CREDS Annual Report: October 2022 to September 2023

November 2023

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With contributions from members of the CREDS consortium

Contents

1 Introduction

The Centre for Research into Energy Demand Solutions (CREDS) was established as part of the UKRI Energy Programme in April 2018 and has been running for 5.5 years, with funding of £19.5M over 5 years from EPSRC and ESRC. Its objective is to understand the role of energy demand change in accelerating the transition to a zero-carbon energy system, including the technical, social and governance challenges of demand reduction, flexible demand and use of decarbonised energy. This is a revised objective following the recommendations of the Mid-term review. We are a team of over 140 people based in 24 UK organisations.

The three aims of the Centre are:

- to develop and deliver internationally leading research, focused on energy demand
- to secure impact for UK energy demand research in businesses and policymaking, and
- to champion the importance of energy demand.

This is CREDS' fifth and final annual report. It covers the whole of the 5.5 years rather than just the period from October 2022 to September 2023. The first annual report was published in November 2019, the second annual report in December 2020, the third annual report in December 2021 and the fourth annual report in December 2022.

The highlight of the year was the launch of the CREDS research findings (November 2022). We decided to summarise all the work across our nine themes to create one synthesised summary for the entire programmes' work. A comprehensive user journey was designed for the website enabling users to access the high-level findings page with link to the pages on each of the topic areas (15 in total), which in turn provides links to the research evidence base (papers and reports). More details of the concept used and the suite of outputs are provided in Section 2.2.4. The synthesis process took approximately 10 months and we have spent a further 12 months sharing these results with stakeholders and users to champion energy demand and create impact.

A social media campaign with accompanying visuals for each topic was designed and released to promote the findings using the hashtag #CREDSresearchfindings. A news release was also developed and tailored to align with the Autumn statement.

The promotion work for this has continued for the remainder of CREDS with extensive personal emails, two major stakeholder events in Edinburgh and London reaching around 300 people, two drop-in sessions for the consortium to share the suite of materials such as a slide pack that they can use when doing talks. Insights from the evaluation of these two large hybrid events are published.

At the London **CREDS in Celebration**, final event we presented the research findings and four major impact case studies. The case studies combined researchers and stakeholder speakers to showcase the strength of the research as well as the strong connection to stakeholders and highlighting the extensive impact of CREDS. Some of the comments we received about the event were:

- Really enjoyed it and it was a superb showcase for CREDS
- Concise summaries which were sound-bite-able
- Unusual format – excellent getting users involved in presenting
- Seeing an overview of all the great work coming out of CREDS. I think this will be a hard act to follow.

2 CREDS Governance, Management, Knowledge Exchange and Impact

2.1 Governance and management of CREDS

Our Advisory Board (AB) has provided guidance on key strategic issues, approves the use of the Flexible Fund and supports specific areas of work such as reviewing outputs for the synthesis process. It includes stakeholders from industry, policy and academia, and has met twice a year.

The Executive Committee (consisting of the Director, Centre Manager and Theme and Challenge leaders) has continued to meet every six weeks. The Executive is the strategic decision-making body for CREDS, under our Consortium Agreement.

The CREDS core team of 10 staff is based in Oxford and they lead the programme management, engagement, knowledge exchange, impact, communication and equality, diversity and inclusion (EDI) activities of the centre.

We communicate within the consortium on a regular basis and have sent 111 internal newsletters (Consortium Updates) during the programme. We have had nine Whole Centre Meetings (WCM) of all staff in the consortium. Event reports are available on request. The Advisory Board are invited to all WCMs in addition to the whole consortium.

The Centre has an active working group to develop and implement its plan for Equality, Diversity and Inclusion (see section 4) and this includes career progression for Early Career Researchers (ECRs) and the studentship programme. Data archiving is covered within section 5 on the Flexible Fund.

2.2 Support for the impact journey

One of CREDS' main objectives is to create impact and this section describes the approaches we have used to achieve this.

CREDS considers that there is a strong link and clear journey from research, promotion and engagement, knowledge exchange and impact and this is the process that we support and encourage the whole consortium to follow.

Research ❯ Promotion & engagement ❯ Knowledge exchange ❯ Impact

CREDS has undertaken the following support for researchers to develop their own engagement, knowledge exchange and impact work.

2.2.1 Guidance notes on the Research to impact journey

There are four notes in the series. The first is a framing document, which describes the journey from research to impact and further three 'how to' guides.

