid technologies prior-to and after a rollout of a trial grid system[69]. The survey asked about acceptance and support for four aspects of smart grids, and found that **acceptance of the technology either remains steady or declines over time.** The study also found that **the factors that shape people's acceptance of smart grids, such as procedural fairness, climate change risks perception, and price consciousness, also change over time.**

A survey by the University of Porto[70] sought to understand user behaviour in smart grid systems, and found that 95% of the participants would accept the control of at least one electrical appliance by an external entity (the appliances they were most happy to be controlled remotely were refrigerator, the washing machine cycle, and the lighting of the house; they were least likely to agree to cede control of the mobile phone charger and the cooling system of the house). They also found that **92.9% would be willing to plan their energy consumption in case of applying hourly energy prices.**

Opportunities for new public engagement on smart grids

- The conversation around decentralisation of energy control and supply could be scaled up. Public engagement could focus on community-level engagement in different areas of the UK, and explore which systems they would favour and why.
- Engagement should particularly focus on vulnerable consumers and communities – for example people who are not connected to the electricity grid, or people who are less able to take advantage of 'off-peak times'.
- Few surveys look at data governance alongside smart grid governance, and it would be helpful to explore how people's views on data privacy apply in this context.

[65] Hargreaves, N., Hargreaves, T., Chilvers, J. (2022). Socially smart grids? A multi-criteria mapping of diverse stakeholder perspectives on smart energy futures in the United Kingdom. Energy Research & Social Science.

[66] Kojonsaari, A. R., Palm, J. (2023). The development of social science research on smart grids: a semi-structured literature review. Energy, Sustainability and Society.

[67] Gasnowski, S., Rowlands, I. H. (2020). Read all about it! Comparing media discourse on energy storage in Canada and the United Kingdom in a transition era. Energy Research & Social Science.

[68] Thomas,G., Demski, C., Pidgeon, N. (2019). Deliberating the social acceptability of energy storage in the UK. Energy Policy.

[69] Budgen,D., Stedman, R. (2021). Unfulfilled promise: social acceptance of the smart grid. Environmental Research Letters.

[70] Gomes, L., Coelho, A., Vale, Z. (2023). Assessment of Energy Customer Perception, Willingness, and Acceptance to Participate in Smart Grids—A Portuguese Survey. Energies.

Household and workplace monitoring

What are 'household and workplace monitoring' technologies?

Note that this section covers household monitoring such as smart meters, and that broader energy infrastructure is covered elsewhere in this report.

Household and workplace energy monitoring is usually achieved by sensor technologies that track indoor environments and then pass that data to a system that controls functions like heating and air conditioning. The past decade has seen a major increase in sensor-based 'Internet of Things' (IoT) devices in homes and workplaces.

One of the most common monitoring technologies is smart meters, which replace traditional electricity and gas meters in homes. Smart meters alongside in-home displays offer customers real-time tracking of energy usage, but also help prepare UK infrastructure for a smart grid, in which user data feeds into a more flexible and efficient energy system.

Data collected by sensor technologies in homes and offices can be used in multiple ways, including[71]:

- To control the system it is collecting data from;
- To create an accurate national model of energy usage;
- To create digital models which predict energy usage, or propose alternative energy systems;
- To identify faults or inefficiencies in the energy system;
- To give the customer insight into and hence more control of energy use in the home;
- To enable automatic energy pricing and trading.

Similarly to smart grids, household and workplace monitoring involves mostly mature technologies with main challenges related to accuracy, security, and regulation.

[71] UK Parliament POST. (2021). Energy Sector Digitalisation. POSTNOTE.

Uptake of household and workplace monitoring

Sensor and data-driven technologies for energy monitoring are likely to become more advanced and more widespread, because they underpin many infrastructure changes that are required to meet net zero targets.

Following the COVID-19 lockdowns in 2020-21, the usage and occupancy of many buildings, particularly office buildings has changed - an increase in remote working means that the 2022 UK average office occupancy rate is around 30%, compared with 60% in early 2020[72]. This could lead to demand for systems that track building occupancy, and use the data to inform environmental controls so that businesses can save money and energy.

Russia's invasion of Ukraine in 2022 increased people's awareness of energy security and fluctuating energy costs. This may have increased demand for the industry rollout of smart meters which help monitor energy costs and give more accurate bills. In September 2022, 30.3 million smart and advanced meters were in homes across the UK, compared with 21.6 million a year earlier[73].

Future UK energy systems that rely on household and workplace monitoring might involve more widespread uses of dynamic pricing, enabling people to store or return power to a smart grid (for example, two-way charging of electric vehicles). The Energy Systems Catapult Living Lab is trialling smart home technologies, services, and products across 1500 interconnected homes in the UK[74].

[72] Financial Times. (2022). England's stock of office space falls at fastest rate for 20 years.

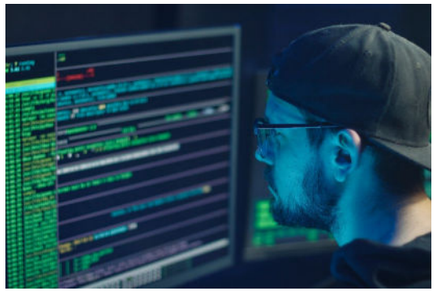
[73] Department for Business, Energy & Industrial Strategy. (2022). Information about the Smart Meters Statistics in Great Britain.

[74] The Energy Systems Catapult. (2023). Living Lab.

Social and ethical issues in household and workplace monitoring

- **Surveillance and cyber security** – data-driven systems could be vulnerable to attack, which would put user data and energy supply at risk. Furthermore, particularly in workplace settings, technologies that monitor occupancy could be used to track the whereabouts and habits of workers.

- **Sensitive information and third-party data linking** – people may have concerns about the data being collected from them and how it is used and governed by businesses, government, and regulators. Data could be used for predictions based on previous behaviours or patterns, which may prove inaccurate or discriminatory. There could also be concerns that the monitoring could lead to people's environment being controlled in ways that they believe might impact their health.



- **Empowerment, participation, and user habits** – household monitoring gives people access to data that may not previously have been available or usable for them; it can contribute to people feeling like they are 'doing their bit' by reducing energy consumption. However, it could also lead to household or workplace disagreements over energy usage, and compound existing inequalities around control of resources.

- **Misinformation** – new technologies can be a target for misinformation, which then shapes people's views and experiences of them.

- **Trust and reliability** – people need to be confident that the technology is providing them with accurate information, and that it is fit for the long-term (e.g. that the hardware and user-interfaces will be compatible across suppliers and energy infrastructure changes).

Findings

We found several UK-based surveys, studies, and engagement initiatives that asked about people's experiences of household energy monitoring technologies, particularly smart meters. These tended to focus on barriers to usage, perceived effectiveness, and the impact on behaviours of users.

A piece of research comparing international smart meter "roll-outs" charted the UK's approach between 2005 and 2019. They found that the early rollout campaign was not responsive to concerns raised in the media and by business, and paid little attention to public attitudes. Between 2010 and 2015, public attitudes towards smart meters became more negative, particularly in relation to cost and effectiveness[75].

More recent studies indicated a positive shift in public attitudes and opinions towards monitoring technologies in the past 3 years. A 2018 survey indicated that 47% of respondents did not want a smart meter, and cited concerns around accuracy and reliability[76]. However, in 2021, Ofgem reported record consumer confidence in smart meters, with 71% reporting that they were satisfied with the device and installation[77]. The energy price increases in 2021-22 are likely to have led to people paying more attention to smart meters than in earlier studies.

Several studies have identified key conditions which were required for support of monitoring technologies. These included expectation of free installation, reduced bills as a result of the technology, and privacy and data protection.

A 2021 study by NatCen and the Department for Business, Energy, and Industrial Strategy[78] reported that people found the benefits of smart meters tended to outweigh the downsides. This study indicated that in general, people feel like the key conditions required for support of monitoring technologies are being met. Downsides and barriers that were still experienced by users included increased anxiety arising from greater awareness of energy costs, and errors in the device or system[79].
The research included engagement with vulnerable participants - who had physical and/or mental health conditions, or who struggled to keep their homes warm – and found that vulnerabilities could interact with the benefits and downsides in different ways.

The 2021 Sciencewise Good Home Inquiry public dialogue[80] found that technology alone rarely motivates people to make behavioural changes, especially if its purpose is unclear to people. Some participants in the dialogue had expected more cost-saving benefits from smart meters, were unsure whether other smart technologies would meet a need, and felt like the technologies were "pushed on them" by government and industry.

A 2020 study with older people (aged 60+)[81] found that this group were generally more aware of their energy use before monitoring technology was installed, and tended to practise energy-saving behaviours anyway. This, combined with lack of confidence and experience with technology, meant that monitoring devices had a negligible or negative impact on the users.