- The research to impact journey: an overview
- How to promote research
- How to undertake knowledge exchange
- How to monitor and record impact

2.2.2 Investigating the academic literature on knowledge exchange to determine the factors for effective KE

Some of the problems surrounding impact and knowledge exchange (KE) is that it is not well defined or understood and researchers have limited time to engage with the topic because they are busy doing their own research work. To try and overcome these barriers the Centre Manager decided to review the academic literature to investigate the range of definitions and concepts linked to knowledge exchange. We were also interested to find out if the literature could boost our existing knowledge with ideas from other disciplines. This resulted in a variety of material that is published on our website.

- Academic peer-reviewed conference paper. Downing C., Higginson S., Wilkins T., Kobusinge R., Simon H., Jenkinson, K. 2021. The role of knowledge exchange in energy demand policy innovation. Conference paper 2-119-21 in *Proceedings of ECEEE Summer Study 2021*.
- Open access version: The role of knowledge exchange in energy demand policy innovation
- Eceee recorded presentation
- Blog: Using knowledge exchange to help research make sense.

2.2.3 Mid-term review

Our Mid-term review documents and 20 case studies provide the evidence for our achievements on impact. CREDS scored very highly in the Mid-term review with a 4 for engagement and 5 for impact out of 6.

2.2.4 Development of the suite of Research Findings materials

We decided to summarise all the work across nine themes to create one synthesised summary for the entire programmes' work over the 5 years. There is a 6-page overall findings summary and 1-page infographic. This has rarely been done in research programmes before. The synthesis project, started with the centre manager developing a timeline, template and instructions using the concept (Figure 1) which was a bottom-up collation of findings per strand of work, summarised into findings per theme, then synthesised by the Director into findings for the whole of CREDS sub-divided into 15 topics that were common across multiple themes with references back to the academic papers. Theme summaries were also written by the core staff using the template as part of the theme liaison role e.g. Buildings theme.

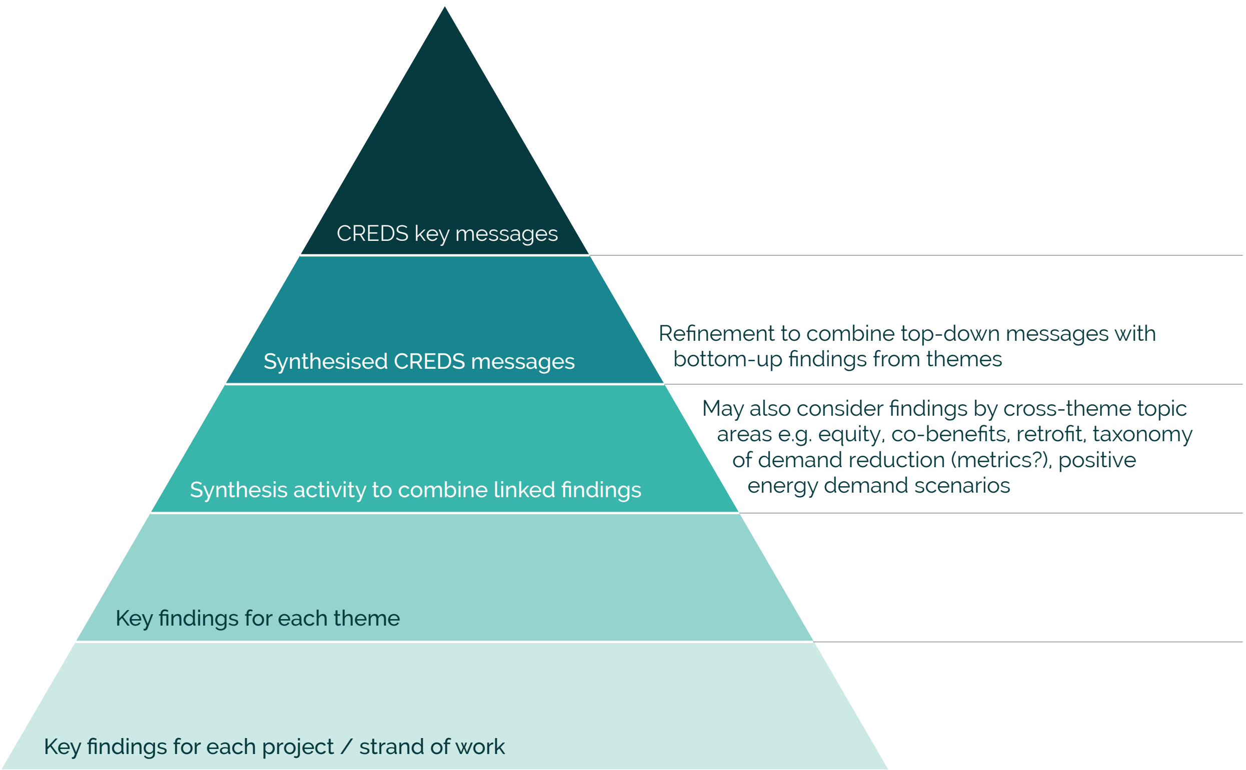


Figure 1: Diagram showing the synthesis co-creation process CREDS designed to develop its key findings.