[75] Geels, F. W., Sareen, S., Hook, A., Sovacool, B. K. (2021). Navigating implementation dilemmas in technology-forcing policies: a comparative analysis of accelerated smart meter diffusion in the Netherlands, UK, Norway, and Portugal (2000-2019). Research Policy.

[76] Smart Energy International. (2018). UK Poll shows public has little confidence in smart meters.

[77] Smart Meters Systems. (2021). Consumer satisfaction with smart meters at record high level, Ofgem finds.

[78] National Centre for Social Research. (2021). Research into maximising the benefits of smart metering for consumers.

[79] BBC. (2023). 'I'm obsessed with my smart meter.'

[80] Sciencewise. (2021). The Good Home Dialogue.

[81] Brown, C.J., Markusson, N. (2019). The responses of older adults to smart energy monitors. Energy Policy.

Two surveys that we looked at indicated that views associated with water meters generally aligned with views of electricity meters. One study showed that males, younger people, and people with generally positive views about technology were most likely to respond positively to water meters[82].

We found fewer studies that asked about workplace-based monitoring and metering. Whilst there is research and engagement focused on workers' energy saving behaviours in office environments, to-date few have included exploring workers' attitudes towards energy monitoring technologies in the workplace. One 2017 survey study[83] found that individuals' behaviour is influenced by perceived economic and environmental benefits, a clear organisational intention to save energy, awareness of information, normalisation of technology, and belief that their actions will make a difference. The research found that more senior workers were more likely to be aware of energy saving measures and believe that they are easy.

A 2020 report by CIPD on employee experiences of workplace technology[84] found that 86% of respondents thought that workplace monitoring and surveillance linked to productivity would become more common in the future. Furthermore, a study by the TUC found that any new monitoring technologies weaken trust between employer and employee, and that monitoring that is seen as individualised or only used with certain teams or groups is seen as unacceptable[85]. It is unclear from these studies whether workers would consider energy monitoring technology within the same category as other forms of workplace monitoring.

[82] Goulas, A., Goodwin, D., Shannon, C., Jeffrey, P., Smith, H.M. (2022). Public Perceptions of Household IoT Smart Water "Event" Meters in the UK—Implications for Urban Water Governance. Frontiers in Sustainable Cities.

[83] Zierler, R., Wehrmeyer, W., Murphy, R. (2017). The energy efficiency behaviour of individuals in large organisations: A case study of a major UK infrastructure operator. Energy Policy.

[84] Chartered Institute of Personnel and Development. (2020). Workplace technology: The employee experience.

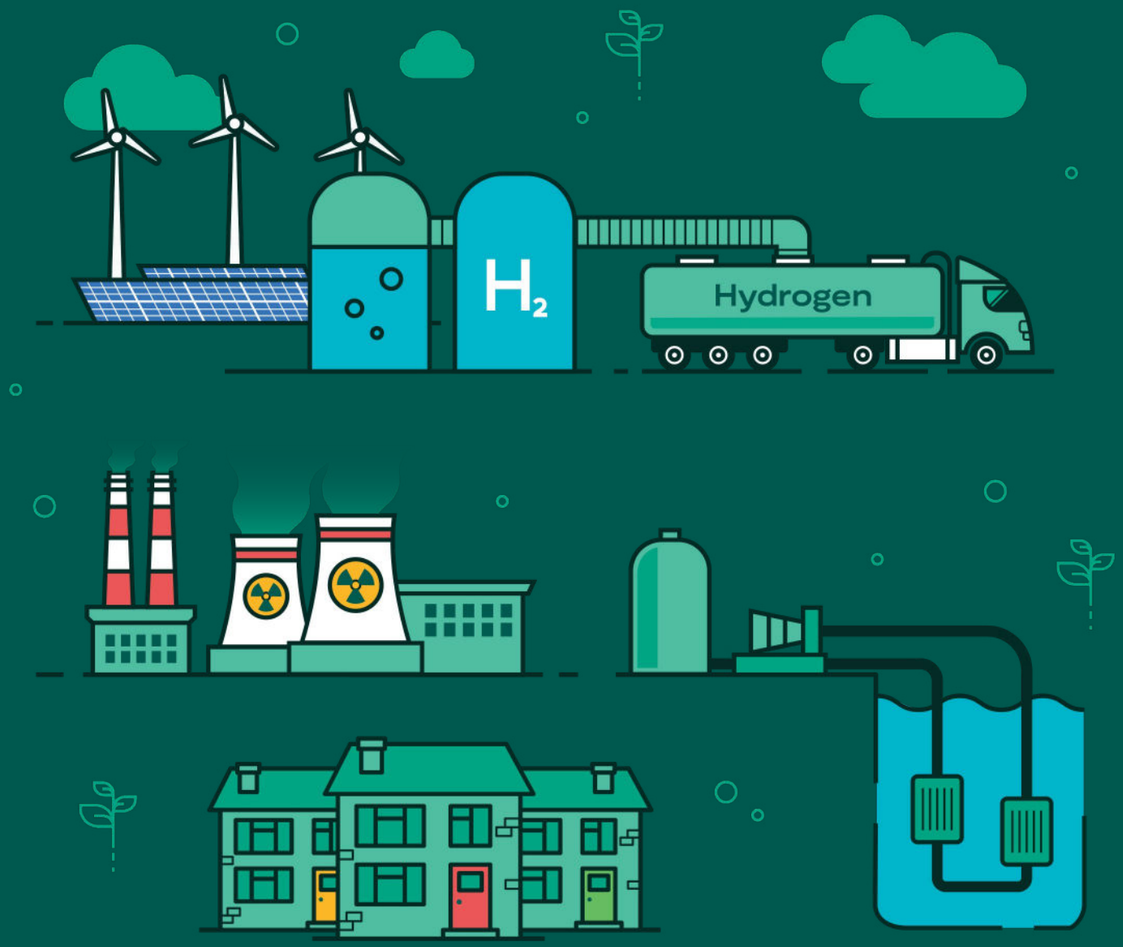
[85] Trades Union Congress. (2018). I'll be watching you - Workers' attitudes to surveillance.

Opportunities for new public engagement on energy monitoring

- There should be continual monitoring of public attitudes towards specific monitoring technologies, and how it is impacted by the economic and political environment. Our analysis indicates that higher energy costs may have driven uptake of energy monitoring devices, however, some studies suggest that people feel a lack of choice or agency around monitoring technology, even when they recognise some of the benefits.

- There could be more studies that ask people about energy monitoring in the context of what they want their homes and workplaces environment to be like, and how technology supports that. There should be particular efforts to engage with disabled people and people on lower incomes to explore how energy monitoring technologies could create benefits for these groups.

- Engagement could do more to explore to what extent technology supports behaviour change, especially among older age groups.



Energy generation technologies

Energy generation is at the heart of the climate change challenge. Burning fossil fuels for energy consumption is the largest source of greenhouse gas emissions from human activities. To achieve a sharp decline in emissions and meet the UK net zero target by 2050, a transition to clean energy is urgently needed.

In 2021, the UK government announced its plans to decarbonise the UK's power system by 2035 by investing in a range of green technologies, such as offshore wind, hydrogen, solar, and nuclear[86].

In this chapter, we explore three potential clean energy sources – hydrogen, ocean thermal energy conversion, and fusion – and what is known about public opinion on their deployment.

[86] Department for Business, Energy & Industrial Strategy. (2021). Plans unveiled to decarbonise UK power system by 2035.

Hydrogen

What are hydrogen technologies?

Hydrogen technologies are technologies that relate to the production and use of hydrogen – the lightest and most abundant element in the universe. Hydrogen atoms are present in water and almost all the molecules in living things[87]. It very rarely exists on its own on Earth but can be separated from other elements and produced from almost all energy sources (natural gas, nuclear power, biogas and renewable power).

Hydrogen has the potential to be a 'clean' alternative to methane, as burning hydrogen does not release carbon dioxide (CO2). When produced using clean energy such as renewables or nuclear to split water molecules, the only by-product produced in the process is oxygen[88]. However, the current use of hydrogen in oil refining and chemical production is mostly made from fossil fuels and is associated with significant CO2 emissions[89].

Although hydrogen itself has no colour, it is often described as "green", "blue" or "grey" depending on its production method[90].

- **Green hydrogen** – the only type of hydrogen produced with minimal greenhouse gas emissions. It is achieved through a process of electrolysis powered by renewable energies such as wind or solar power. Currently it makes up only a small percentage of the global hydrogen production, because the process is expensive.
- **Blue hydrogen** – sometimes described as "low-carbon hydrogen". It is produced from natural gas, using a process called steam reforming. Because carbon is produced as a by-product in the process, carbon capture and storage (CCS) is used to trap and store this carbon.
- **Grey hydrogen** – currently the most common form of hydrogen. It is produced from natural gas (usually methane), using a technique called steam methane reformation. A small amount of carbon dioxide is released during this process, and unlike blue hydrogen, it is not capturable.