2.2.5 Skill base and management

The core team were strategically managed to focus on achieving impact and the skill base included extensive professional expertise especially on communications, web and social media, marketing, stakeholder engagement and knowledge exchange.

2.2.6 Training courses on impact were arranged for the whole consortium

We contracted in an external consultant who ran two sessions for each of the nine themes. The training covered a review of what impacts have already been achieved and ensured that everyone recognised these, then identifying opportunities for further impact, discussing how they might be realised and creating an understanding of the priorities and resource implications. Then finally a second session prioritised the long list into an impact plan for each theme. This training has been funded from the core teams' budget. The feedback from the themes was that it gave them good ideas, thinking time to consider how their work could be more impactful, and practical ways of approaching new audiences with tailor-made material.

2.2.7 Impact Accelerator Award (IAA) funding was made available from the Flexible Fund within CREDS

The budget was approved by the Executive Management and the Advisory Board and the process developed by the Centre Manager. There are budget and proposal templates to complete that are submitted and reviewed by 3 members of the Executive that are not compromised (the work does not belong in their theme). By putting aside budget to fund these types of projects it sets the culture within the programme that we consider impact to be valuable. The funding can cover both fixed term and permanent staff time, not just expenses and there is one-to-one coaching and support available from the core team for promotion, stakeholder engagement, knowledge exchange and publication. These kinds of awards also support researchers to gain experience of impact generating activities, build stakeholder relationships and enhance their professional reputation through the process. (See section 5.5 for details).

2.2.8 Event management to maximise engagement and impact.

Every event/activity has a person allocated to it as the project manager. They set agendas for meetings, arrange meetings of the project team, manage the schedule, record actions, ensure activities are on track, manage the budget and arrange the marketing and promotion. The standard marketing routes are via internal communications processes (Consortium Update, administrators in core team, Whole Centre Meetings (WCMs), theme liaison process) and external systems (social media, website, Energy Demand Research Network, external newsletter). We always ensure that the notes of a meetings are shared with those that attended so that everyone is clear what was agreed and what actions are required, by when. This ensures that the cause and effect can be joined together, ensures that responsibility for actions are accepted and transparent and can form the interim milestones towards impact.

2.2.9 Impact recording

CREDS-wide impact spreadsheet, theme level impact spreadsheets – activities are drawn initially from the outputs table in the quarterly reports and then 'cause and effect' relationships are recorded, often in discussion with theme leads. Researchfish is a useful record of outputs but does not have any way of recording linked activities (cause and effect). This process also enables the Centre manager to identify new impact case studies to develop and evidence for Annual Reports and other documents.

2.2.10 One to one coaching

One to one coaching from the core team for individual papers, reports and outputs (workshops, webinars) was regularly given. In response to a request from researchers in the consortium who have a new output or activity, the core team will work with them on a one-to-one basis to develop a promotion plan initially identifying the audience, marketing tools, timing and any follow-on activities to maximise engagement with the research and the potential for future impact. They will manage that activity throughout its lifetime including follow-on activities. The aim of this promotion is to get the knowledge that has been learned from doing this research to those that might want to use it, whether that is beyond academia or to other disciplines and networks within academia.

2.3 Engagement and knowledge exchange activities

Engagement with UKRI has included twice-yearly meetings and regular emails including sharing big news stories. These are in addition to the WCMs and Advisory Board meetings where UKRI are also invited.

Wider engagement, impact and championing of energy demand has continued to be a major part of work this year and these activities are provided in detail in the Communications and Engagement Plan 2022.

Engagement with other consortia has strengthened with the Cross-consortium Engagement Meeting (CCEM) run by CREDS and UKERC in October 2022 and 2023. This resulted in a project on mapping the UKRI energy research investments being funded and activities. Challenges and next steps for EDI was discussed at the meeting in 2022 and knowledge exchange is the focus of the meeting in 2023. There was also an ECR cross-consortium net-zero conference 30 November to 1 December 2022 in Manchester. CREDS was one of nine partners led by UKCCSRC, and contributed funding, as well as speakers for an interactive session on knowledge exchange and a plenary on Bottlenecks and barriers to delivering net-zero: Recapping the discussion at the ECR net-zero conference.

When new research has a strong message for one of our main audiences and when it supports our key messages of energy demand reduction, we endeavor to undertake more comprehensive promotion and engagement work. This is normally with support from the core team and a bespoke promotion plan is developed that specifies the purpose of the engagement and the activities. The promotion planning process is where we determine which promotional tools would best reach the desired audience (e.g. blogs, policy briefs, webinars, social media campaign).

One of the tools we use is case studies of which there are now 20.

This year, CREDS core team hosted or assisted in the following 24 events. This list only covers our larger meetings and does not include our specific meetings with stakeholders or policy-makers.

Table 1: CREDS UK events

	Event title	Date	Speakers	Number of attendees
1	Public webinar: Policy options for a fair and equitable transition to net-zero	11 October 2022	Mari Martiskainen and Stuart Dossett	143
2	Cross-consortium ECR Net Zero Conference	30 November to 1 December 2022	Clare Downing, Sarah Higginson, Nick Eyre and Uttara Narayan (CREDS only)	200+
3	Webinar: Call for Supervisors for CREDS Studentships	09 November 2022	Nick Eyre and Sarah Higginson	17
4	Digitalisation for people and the planet – CREDS in Conversation international series	06 December 2022	Siddharth Sareen, Steffen Lange, Tilman Santarius, Tim Foxon, Noam Bergman, Tim Schwanen and Debbie Hopkins	80
5	Drop-in session: CREDS research findings promotion progress	06 January 2023	Hannah Harris and Kay Jenkinson	48
6	'Real performance' stock model workshop	31 January 2023	Richard Jack, Cliff Elwell, Michael Harrison, David Allinson, Dai Grady, Tadj Oreszczyn, Ahsan Khan and Sam Mancey	32
7	CREDS Future societies – digitalisation and energy demand Online Workshop	22 February 2023	Doug Cook, Maria Sharmina, Noam Bergman and Tim Foxon.	19
8	Data archiving troubleshooting session for consortium members	24 February 2023	Hina Zahid, Anca Vlad, Maureen Haaker from UKDS and Sarah Higginson	12
9	Public webinar: Clean steelmaking in the UK: How do we get there?	01 March 2023	Andrew Pimm, Paul Upham, Clare Richardson-Barlow, Alice Garvey, Verner Viisainen, Julian Gregory and William Gale	123
10	CREDS in Collaboration: Scotland (Public hybrid event)	29 March 2023	Nick Eyre, Greg Marsden, Connor McGarry, John Barrett, Kirsten Jenkins, Alex Hilliam, Faye Wade, Jan Webb, Gesche Huebner and Tadj Oreszczyn	In person 77 Online 67 Total 144
11	How can energy demand research take the racial justice agenda forward?	26 April 2023	Facilitation by Perry Walker, Uttara Narayan, Nick Eyre and Sarah Higginson	47
12	CREDS in celebration (Public hybrid event)	23/05/2023	Joanne Wade, Malcolm Morgan, Valentine Quinio, Sarah Higginson, Faye Wade, Tina Fawcett, Brian Berry, John Barrett, Jack Snape, Cliff Elwell and Nick Eyre.	In person 71 Online 74 Total 145
13	Heat pump flexibility: developing a common vision – stakeholder workshop	14 May 2023	Sarah Bailey, Stuart Fowler, members of the EQUINOX and HeatFlex heat pump flexibility projects	53
14	UKERC Summer School	19 to 23 June 23	Sarah Higginson and Nick Eyre	88

	Event title	Date	Speakers	Number of attendees
15	Retrofit Salary Sacrifice Scheme Workshop	27 June 2023	Facilitator: Mike Colechin, with facilitation team: Marina Topouzi, Peter Mallaburn, Colin Nolden, Tina Fawcett, Rali Hiteva, Kay Jenkinson and Yekatherina Bobrova	14
16	Public Webinar: From crises to net-zero	04 July 2023	James Dixon, Jillian Anable, Tim Foxon and Gesche Heubner	116
17	Improving data sharing workshop	19 October 2023	Catherine Jones, Rachel Bruce and Sarah Higginson	34
18	Cross-consortium Engagement Meeting 3	10 November 23	James Curwen, Clare Downing, Sarah Higginson, Rhiannon Lamb and Mari Martiskainen	25
19	How we use research in policy	14 November 23	Peter Mallaburn, Nick Eyre and Clare Downing	32
20	Governance of Heat workshop	21 November 23	Kayle Ente (Brighton & Hove Energy Services Co-op), Alan Patrickson (Durham County Council), Anna Devenish (Eindhoven University of Technology), Luke Fraser (Aquatera) Facilitators: Jake Barnes, Andrew Peacock, Gavin Killip, David Jenkins, Sarah Higginson	51
21	Insights from Covid-19 Travel Behaviour Survey (TRANSAS)	4 December 2023	Jillian Anable, Greg Marsden, Christian Bretter, Nadia Naqvi, Phoebe Pitcher. Chair: Nick Eyre.	108
22	DeViz Project stakeholderworkshop	7 December 23	Julie Goodhew	TBC
23	Which net-zero policies do people want? Local Green New Deals webinar	11 December 23	Caroline Lucas, MP for Brighton Pavilion, Tim Foxon, Claire Copeland, Donal Brown and Christian Jaccarini, Sussex University, Jamie Driscoll, North of Tyne Mayor, Sian Berry, Green MP Candidate for Brighton Pavilion, Ross Lowrie, Principal Manager for Net Zero at the North of Tyne Combined Authority	191
24	Unlocking Local Energy Plans Workshop: greater electrification of demand	13 December 23	Sarah Hassenpflug (Oxford City Council), Mark Saunders (Oxfordshire County Council), Damien Kelly (Energy Superhub Oxford), Michael Baker (Scottish and Southern Electricity Networks), Jacopo Torriti University of Reading (CREDS and Energy Demand Research Centre)	45