Other colours, such as brown, yellow, pink, and turquoise are sometimes also used to describe different types of hydrogen production, but the colours assigned to production methods can change over time and may vary across countries[91].

Hydrogen has been described as "the clean fuel of the future", but with green hydrogen currently accounting for only 0.1% of overall hydrogen production, scale-up is essential to reduce the costs of technologies for producing and using clean hydrogen, such as electrolysers, fuel cells and hydrogen production with CCS[92].

[87] National Grid. (2023). What is hydrogen?
[88] New Scientist. (2023). Hydrogen fuel.
[89] International Energy Agency. (2023). Hydrogen.
[90] National Grid. (2023). Hydrogen colour spectrum.
[91] National Grid. (2023). Hydrogen colour spectrum.
[92] International Energy Agency. (2023). Hydrogen.

In terms of technological maturity, producing green hydrogen through alkaline or polymer electrolyte membrane electrolysis stands at Technical Readiness Level (TRL) of 8-9 (demonstration and early adoption); while electrolysis through solid oxide electrolyser cells is at stage 6-7 (large prototype/ demonstration)[93]. It is estimated that competitive green hydrogen will be available at scale in the next 5-10 years[94].

Global efforts are underway to bring down the cost of clean hydrogen and to better understand the role it will play in decarbonising the energy system. The urgency of reducing emissions and meeting net zero targets by 2050 means that governments are under pressure to publicise their plans for ramping up the production and use of hydrogen over the coming decade. In recent years, several countries and blocks have published their plans for a low-carbon hydrogen sector, with the UK government publishing the Hydrogen Strategy in August 2021[95].

Social and ethical issues in hydrogen technologies

Hydrogen continues to attract investments in the UK – in 2021, the UK Government released a 10-point plan alongside an initial £105 million investment[96]. The Government hopes to unlock a total of £4 billion of public and private investment by 2030. It is anticipated that hydrogen will gradually start replacing natural gas as the fuel in people's homes, with a projection of 20-35% of the UK's energy consumption being driven by hydrogen in 2050[97]. This poses a range of questions about the social implications of large-scale deployment of hydrogen and associated risks:

- **Regulation and transparency** – different "colours" and production methods of hydrogen can be a source of confusion for the public. There is a need for clear definitions and transparent communication about the origins of hydrogen. To prevent greenwashing, international principles and tracking instruments certifying the source of hydrogen might need to be developed[98].

[93] Do Better by Esade. (2020). Technologies of the energy transition: Low and zero-carbon hydrogen.

[94] World Economic Forum. (2021). What is green hydrogen and why do we need it? An expert explains.

[95] HM Government. (2021). UK Hydrogen Strategy.

[96] Department for Business, Energy & Industrial Strategy. (2021). UK government launches plan for a world-leading hydrogen economy.

[97] Scott, M., Powells, G. (2020). Towards a new social science research agenda for hydrogen transitions: Social practices, energy justice, and place attachment. Energy research & Social Science.

[98] International Renewable Energy Agency. (2022). Decarbonise end-use sectors: Green hydrogen certification.

- **Safety** – hydrogen leaked to the atmosphere can act as an indirect greenhouse gas. It can also impact ozone concentration and potentially harm air quality[99]. Although the current technology and operational best practice can minimise hydrogen leakage, the farther it will travel between production and end-use, the greater the potential for leaks[100]. More research and data are needed to better understand the potential harm of hydrogen leakage throughout the value chain. Finally, there are concerns around explosions in hydrogen power plants.

- **Affordability and supply** – because hydrogen is very expensive, there is a risk that heating homes with hydrogen would worsen energy poverty[101]. Establishing large-scale trials of hydrogen for domestic heating and consulting on hydrogen-ready boilers are essential to better understand the costs and benefits of hydrogen for heating[102]. There would also need to be confidence in the security of supply, as hydrogen is difficult to produce.

Findings

Following a strong momentum behind hydrogen in the last few years, there has been a proliferation of studies looking at public opinion on hydrogen technologies at both national and global levels. Very few of these studies differentiate between the different colours or production methods of hydrogen.

A study by Cranfield University which summarises the existing research on public perceptions of hydrogen found positive association between knowledge of hydrogen technologies and willingness to use them[103]. This means that **a lack of information provision about hydrogen could be a major barrier to public acceptability** which would need to be addressed before any large-scale adoption of hydrogen technologies can take place. The study also refers to a broader trend of knowledge being an important driver of public support for low-carbon technologies and, to an extent, the net zero agenda.

[99] energypost.eu. (2022). Hydrogen is also a greenhouse gas, so leaks must be minimised.

[100] Environmental Defense Fund. (2022). For hydrogen to be a climate solution, leaks must be tackled.

[101] Euractiv. (2021). Pipe dream: alleviating energy poverty with hydrogen.

[102] House of Commons Science and Technology Committee. (2022). The role of hydrogen in achieving Net Zero.

[103] Gordon, J. A., Balta-Ozkan, N., Ali Nabavi, S. (2022). Homes of the future: Unpacking public perceptions to power the domestic hydrogen transition. Renewable and Sustainable Energy reviews.

In the UK, **the overall awareness of hydrogen is relatively high, with 76% stating that they knew a fair amount, a little, or at least have heard of hydrogen already being used as a fuel in some industrial processes**[104]**.** However, the level of understanding of hydrogen as an energy technology is generally low. A study by Keele University on consumer perceptions of blended hydrogen in the home has found that **the public association with hydrogen is mixed**[105]**. Negative views associated hydrogen with explosiveness, while positive associations were connected to being "clean".** Some assume that hydrogen is "green" regardless of its production method which reveals **the lack of understanding of the different types of hydrogen and its implications.**

Safety and cost are consistently cited as the main concerns of the public. A survey by UK Energy Research Centre (UKERC) on public perception of low-carbon hydrogen has found that **the explosive nature of the gas and its flammability were the most common reasons for the survey participants' opposition to hydrogen**[106]**. Another major concern was cost with some participants citing energy poverty** and pointing out that new technologies are often available only to those who can afford them.

Despite the public's worries about safety and cost, the study reveals that hydrogen is generally perceived more positively when there are concrete plans in place to ensure a fair distribution of community benefits, when safety concerns have been adequately addressed, and where the hydrogen is produced in a greener way. The study notes that **men and high-income groups express much more support.**

BEIS Public Attitudes Tracker, a quarterly survey on public awareness and attitudes relating to the department's policy areas, reports that in Spring 2022 men were much more likely to be aware of hydrogen as a fuel and say that they knew at least a fair amount about it (25% compared with 6% women)[107]. Another demographic characteristic linked with higher awareness of hydrogen as a fuel is higher level of education: 86% of those educated to a degree level report that they have heard of the technology, compared with 76% of those with other qualifications and 57% of people with no qualifications. The survey also concludes that **young people were more likely to be aware of hydrogen energy, with 21% of people aged 16 to 24 stating that they knew at least a fair amount about hydrogen** (compared with 15% of people aged 25 or older).

Several of the studies suggest that greater knowledge of hydrogen technologies is usually associated with greater support. A report about the UK public's perspective on blended hydrogen by Newcastle University has found that **once people are informed that UK appliances have already been tested to run on 'blended' hydrogen (where hydrogen is introduced into the grid alongside natural gas**[108]**), and that hydrogen-rich town gas was previously used in the UK, they are more willing to use hydrogen as a fuel at home** and were not unsupportive of a blended hydrogen trial

[104] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Energy Infrastructure and Energy Sources, Spring 2022, UK.

[105] Keele University. (2022). Consumer perceptions of blended hydrogen in the home: learning from HyDeploy.

[106] UK Energy Research Centre. (2022). Public perceptions of low-carbon hydrogen.

[107] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Energy Infrastructure and Energy Sources, Spring 2022, UK.

[108] Energy Networks Association. (2020). Hydrogen blending - what is it and why does it matter?

taking place in their local area[109]. However, many energy experts argue that hydrogen is not suitable for home heating. Research suggests that hydrogen is less efficient and more expensive than alternatives such as heat pumps and solar thermal, and, therefore, is not a viable low-carbon heating fuel[110].

There have been reports of **communities in Whitby feeling like "lab rats" who are being used to test the potential of hydrogen** without a guarantee that their participation will be worthwhile in the long-term. People's concerns in this case centre around whether the technology is fit for the future, a lack of choice or agency in how the trial is managed, and the prominent role of large energy companies in running the trial[111].

The public's attitude to hydrogen is also linked to their political affiliations. According to the UKERC survey, **people who support political parties "left-of-centre"** (Labour, Lib Dem, SNP, Green, Sinn Fein, Plaid Cymru) **expressed the highest level of support for hydrogen**[112]**.** Respondents who said they would not vote at all were the least likely to support hydrogen as an energy source in the UK. Another factor associated with support for hydrogen is the level of worry about climate change. Newcastle University has found that **people who identify as having strong environmental values, awareness and responsibilities are more likely to support hydrogen**[113]**.**

Opportunities for new public engagement on hydrogen technologies

- It is well understood that public acceptability will play an important role in the successful deployment of hydrogen technologies, and there is a wealth of research published on this topic in the last few years. However, we found that most of the studies focus on a specific use of hydrogen, for example, heating homes or fuelling cars. Looking at public opinion about the full value chain, including production, transport, and storage, should be considered in future studies[114].

- How can the public be involved in a conversation about the potential environmental, economic and community benefits of hydrogen technologies, and whether those benefits are meaningful to them? What are the opportunities to engage women, older people, people with lower levels of education and from lower income groups?

- What can be done to prevent potential societal inequalities and distributional injustice caused by hydrogen technologies? How can we make sure that transition to hydrogen would not worsen the problem of energy poverty and that low-income households are supported?

- How does the merit of hydrogen compare with its alternatives, such as heat pumps?

[109] https://eprints.ncl.ac.uk/file_store/production/261762/77656234-5E46-460F-8A9C-211C0458E36D.pdf.

[110] The Guardian. (2022). Hydrogen is unsuitable for home heating, review concludes.

[111] The Guardian. (2022). 'We've got no choice': locals fear life as lab rats in UK hydrogen heating pilot.

[112] UK Energy Research Centre. (2022). Public perceptions of low-carbon hydrogen.

[113] Newcastle University. (2019). Blended Hydrogen: The UK Public's Perspective.

[114] UK Energy Research Centre. (2022). Public perceptions of low-carbon hydrogen.

Ocean Thermal Energy Conversion

What is Ocean Thermal Energy Conversion?

Ocean Thermal Energy Conversion (OTEC) is a technology for producing energy by harnessing the temperature difference between ocean surface waters and deep ocean waters. It is best suited for tropical and sub-tropical regions where the sun light warms the surface layer to more than 25°C depending on location[115]. Warm seawater causes liquids with low boiling points, such as ammonia, to vaporise and spin a turbine, which in turn drives a generator to produce electricity. The vapour is then exposed to cold water (approximately 5°C), which turns it back into a liquid[116].

The environmental benefits of the system are very strong. Unlike other renewable energy technologies like solar and wind, OTEC can generate a stable supply of electricity around the clock. Additionally, the process does not create any harmful by-products and post OTEC plant seawater is almost identical to open water[117].

The idea of using temperature differences to create power is nothing new – similar principles are used in coal, gas, and geothermal power plants. But despite ocean thermal energy conversion being explored by researchers for more than a century, the technology is still relatively nascent[118]. Existing pilot plants operate only on a small scale (TRL7) with the capacity of approximately 100 kilowatts, which is 20-30 times less than a typical wind turbine. Scaling up and moving beyond small demonstration plants are the next steps for OTEC, but attracting investment has been a challenge and it is unclear when OTEC might be commercially ready. Pre-commercial prototype buildings will need access to large volumes of cold seawater which requires expensive infrastructure going as deep as one kilometre into the ocean depth[119].

Although OTEC is unlikely to compete with solar or wind energy in large continental markets in the foreseeable future, researchers believe it to be a promising green technology for small islands and remote coastal areas close to the equator, where the ocean temperature difference is high, electricity demands are low, and the costs of electricity are high.

Due to the low temperature differentials in the waters surrounding the UK, OTEC is unlikely to be a viable option[120]. We have included it in this report because the technology is being developed by UK firms for use elsewhere – Cornwall-based firm Global OTEC has agreements in place to start supplying OTEC technology in the African island nation of São Tomé and Príncipe[121].

[115] Ocean Energy Systems. (2021). White Paper: Ocean Thermal Energy Conversion.

[116] The Conversation. (2022). Electricity from the cold ocean depths could one day power island states.

[117] Ocean Energy Systems. (2021). White Paper: Ocean Thermal Energy Conversion.

[118] The Conversation. (2022). Electricity from the cold ocean depths could one day power island states.

[119] The Conversation. (2022). Electricity from the cold ocean depths could one day power island states.

[120] The Conversation. (2022). Electricity from the cold ocean depths could one day power island states.

[121] Falmouth Packet. (2021). Cornwall firm world first with OTEC platform to convert sea heat to energy.

Social and ethical issues in Ocean Thermal Energy Conversion

- **Environmental and visual impact** – local communities might be resistant to large OTEC infrastructure being built in their areas based on their concerns about environmental, biodiversity, and visual impacts[122].
- **Spatial planning** – OTEC projects might compete for space with other uses of the sea, such as fishing and tourism, which might have an impact on local communities[123].
- **Power and impact** – OTEC technology is being developed by large corporations and by economically developed countries for use in areas where the impacts of climate change are likely to be highest[124]. There are potential issues around the power dynamics between communities and corporations.

Findings

Existing studies on the future of OTEC and its potential to decarbonise the energy sector are mostly technical in focus. They consider pathways to upscaling and commercialisation of OTEC, and the technical challenges to the adoption of ocean energy technologies. Some of the **resources mention public acceptability as an important step to a successful scale-up of OTEC, but no surveys on the public's attitudes are available yet.** We found no relevant research about the role OTEC could play in the energy transition in the UK, with most of the studies produced by countries with large coastal areas relatively close to the equator, such as Japan, South Korea, USA, and China.

The most comprehensive reports we found were produced by the Ocean Energy Systems (OES) - an intergovernmental collaboration between countries established by the International Energy Agency (IEA). The UK's participation in the OES is facilitated by the Department of Business, Energy and Industrial Strategy (BEIS).

A white paper produced by the OES in 2021 notes that **because it is not immediately apparent how OTEC works, it remains a fairly unknown technology**[125]**.** In contrast, it is clear that a wind turbine generates power by wind rotating the blades. The perceived complexity of the technology can be a barrier to commercialisation and could be addressed by providing accessible information on the benefits of OTEC to the public and policymakers.

[122] Ocean Energy Systems. (2020). Ocean Energy in Islands and Remote Coastal Areas: Opportunities and Challenges.

[123] Ocean Energy Systems. (2020). Ocean Energy in Islands and Remote Coastal Areas: Opportunities and Challenges.

[124] The Green Age. (2020). Ocean Thermal Energy Conversion.

[125] Ocean Energy Systems. (2021). White Paper: Ocean Thermal Energy Conversion.

Another report by the OES examines opportunities and challenges for ocean energy in islands and remote coastal areas[126]. Because of their moderate energy consumption, high resource potential, and difficult access to clean and affordable energy, small islands and remote coastal areas are believed to be best placed to take advantage of their ocean energy technologies potential. One of the chapters of the report looks at socio-environmental challenges to the adoption of ocean energy technologies, and suggests that **the lack of easily understandable information for stakeholders, governments, and end-users hinders public engagement and social acceptance.** To reduce OTEC's path to widespread adoption and facilitate energy transition, local communities need to be included in the early discussions and decision-making around future projects planned in their areas.

Opportunities for new public engagement on OTEC:

- Currently the public's opinion is absent in the conversations about OTEC. There is an opportunity for a global conversation about climate technology development and deployment which connects communities who may be most impacted.

- Existing literature on the future of OTEC focuses on technical issues and pathways to commercialisation. There is a need to produce non-technical information for stakeholders and potential end-users that will help to build a better understanding of the technology, so that the conversation can move beyond the small group of experts working on the scale-up of OTEC.

[126] Ocean Energy Systems. (2020). Ocean Energy in Islands and Remote Coastal Areas: Opportunities and Challenges.

Fusion

What is fusion energy?

Fusion is the process by which two atomic nuclei combine to make one larger one while releasing massive amounts of energy. It is what happens in the sun and other stars where nuclei collide with each other at temperatures around ten million degrees Celsius[127]. Fusion is often described as the opposite of nuclear fission – a process in which energy is released when a nucleus splits apart to form smaller nuclei[128]. Fission is the reaction used in current nuclear power stations, and while it is much easier to achieve than fusion, it produces harmful radioactive by-products that need to be stored for thousands of years[129].

Fusion is an expensive process that is difficult to recreate and control, but it has potential benefits as a source of clean energy:

- **No pollutants or greenhouse gas emissions** – fusion reaction produces only small amounts of helium as its by-product.
- **Energy efficiency** – in theory, fusion could generate four times more energy per kilogram of fuel than fission and almost four million times more energy than burning fossil fuels[130].
- **Safety** – fusion as a process is safer than fission. It only uses a very small amount of fuel at any one time, and it does not produce any radioactive waste[131].

Before fusion can be used for power generation, many scientific and technological barriers will have to be resolved. In the sun, the extreme pressure produced by its immense gravity creates the right conditions for fusion, but this is very difficult to achieve on Earth[132]. Temperatures of over 100 million degrees Celsius are needed to overcome the strongly repulsive electrostatic forces between positively charged nuclei to allow them to fuse[133]. Despite years of research, fusion technology falls between TRL of 3 and 4 (proof of concept and component testing)[134].