Part of the impact and championing objectives of CREDS is to share the findings of our research with policy-makers through two routes – consultations and direct relationships.

We have submitted 36 consultation responses since 2018 and these are all available on our website.

We have monthly meetings with two policy teams in DESNZ (housing retrofit and business energy use) and have had specific meetings about governance of heat, performance gap of buildings, adaptation, research needs and retrofit salary sacrifice concept. Ed Miliband MP (Shadow Secretary of State for energy security and net-zero) participated in our workshop on local delivery of retrofit.

The promotion of the CREDS research findings has resulted in meetings with the National Infrastructure Commission and various consultancy companies on the business side and the CCC and Scottish and Welsh Governments on the policy side. Discussions following the CREDS digitalisation event prompted new engagement with the digital team in Ofgem.

Many of the themes have ongoing, direct relationships with policy influencers and civil servants within these organisations. For example, the research team on the Positive Low Energy Futures (PLEF) team have ongoing relationships with DESNZ energy modellers, Government Office of Science and the Climate Change Committee (CCC).

Reports published and promoted this year

A few major reports were published and promoted this year in addition to the large number of academic papers published (see Research Fish for a full list).

- Reverse gear: The reality and implications of national transport emission reduction policies 1,588 page views (full report online) downloads 184
- The missed opportunity – ignoring the evidence on energy demand reduction 330 (full report online) downloads 68
- Green uplift: how a net zero economy can reduce fuel and transport poverty 314. Downloads 69
- Local Green New Deals: A transformative plan for achieving the UK's climate, social and economic goals locally
- Catalysing netzero retrofit: feasibility of an innovative salary sacrifice scheme

Blogs, reports and briefing analysis – total to date

There have been 226 blogs and news pieces, 28 briefings and 47 reports in total to date, from September 2018 to October 2023.

The top blog views to date are:

1. 2,328 Why we built a Place-Based Carbon Calculator
2. 2,077 New retrofit standards, new roles, existing policy, do they all fit together?
3. 1,743 You can't always get what you want: a reflection on Climate Assembly UK's deliberations on decarbonising passenger transport
4. 1,687 Rearranging elephants on the Titanic – Jillian Anable's keynote presentation from UTSG Annual Conference
5. 1,270 Cumbria mine: is there a technical need for new coal mines in the UK?
6. 1,196 A New Green Shovel? Options for the transport stimulus package
7. 1,052 Ending the daily work commute may not cut energy usage as much as one might hope
8. 1,030 The secret life of boilers – part two: how to burn less natural gas at home
9. 909 All crises are not made equal: what does Covid19 tell us about the public's capacity to change behaviour?
10. 878 Getting home insulation right

Report / briefings views to date

We have produced 47 reports to date and the top twenty most viewed are listed in order:

1. 7,104 Shifting the focus: energy demand in a net-zero carbon UK | downloads 3,062
2. 5,766 e-bike carbon savings – how much and where? | downloads 575
3. 4,937 Less is more: Changing travel in a post-pandemic society | downloads 666
4. 3,041 Positive low energy futures report (CREDS and PLEF site combined) | downloads 1,101
5. 2,746 Shared mobility – where now, where next? Second report of the Commission on Travel Demand | downloads 736
6. 1,594 Reverse gear: The reality and implications of national transport emission reduction policies | downloads 185
7. 1,447 Curbing excess: high energy consumption and the fair energy transition | downloads 245
8. 1,295 At a crossroads: Travel adaptations during Covid-19 restrictions and where next? | downloads 112