[127] International Atomic Energy Agency. (2022). What is Nuclear Fusion?
[128] Culham Centre for Fusion Energy. (2023). Fusion in brief.
[129] TWI Global. (2023). Nuclear fusion vs fission: what's the difference?
[130] International Atomic Energy Agency. (2022). What is Nuclear Fusion?
[131] Culham Centre for Fusion Energy. (2023). Fusion in brief.
[132] International Atomic Energy Agency. (2022). What is Nuclear Fusion?
[133] TWI Global. (2023). Nuclear fusion vs fission: what's the difference?
[134] Barnes, R. (2020). How mature are renewable energy technologies. Medium.

In December 2022, scientists in the United States announced a fusion energy breakthrough. They had created a reaction that produced more energy than it consumed for the first time, which helps to prove that the process could be a reliable alternative to fossil fuels and nuclear fission energy[135]. Although this is a significant achievement, experts warn that the level of energy produced so far is modest, and many more years of research and global collaboration are needed before fusion can be proved to be an economically viable solution[136].

In the UK, Culham Centre for Fusion Energy based in Oxfordshire is the national fusion laboratory, and is part of the UK Atomic Energy Agency (UKAEA). In 2021, the UK Government launched its fusion strategy[137], and in 2022 it was announced that the West Burton power station site in Nottinghamshire was selected as the home for the UK's prototype fusion energy plant which aims to be built by 2040[138].

Social and ethical issues in fusion energy

Due to radiation hazards being associated with nuclear energy, there is a risk that a rollout of fusion would not be supported by the public. To make sure that commercial-scale fusion is in line with social values, the following issues should be considered:

- **Environmental impact and safety** – there is a risk that fusion will be confused with fission by the public. It needs to be clearly communicated why fusion energy is greener, more efficient and safer than nuclear plants currently operating.
- **Nuclear proliferation** – there is a concern that the spread of nuclear technologies might speed up the development of nuclear weapons and increase the risk of nuclear conflict[139].
- **Competition with renewables** – the public might worry that nuclear plants are competing for funding with greener renewable energy sources such as wind, solar and geothermal, or that it may be seen as a "silver bullet" which leads to less investment in other nearer term or low-tech solutions.
- **Feasibility** – fusion is reported to take several more decades of research before it is commercially ready. The distant timescales can be a source of worry and scepticism about the feasibility of fusion technology.

[135] Financial times. (2022). Fusion energy breakthrough by US scientists boosts clean power hopes.

[136] World Economic Forum. (2022). What is nuclear fusion? The science- and a new milestone - explained.

[137] Department for Business, Energy, and Industrial Strategy. (2021). Towards Fusion Energy. The UK Government's Fusion Strategy.

[138] Department for Business, Energy & Industrial Strategy and UK Atomic Energy Authority. (2022). Site of UK's first fusion energy plant selected.

[139] ITER. (2023). Advantages of fusion.

Public opinion on fusion energy

Most of the sources of public opinion on fusion energy we found were from the international contexts, but BEIS Public Attitude Tracker provides an important insight into the awareness and support for fusion energy in the UK. In Spring 2022, **63% of people had at least some knowledge of fusion, with 4% self-reporting as knowing a lot, 12% a fair amount, and 23% a little. 24% said they "have heard of it but knew hardly anything"[140]. Men and younger people (aged 16 to 24) were more likely to be aware of fusion energy** and to say that they knew at least a fair amount about it.

The survey also notes **no change in the level of awareness or knowledge between Autumn 2021 and Spring 2022, but the support for fusion increased from 39% to 48%.** This was driven by a fall in the number of respondents who said they neither supported nor opposed fusion from 38% to 29%. Although men were more likely to be supportive of fusion than women, there was a greater increase in support since Autumn 2021 for women (36% up from 25%) than for men (60% up from 55%).

A 2019 study by the University of Surrey, University of Sheffield and UK Atomic Energy Authority looked at social acceptance of fusion in the UK and Germany[141]. The research is based on a survey designed to assess lay attitudes to fusion and the planned use of depleted uranium beds (which are used during nuclear fission) as a storage for nuclear fusion fuel. According to the study, **attitudes to fusion are generally more positive in the UK than in Germany. However, the opinions of both the UK and German cohorts became more positive towards nuclear fusion after receiving information which delineated fusion from fission.** The study also suggests **that correcting misconceptions and engaging the public in an informed debate will be a crucial element of building social acceptability of fusion technologies.**

How supportive or sceptical people are about fusion energy appears to be correlated with what they think about similar issues. In their 2020 study of fusion energy and the public opinion, Belgian Nuclear Research Centre and Sociotechnical Research Centre in Barcelona found that the **most influential predictors of attitudes towards fusion are attitude towards nuclear energy, attitude towards science and technology, and the perceived importance of costs and time needed to develop fusion energy[142].** The research also shows that nuclear fission plays an important part in the sense making about fusion, with respondents often defining fusion by comparing it with fission.

[140] Department for Business, Energy & Industrial Strategy. (2022). BEIS Public Attitudes Tracker: Energy Infrastructure and Energy Sources, Summer 2022, UK.

[141] Jones, C. R., Yardley, S., Medley, S. (2019). The social acceptance of fusion: Critically examining public perceptions of uranium-based fuel storage for nuclear fusion in Europe. Energy Research & Social Science.

[142] Turcanu, C., Prades, A., Sala, R., Perko, T., Oltra, C. (2020). Fusion energy: A deeper look into attitudes among the general public. Fusion Engineering and Design.

Studies which look at public attitudes to fusion across Europe report **strong differences in public opinion between countries.** A 2019 report by Eurofusion examined public awareness, attitudes and acceptability of fusion energy research in 21 European countries[143]. It found that countries with the highest support levels were Romania and Bulgaria, while Austria and Belgium were the least supportive. **The UK was placed above the average in the support index,** with Czech Republic, Denmark, the Netherlands, France, Germany, Latvia, Italy, Belgium and Austria all displaying lower levels of support. This is consistent with a more recent study by the University of Surrey and Sociotechnical Research Centre in Barcelona which surveyed the public in Austria, Finland, Spain and the UK in 2021[144]. Their findings reveal that attitudes to fusion in Europe are the most favourable in Finland, followed by the UK and Spain, and the least favourable in Austria. The study confirms that **significant differences in attitudes to fusion can be found across Europe and concludes that programmes of public engagement in different countries should take these differences into account.**

Opportunities for new public engagement on nuclear fusion technologies

- The conversation about the benefits and challenges around the deployment of fusion technology should be continued. Public engagement programmes should make sure that groups which currently feel less informed, such as women and older people, are included in the conversation.

- Most surveys and studies look at the general level of awareness and support for fusion among the public in the UK. To better understand the social issues around scale-up of fusion technology and place-based barriers, there is a need to engage local communities and ask them about the reasons for potential support and/or opposition.

- There should be early conversations with the public about governance of fusion technologies. A dialogue on the role of fusion in the wider energy mix would help to understand the public's expectations and opinions around regulation and potential benefits (e.g. employment opportunities).

[143] Eurofusion. (2019). Informed Public Attitudes towards Fusion Energy in Europe.

[144] Jones, C. R., Oltra, C., Prades, A. (2021). Predicting attitudes towards fusion energy in Europe: Results of a cross-national public survey in Austria, Finland, Spain, and the UK. Energy Research and Social Science.

Carbon dioxide removal

Carbon dioxide removal (CDR) aims to slow down and mitigate the impact of climate change by removing previously-emitted carbon from the atmosphere. The UK Government often uses the term Greenhouse Gas Removal (GGR).

CDR is distinct from carbon reduction, which aims to reduce the flow of emissions into the atmosphere, and which encompasses all other energy supply and demand interventions.

According to the Intergovernmental Panel on Climate Change[145], CDR has three functions: a) to compensate for "hard-to-decarbonise" sectors where full decarbonisation by 2050 may be too costly or difficult, such as agriculture; b) to reduce net emissions in the atmosphere faster in the short-term (for instance by planting trees); c) to eventually restore the climate system in the long-term, if deployed at a rate which outstrips all emissions from human activities.

Campaigning groups are concerned that technology-led carbon removal efforts service the interests and profits of large corporations who are refusing responsibility for their part in the climate crisis, and that they will not be sufficient to achieve net zero. To these groups, CDR is seen as a "distraction" from the near-term actions that are necessary[146]. Organisations such as Greenpeace and the UK Committee on Climate Change (CCC) set out a precautionary approach to CDR[147].

In 2020, the UK Government stated that "Our priority is to tackle the root cause of climate change by reducing emissions of greenhouse gases from human activities, and adapting to those impacts that are unavoidable. Mitigation of climate change by reducing emissions and protecting natural carbon sinks remains the main focus of our efforts to increase our chances of avoiding dangerous climate change[148]."

In this chapter we explore one proposed CDR technology – Direct Air Capture and Storage (DACS). A large number of CDR proposals exist, and public attitudes will likely vary significantly between different proposals. Compared to many more established options for CDR such as afforestation and ecosystem restoration, DACS is likely to play just a very small role (if any) in the UK's net zero transition[149].

[145] IPCC. (2018). Global Warming of 1.5 °C.

[146] Corporate Accountability. (2021). The Big Con: How Big Polluters are advancing a "net zero" climate agenda to delay, deceive, and deny.

[147] Healey, P., Scholes, R., Lefale, P., Yanda, P. (2021). Governing Net Zero Carbon Removals to Avoid Entrenching Inequities. Frontiers Climate. and Climate Change Committee. (2021). Time is running out for realistic climate commitments.

[148] Department for Business, Energy & Industrial Strategy. (2020). UK government's view on greenhouse gas removal technologies and solar radiation management.

[149] Climate Change Committee. (2020). The Sixth Carbon Budget: the UK's path to Net Zero.

Direct Air Capture

What is "Direct Air Capture" (DAC)?[150]

Direct Air Capture, or DAC is a process of carbon removal in which chemical processes remove carbon dioxide (CO_2) from the air. In Direct Air Capture and Storage (DACS), the CO_2 is then stored underground where it cannot interact or be re-released into the atmosphere. Direct Air Capture can be used to capture CO_2 which is then used in manufacturing, horticulture or other sectors, but this does not constitute a CDR technology, since the CO_2 is returned straight to the atmosphere. However, there are some emerging proposals for CO_2 usage which can store the carbon for longer, such as using the captured CO_2 to create concrete for buildings.

There are two methods for capturing CO_2 using DAC that are currently in use: one using solid adsorbents which operate at low pressure and medium temperature; and one using liquid solutions at high temperatures. Other methods for DAC technologies are emerging, but not yet in use. All DAC methods are currently very energy intensive, because of the relatively low concentration of CO_2 in the atmosphere. There is potential for DAC to be powered by low- or zero-carbon energy sources.

DAC is underway at a small scale (TRL6)[151] in Europe and America, with eighteen "plants" in operation. These facilities tend to utilise the captured CO_2 straight away, for example to produce carbonated drinks, or to increase oil production from depleted wells using Enhanced Oil Recovery (EOR), which may actually increase atmospheric emissions overall. Only two plants currently store in the earth. A larger scale DACS plant is planned to begin operation in 2024 in the Permian Basin which spans Texas and New Mexico. Ten further DACS plants are at the development stage, including Storegga in north east Scotland. The technology currently requires plants to be located near to a CO_2 storage facility and low-carbon energy source, although there are many proposals for large-scale transport of CO_2 using pipelines or ships.

In July 2020, the UK Government announced £100 million funding to research and develop new CDR technologies. In the first phase, 23 projects received funding, of which six involved DAC. In 2022, 15 of these projects were advanced to the second phase of funding, of which four involved DAC[152].

Analysis has shown that DACS has higher set-up costs than other CDR technologies, and may not be economically viable[153]. Additionally, the "State of CDR" report suggests a gap between the proposed scale and timeline of CDR and the level that would be required to limit global heating to 1.5º.[154]

Social and ethical issues of DACS[155]

Direct Air Capture and Storage (DACS) has the potential to deliver economic benefits to the communities around it, however this would require ongoing engagement with those communities. Potential social and ethical considerations associated with DACS include[156]:

- **Safety and effectiveness** – DACS involves new processes and facilities, which could lead to concerns around safety.
- **Community impact** – new technology and new infrastructure can deliver job creation (although the scale of job creation for DACS would be highly dependent on the scale of deployment). DACS requires less land than other CDR options, however, plants may be sited in areas which are historically low impact in terms of carbon emissions, leading to views that the community is "paying" for emissions elsewhere.
- **Timescales** – the technology is still at an early stage, and may not be deployable at scale before 2050, when the UK is supposed to meet 'net zero' emissions. However, if and when the technology is ready, change may happen very quickly. There is also an issue of intergenerational inequality, where responsibility for addressing carbon levels in the atmosphere is passed on to younger generations who are not responsible for current high emissions.
- **Governance and cost** – who decides where, when, and how DACS is used, and therefore which communities it will impact most. The technology has higher set-up costs than other CDR and mitigation methods, and has not been shown to be economically viable. If it were implemented at scale, there would be tensions about who paid for set-up costs.
- **Does not address underlying systemic issues** – DACS happens after the emissions of carbon into the atmosphere have occurred, so can be seen as a "sticking plaster" or "insurance policy" to the issue which does not change systems or practices. However, it could also be seen as "repairing the damage".

[150] International Energy Agency. (2022). Direct Air Capture.

[151] Do Better by Esade. (2020). Technologies of the energy transition: Direct air capture.

[152] Department for Business, Energy & Industrial Strategy. (2022). Projects selected for Phase 2 of the Direct air capture and greenhouse gas removal programme.

[153] Erans, M., Sanz-Perez, E. S., Hanak, D. P., Clulow, Z., Reiner, D. M., Mutch, G. A. (2022). Direct air capture: process technology, techno-economic and socio-political challenges.

[154] The State of Carbon Dioxide Removal. (2023). The State of Carbon Dioxide Removal - 1st Edition.

[155] Cox, E.M., Pidgeon, N., Spence, E. and Thomas, G. (2018). Blurred Lines: The Ethics and Policy of Greenhouse Gas Removal at Scale. Frontiers Enviromental Science.

[156] Erans, M., Sanz-Perez, E. S., Hanak, D. P., Clulow, Z., Reiner, D. M., Mutch, G. A. (2022). Direct air capture: process technology, techno-economic and socio-political challenges.

Findings

We found a number of in-depth studies of UK public attitudes and values around carbon dioxide removal (CDR) and carbon capture usage and storage (CCUS), many of which included direct air capture (DAC). These studies centered on awareness of the technology, acceptability, governance, and its place alongside other mitigation technologies.

A 2021 Sciencewise public dialogue on CCUS[157] found that study participants **saw DACS as a "smarter" and more conceptually simple carbon removal technology than Bioenergy with Carbon Capture Storage** (BECCS – where biomass is used as a storage medium and energy source for carbon capture). However, people were concerned that **the technology might be "too good to be true", may have high set-up costs, or be powered by fossil fuels.** By contrast, a separate workshop study by the Leverhulme Centre for Climate Change Mitigation in the same year had the opposite finding – participants found DACS difficult to conceptualise[158]. In their research, people associated DACS with air pollution measures (although DACS will not, in fact, address air pollution), and were worried about the costs and power requirements of the technology.

A study which looked in detail at public appraisals of various carbon dioxide removal methods found that **DACS had relatively lower public support than other CDR methods studied**, with participants **generally favouring more natural CDR methods** such as afforestation and habitat restoration. The lowest performing option in the survey was 'no CDR'. The finding that people favour more natural methods of carbon removal and climate change mitigation has been found in multiple studies. The research also noted that people based in the North West of England were most likely to support DACS compared with other areas of the UK, possibly because it could restore industry and employment to the area, although this finding was not statistically significant[159].

Similarly, the UK Climate Assembly looked at DACS, and found that it compared less favourably to more natural methods of CDR[160]. The Assembly raised concerns about leaks from carbon storage facilities, and about the technology not addressing the causes of climate change. However, some participants did support continued research and development of DACS to ensure the technology is ready to play a role if needed in future.

[157] Sciencewise. (2021). Carbon Capture Usage and Storage. Public Dialogue.

[158] Leverhulme Centre for Climate Change Mitigation. (2021). Policy brief: Public perceptions of Carbon Dioxide Removal in the UK.

[159] Bellamy, R. (2021). Mapping public appraisals of carbon dioxide removals. Global environmental Change.

[160] Climate Assembly UK. (2020). The path to net zero.

A 2020 mixed methods comparison of US and UK public opinion on CDR found that **10% of respondents had awareness of CDR technologies**[161]. The researchers found that UK respondents had both higher levels of concern about climate change, and were more likely to perceive benefits of CDR. The technology **was seen as simultaneously too short-term (not addressing underlying causes of climate change) and too long-term (not yet ready for deployment), and did not necessarily fit with people's visions of a more sustainable future.** However, UK respondents felt that CDR could "buy time" to develop better carbon reduction measures. Workshops accompanying the survey found that **people were less likely to understand and support DAC than other CDR technologies**[162]**.**

A 2021 policy briefing analysed surveys on DACS and other energy and climate technologies such as nuclear power, and indicated that public support for DACS would be dependent on public confidence that it is deployed as part of a credible net-zero strategy built on accountability and transparency, rather than as a "quick fix"[163].