9. 1,264 The role of energy demand reduction in achieving net-zero in the UK | downloads 296
10. 1,174 Resource efficiency scenarios for the UK: A technical report | downloads 358
11. 1,140 Existing and future technologies for retrofitting the UK housing stock
12. 748 Reducing the UK's food footprint: Demand-side action for more palatable food emissions | downloads 80
13. 737 Vulnerability to fuel and transport poverty | downloads 114
14. 639 Industrial decarbonisation policies for a UK net-zero target | downloads 146
15. 639 Policy for energy demand reduction | downloads 118
16. 594 Building on our strengths: A market transformation approach to energy retrofit in UK homes | downloads 167
17. 583 Top ten tips for reducing your carbon footprint attracts international attention
18. 572 Building stock energy modelling in the UK: the 3DStock method and the London Building Stock Model | downloads 85
19. 569 Report: At a crossroads – Travel adaptations during Covid-19 restrictions and where next? | downloads 168
20. 495 The history of heat-as-a-service for promoting domestic demand-side flexibility: lessons from the case of budget warmth

Digital marketing

One of the many tools we use to promote the findings of CREDS is through our digital media channels (social media and website).

Digital newsletters were sent every month during 2023. There were 1045 subscribers to the newsletter by the end of September 2022, up from 833 last year.

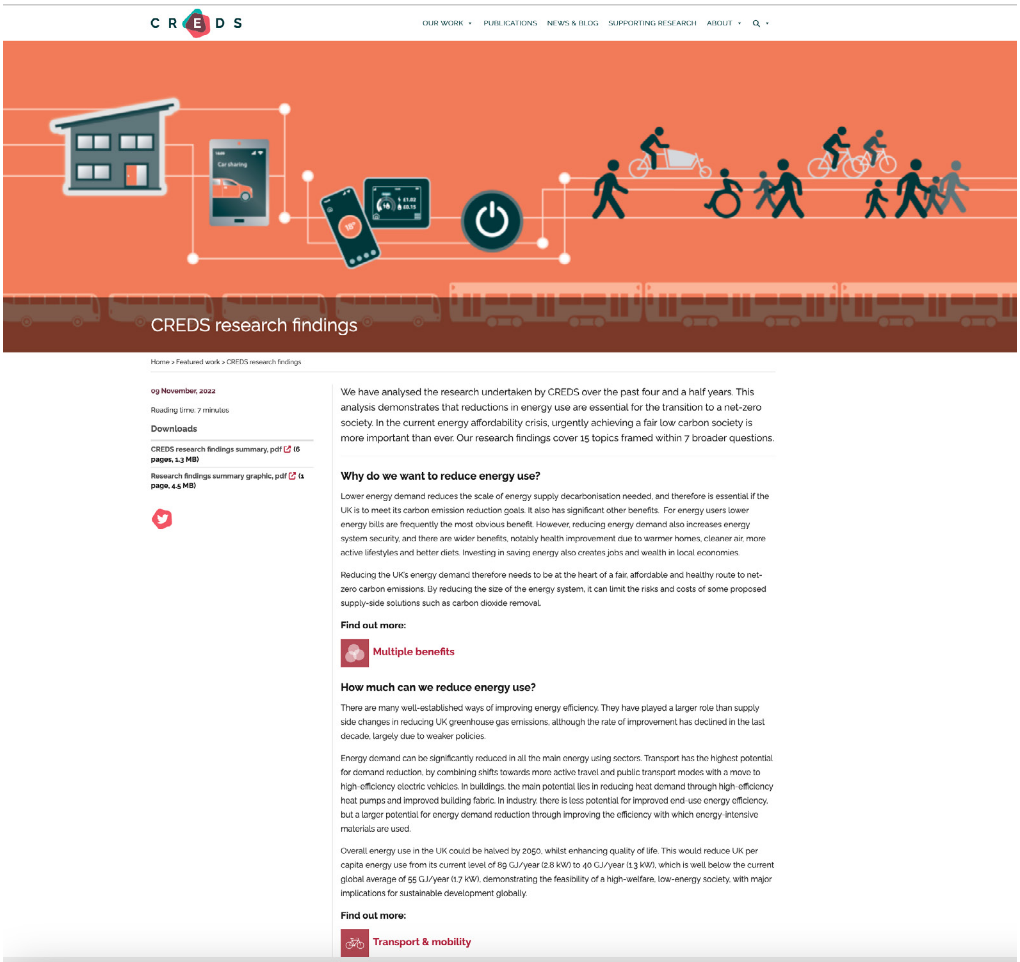
Twitter

- There were 3,155 Twitter/X followers by September 2022, up from 2,855 last year (an increase of 300).

Website developments

In 2022 we made a few design changes to improve the usability and findability of content on the website, specifically for researchers. A new section labelled 'supporting research', designed for the research community to access guidance materials on funding, engagement, events and knowledge exchange was added. We also now include preprints on the website.

We redesigned the CREDS homepage to reduce energy usage and become a best practice example:



CREDS OUR WORK PUBLICATIONS NEWS & BLOG SUPPORTING RESEARCH ABOUT

CREDS research findings

Home > Featured work > CREDS research findings

09 November, 2022

Reading time: 7 minutes

Downloads

CREDS research findings summary, pdf (6 pages, 1.3 MB)

Research findings summary graphic, pdf (1 page, 4.5 MB)

We have analysed the research undertaken by CREDS over the past four and a half years. This analysis demonstrates that reductions in energy use are essential for the transition to a net-zero society. In the current energy affordability crisis, urgently achieving a fair low carbon society is more important than ever. Our research findings cover 15 topics framed within 7 broader questions.

Why do we want to reduce energy use?

Lower energy demand reduces the scale of energy supply decarbonisation needed, and therefore is essential if the UK is to meet its carbon emission reduction goals. It also has significant other benefits. For energy users lower energy bills are frequently the most obvious benefit. However, reducing energy demand also increases energy system security, and there are wider benefits, notably health improvement due to warmer homes, cleaner air, more active lifestyles and better diets. Investing in saving energy also creates jobs and wealth in local economies.

Reducing the UK's energy demand therefore needs to be at the heart of a fair, affordable and healthy route to net-zero carbon emissions. By reducing the size of the energy system, it can limit the risks and costs of some proposed supply-side solutions such as carbon dioxide removal.

Find out more:

Multiple benefits

How much can we reduce energy use?

There are many well-established ways of improving energy efficiency. They have played a larger role than supply side changes in reducing UK greenhouse gas emissions, although the rate of improvement has declined in the last decade, largely due to weaker policies.

Energy demand can be significantly reduced in all the main energy using sectors. Transport has the highest potential for demand reduction, by combining shifts towards more active travel and public transport modes with a move to high-efficiency electric vehicles. In buildings, the main potential lies in reducing heat demand through high-efficiency heat pumps and improved building fabric. In industry, there is less potential for improved end-use energy efficiency, but a larger potential for energy demand reduction through improving the efficiency with which energy-intensive materials are used.

Overall energy use in the UK could be halved by 2050, whilst enhancing quality of life. This would reduce UK per capita energy use from its current level of 89 GJ/year (2.8 kW) to 40 GJ/year (1.3 kW), which is well below the current global average of 55 GJ/year (1.7 kW), demonstrating the feasibility of a high-welfare, low-energy society, with major implications for sustainable development globally.

Find out more:

Transport & mobility

- There is now no hero image (the large picture at the top of the home page of a website). Images are big energy eaters. Instead, a clear sentence about who we are is shown in more accessible language.
- There is now less content on the homepage. Previously, we would pull in six of the latest content posts (blogs, news etc.) – these queries used a lot of energy. Three is not only better for efficiency, but also simplifies things for the user. When there is less choice, there is less cognitive load (the strain a user experiences when he/she has to think too much just to get something done or make a choice).
- We also changed the image type throughout the site to WebP (lowers page load).

2.4 International activities

Visitors International: Programme (VIP)

The Visitors International: Programme (VIP) was launched at the ECEEE conference in France on 6th June 2019 (See Annual Report 2019 Impact case study 2.3). As a result of the COVID pandemic a few of the visits did not go ahead but the collaborations continued remotely. Two visits went ahead in 2023.

List of applicants accepted as VIPs

Name	Affiliation	Host
Yohei Yamaguchi	Osaka University, Japan	Jacopo Torriti
Selin Yilmaz	University of Geneva, Switzerland	Jacopo Torriti
Max Kleinebrahm	Karlsruher Institut für Technologie (KIT), Germany	Jacopo Torriti
Fatima Khushnud	Independent Power Producers Association (IPPA), Pakistan	Tina Fawcett
Yael Parag	School of Sustainability, Interdisciplinary Center, Israel	Tina Fawcett, Mike Fell
Petra Hofman	Tilburg University, The Netherlands	Jan Webb
Thomas Longden	Western Sydney University, Australia	Tina Fawcett

International engagement

There has been extensive international engagement with all themes involved in individual collaborations and many papers presented at international conferences.

In addition, as a whole consortium we also sponsored the eceee (European Council for and Energy Efficient Economy) conference, Summer Study in 2019, 2021 and 2022. In 2019 we ran 3 workshops, presented 11 papers, wrote 2 blogs and won a poster prize, in 2021 (virtual conference) we presented 13 papers and in 2022 we ran two plenary sessions, 3 workshops and presented 11 papers.