Opportunities for new public engagement on DACS

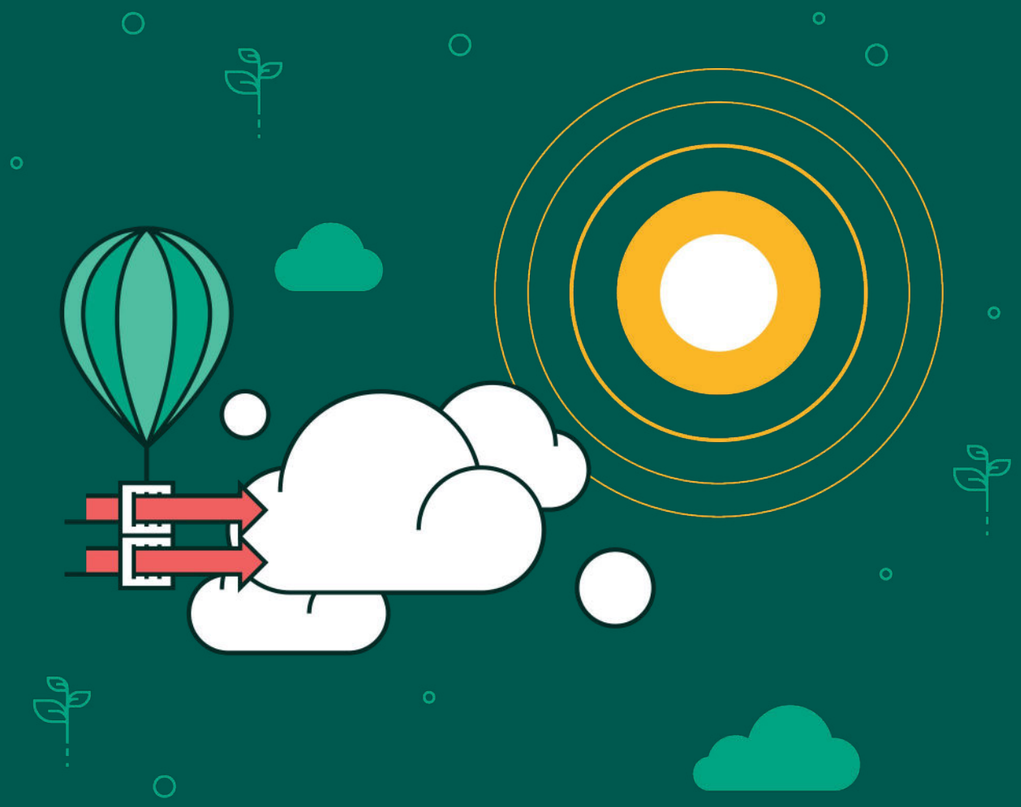
There are clear opportunities for people to be more involved in decisions around if and how DACS is used. Initiatives should particularly focus on involving marginalised people and communities, and work with the public to codesign the information they receive around DACS and other CDR technologies.

Engagement should consider how DACS would fit into a much broader series of measures to mitigate climate change, and what mixture of natural and technological measures people would favour, as well as considering potential trade-offs between options.

[161] Cox, E., Spence, E., Pidgeon, N. (2020). Public perceptions of carbon dioxide removal in the United States and United Kingdom. Nature Climate Change.

[162] Carbon Brief. (2020). How public attitudes towards 'CO2 removal' differ in the UK and US.

[163] Lezaun, J., Healey, P., Kruger, T., Smith, S.M. (2021). Governing Carbon Dioxide Removal in the UK: Lessons Learned and Challenges Ahead. Frontiers Climate.



Speculative technologies

Solar Radiation Management

What is "Solar Radiation Management"?

Solar radiation management (SRM) or solar geoengineering, aims to temporarily cool the planet by reflecting a proportion of the sun's rays away from earth.

Some researchers argue that SRM is thus distinct from both emissions reduction and carbon removal, since it would not have any impact on the levels or CO2 or other greenhouse gases in the atmosphere.

Most techniques involve boosting the reflectivity of the earth's surface or its clouds, thus increasing the earth's albedo (reflectivity), and reducing warming by reflecting more incoming solar radiation back out to space. Methods for SRM include:

- Distributing reflecting aerosols into the atmosphere;
- "Cloud thinning" – distributing particles that dissipate cirrus clouds (which tend to absorb heat);
- "Brightening" the clouds over ocean areas using salt-spray;
- Artificially increasing ice cover at the poles, increasing the reflectivity of the land surface;
- Creating an orbiting fleet of mirrors.

SRM technology is at an early stage, and a 2023 UN report estimates that it will take at least 10-20 years for different SRM approaches to be deployed [164]. Computer models which aim to predict whether and how SRM would work show that although the technology could be effective, it could cause unpredictable impacts on weather patterns globally, especially if it was initiated or terminated suddenly. In particular, concerns have been raised over impacts on precipitation and monsoon rains, which are especially challenging aspects of the climate system to accurately model. Therefore, global governance is a key discussion within geoengineering, since side-effects could be experienced far from the sites of SRM interventions.

The circumstances in which SRM might be deployed include preventing drastic changes to the Earth's environment as a result of climate change, for example if the Greenland ice cap was under threat. Some scientists take the view that it is our responsibility to continue building evidence of the technology's likely impact and effectiveness in order to be prepared for discussions about if and how to deploy SRM in the face of extreme environmental change.

The House of Commons Science and Technology Select Committee made a recommendation in 2019, that UK Research and Innovation should "review the current state of research into solar radiation management, the likely timeframes that would be required for detailed research and potential testing of such technologies, and the case for any increased research now. It should ensure that research into solar radiation management is sufficient to allow for any potential future decisions to be made on the deployment of such technology to be sufficiently well-informed.[165]"

In 2020, the UK Government stated that they were not deploying SRM and had no plans to do so, but that they were monitoring research on the effects of SRM on climate[166].

[164] United Nations Environment Programme. (2023). One atmosphere: an independent expert review on Solar Radiation Modification research and deployment.

[165] House of Commons Science and Technology Committee. (2019). Clean Growth: Technologies for meeting the UK's emissions reduction targets.

[166] Department for Business, Energy & Industrial Strategy. (2020). UK government's view on greenhouse gas removal technologies and solar radiation management.

Social and ethical issues with SRM
Solar Radiation Management (SRM) is, as outlined above, an early-stage and already controversial idea. Potential social and ethical considerations associated with SRM include [167]:

• **Research and effectiveness** – SRM's effectiveness may not be apparent until real-world testing took place, but this testing would in itself have impacts on the planet.

• **Impact on vulnerable populations** – SRM impacts are not likely to be evenly distributed around the Earth, so some populations, especially those in parts of the Global South who are already experiencing the most damaging effects of climate change, may be most impacted by SRM.

• **Governance** – who takes the decisions and accountability over how and when the technology is used.

• **Does not address the cause of climate change** – SRM happens after the emission of carbon into the atmosphere, so can be seen as a "sticking plaster" or "insurance policy" to the issue which does not change systems or practices; however it can also be seen as "repairing the damage".

Findings

Although geoengineering and SRM were the topic of several engagement programmes and dialogues in the late-2000s and early 2010s, we found very few UK-based public engagement initiatives from the past five years. This could be because the UK Government has maintained its strong stance not to practise SRM, and any engagement could give the impression that a policy change is imminent, or because previous attempts at public engagement on geoengineering such as the SPICE project were controversial[168].

A 2022 paper prepared for the UK Committee on Climate Change suggested: "In the case of climate policy, the use of negative emissions technologies, and potentially even geoengineering, are widely discussed and appear in climate models.

This is, therefore, **an area that could benefit from a more principles based application of a deliberative method.** In this case, the process would be unlikely to consider specific policy proposals or measures but, instead, it **would focus on building understanding of the technology and the trade-offs and uncertainties involved.** It could aim to reach a consensus on the broad principles guiding the adoption of the technology within real world deployment scenarios[169]."

[167] Carr, W.A., Preston, C.J., Yung, L. et al. (2013). Public engagement on solar radiation management and why it needs to happen now. Climatic Change.

[168] Nature.com. (2011). SPICE put on ice.

[169] Climate Citizens. (2022). The role of deliberative public engagement in climate policy development.

One study involved **young people from the UK and globally,** and led to the development of a **set of principles** that the research participants saw as key to climate action involving SRM[170]:

- Decisions around geoengineering should not be taken top-down, and people and communities should be given the information and power to participate;
- Climate technologies should be a "last resort" and other adaptation and mitigation efforts must be scaled up;
- Prioritise interventions that are well-evidenced and low-risk to all communities;
- Cooperate internationally to find equitable solutions;
- Involve young people, since climate change impacts and decisions will be felt for generations to come.

Non-UK findings

We found many more international sources of evidence on public opinion, particularly from the USA. The research cannot be assumed to be transferrable to the UK context. The key findings are:

- A 2019 paper found that people in the US are more likely to support SRM if they think that the speed and cost of the technology is an important factor in deciding whether to use it. They did not note a relationship between people's support for SRM and their concerns about SRM's shortcomings. This study noted acquiescence bias or "agreement bias"– that people tend to agree with an action without it being reflective of their views or actions - could have played a part in people's responses to the survey[171].
- Another paper published in 2019 stated that representative surveys are limited in how much information they can provide about people's views of SRM, as the technology is so unfamiliar to people[172].
- A US-based study in 2022 found that negative information can be more influential on people's decisions about whether they support SRM than positive information. It also noted the point that SRM is an unfamiliar technology, and that it is not as politicised as other science and climate topics in the US[173].

[170] Dunlop, L., Rushton, E., Atkinson, L. et al. (2022). Youth co-authorship as public engagement with geoengineering. International Journal of Science Education.

[171] Mahajana, A., Tingleya, D., Wagner, G. (2018) Fast, cheap, and imperfect? U.S. public opinion about solar geoengineering.

[172] Merk, C., Klaus, G., Pohlers, J., et al. (2019). Public perceptions of climate engineering: Laypersons' acceptance at different levels of knowledge and intensities of deliberation.

[173] Bolsen, T., Palm, R., Kingsland, J. (2022). How Negative Frames Can Undermine Public Support for Studying Solar Geoengineering in the U.S.

- Similarly, a 2021 survey by Pew Research found 4% of respondents had heard or knew a lot about SRM. People's main concerns about the technology involve SRM being deployed without proper testing, and people with prior knowledge of the technology are particularly likely to express this concern than those who hadn't heard much about it[174].

- A study of college students in the Asia-Pacific region looked at differences in opinions in the Global North (Australia, Japan, and South Korea) and Global South (China, India, the Philippines) and found that students in the Global North were much more hesitant towards SRM[175]. However, they found that all respondents agreed on six main principles for governance of SRM, including regulation and information transparency.

Opportunities for new public engagement on SRM

There are risks with public engagement on SRM, as there are no immediate plans for policy decisions on its testing or use, so people may not feel their input is worthwhile. However, an engagement approach that takes a "principles-based" approach – such as using the Oxford Principles for Geoengineering[176] - could be a useful starting point, and could build upon studies from 2000 – 2014 to see if views and values have changed. Future engagement initiatives should consider exploring with the public the direction of travel of SRM and its potential impacts.

[174] Pew Research Center. (2021). U.S. adults have mixed views on whether geoengineering would help reduce effects of climate change.

[175] Sugiyama, M., Asayama, S., Kosugi, T. (2020). The North–South Divide on Public Perceptions of Stratospheric Aerosol Geoengineering?: A Survey in Six Asia-Pacific Countries.

[176] University of Oxford. (2018). Oxford Geoengineering Programme. Oxford Principles.

GLOSSARY

AI – Artificial Intelligence

BECCS – Bioenergy with Carbon Capture Storage

CCS – Carbon Capture and Storage

CCUS – Carbon Capture, Utilisation and Storage

CDR – Carbon Dioxide Removal

COP26 – the 26th United Nations 'Conference of the Parties' Climate Change Conference, which took place in Glasgow in November 2021.

DAC – Direct Air Capture

DACS – Direct Air Capture and Storage

EOR – Enhanced Oil Recovery

GGR – Greenhouse Gas Removal

GM – Genetic Modification

IoT – Internet of Things

Just transition – "greening" the economy in a way that is fair and socially inclusive and "leaves no one behind".[177]

Net zero – balance between the amount of greenhouse gas (GHG) that's produced and the amount that's removed from the atmosphere. It can be achieved through a combination of emission reduction and emission removal.[178]

Net Zero Strategy – the UK government's strategy which sets out how the UK will deliver on its commitment to reach net zero emissions by 2050.[179]

OTEC – Ocean Thermal Energy Conversion

SRM – Solar Radiation Management

TRL – Technical Readiness Level
Technology readiness levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. There are nine technology readiness levels: TRL 1 is the lowest and TRL 9 is the highest.

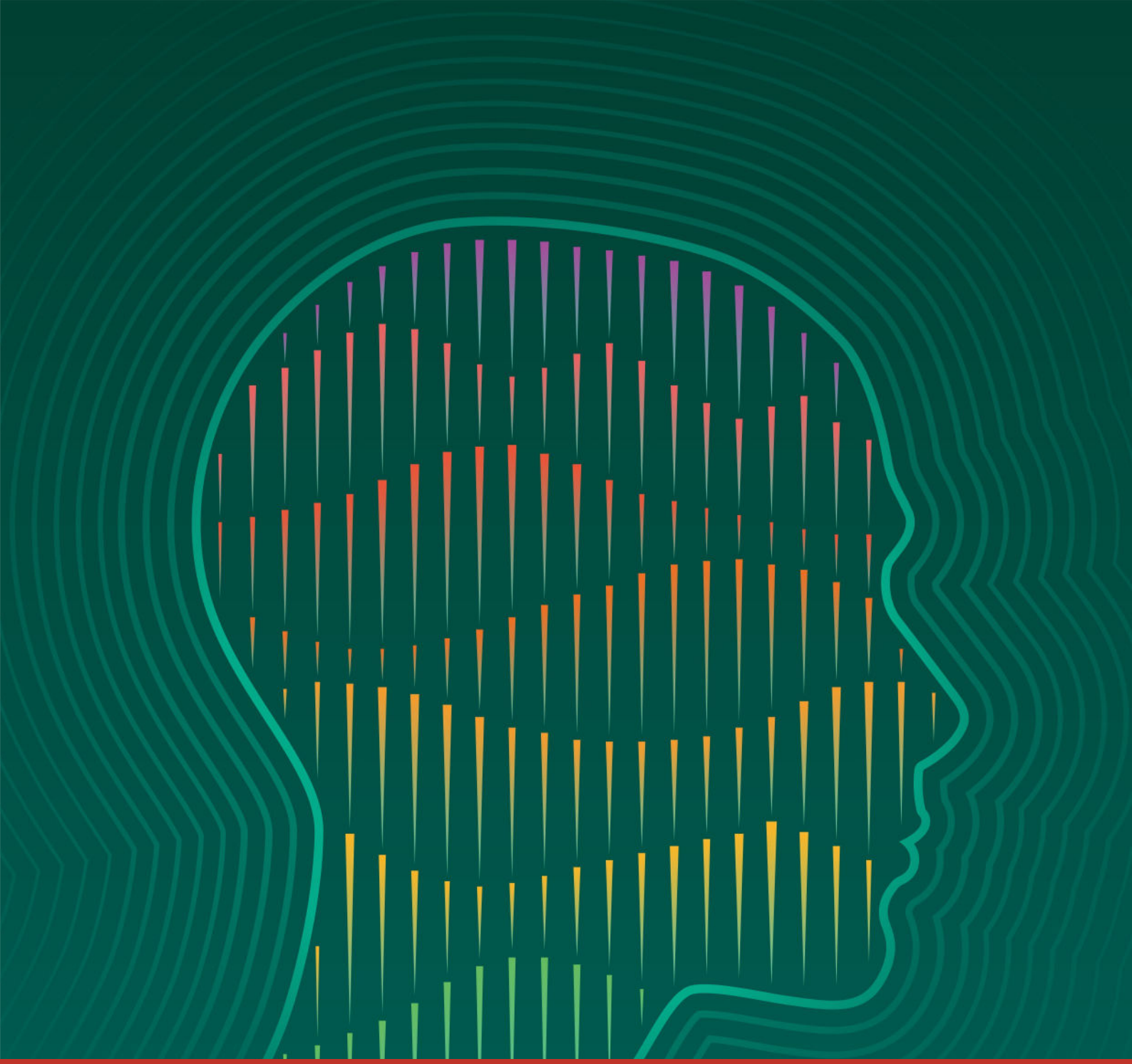
The TRL levels and definitions are as follows:
TRL 1: basic principles observed and reported
TRL 2: technology concept or application formulated
TRL 3: analytical and experimental critical function or characteristic proof-of-concept
TRL 4: technology basic validation in a laboratory environment
TRL 5: technology basic validation in a relevant environment
TRL 6: technology model or prototype demonstration in a relevant environment
TRL 7: technology prototype demonstration in an operational environment
TRL 8: actual technology completed and qualified through test and demonstration
TRL 9: actual technology qualified through successful mission operations.[180]

[177] UNDP Climate Promise. (2022). What is just transition? And why is it important?

[178] National Grid. (2023). What is net zero?

[179] Department for Business, Energy & Industrial Strategy. (2022). Net Zero Strategy: Build back greener.

[180] Science and Technology Facilities Council. (2022). Eligibility of technology readiness levels (TRL).



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