Finally, during 2022-23 we ran a webinars series entitled 'CREDS in Conversation' and the details are listed in Table 2. We also interviewed some of the speakers from our webinar series to produce a podcast series showcasing CREDS' involvement in internationally leading research. This is accompanied by a blog to explain our novel approach.

Table 2: International events

	Title of event	Date	Speakers	Attendees
1	Making mass retrofit a reality: A webinar from CREDS and Buildings & Cities	20 October 2022	• Nick Eyre | CREDS • Faye Wade & Jan Webb, MBE | Edinburgh University • Erwin Mlecnik & Henk Visscher | TU Delft • Kate Simpson | ICL • Veronika Schropfer | Architects' Council of Europe • Lord Deben | Climate Change Committee	137
2	Webinar and Panel Discussion: IPCC finding on Energy Demand Reduction	11 May 2022	• Yacob Mulugetta | Climate Compatible Growth • Joyashree Roy | Jadavpur University, • Felix Creutzig | TU, Berlin • John Barrett | CREDS • Patrick Devine-Wright | University of Exeter	179
3	International Reading Rooms and podcast on Price Elasticity	18 May 2022	Jose Luis Ramirez-Mendiola, Jacopo Torritti, Anna Alberini	Invited audience
4	Realistically radical policy options	7 September 2022	• Magnus Bengtsson | Hot or Cool • Yael Parag | Reichmann University, Yamina Saheb | OpenExp • Stuart Capstick | CAST Centre	159
5	Digitalisation for people and the planet	6 December 2022	Siddharth Sareen, Steffen Lange, Tilman Santarius, Tim Foxon, Noam Bergman, Tim Schwanen and Debbie Hopkins	80
6	Clean steelmaking in the UK: How do we get there?	1 March 2023	Andrew Pimm, Paul Upham, Clare Richardson-Barlow, Alice Garvey, Verner Viisainen, Julian Gregory and William Gale	123

We collect feedback from our events, for example 'Thank you very much sharing the presentations from the Clean Steelmaking webinar. It is so valuable and very kind of you and CREDS team.' Technical Affairs Director, Turkish Steel Producers Association.

3 Research progress

During this period, CREDS staff have authored over 100 publications, and these outputs are listed in Research Fish. We have summarised the outputs from the 5+ years below:

464	Publications
108	Collaboration & partnerships
136	Further funding
1212	Engagement activities
428	Influence on policy
135	Influence on business
6	Research tools & methods
61	Artistic & creative products
2	Spin-outs
8	Awards & recognition
7	Use of facilities & resources
29	Other

In this annual report, we have focused on summarising the findings from each theme for the whole of the 5 years rather than describing the project activities.

3.1 Buildings

Our buildings and energy research looked at how to shift the UK built stock to net-zero by 2050 in the most cost effective, resilient, acceptable and practical way, maximising the multiple benefits and minimising unintended consequences.

There is a significant resource of untapped energy-saving opportunities in UK homes, with technical potential exceeding 50% and a cost-effective potential exceeding 25% by 2035. We have found that the majority of the long-term energy saving comes from moving to high-efficiency heating systems (like heat pumps), rather than from insulation.

Energy Performance Certificates (EPCs) must be improved

We incorporated smart meter data into energy ratings to cover both flexibility and energy efficiency.

Flexibility: Providing electrical demand response from structural thermal mass has been studied from a modelling perspective and through a small number of commercial trials. Modelling studies do not realistically estimate the transient characteristics of real buildings and their heating systems such as how they cool down and warm up. Commercial trials have not explored perceptions of the occupants and their thermal comfort related to heat-related demand response, nor the real-life behaviour of heat pumps under demand response instructions.

The flexibility work has had two main outcomes. Firstly, the proposal of a flexibility rating system (metric) for domestic buildings. Secondly, the generation of insights into how this flexibility potential may be achieved or limited.

The first outcome was accomplished by trialling and developing different possible metrics, all using smart meter and internal temperature data (the same data as used by the energy efficiency metric below). We collaborated with the Flexibility theme whose work is broader than the building and EPC perspective on which we focus. The metric has been tested on a medium-sized dataset of homes and now requires further testing and validation. This work is starting to have significant impact, with strong interest from the Department for Energy Security and Net Zero (DESNZ), including a jointly organised flexibility metrics workshop.

The second outcome was achieved using three case studies of real heat pumps providing demand response. This small-scale study was the first to report on different control strategies for demand response and their consequences in real homes, and to analyse in detail the thermal comfort of the occupants.

This flexibility metric could allow an estimate of financial savings from time-of-use tariffs to be provided to householders as part of a decision on heat pump installation. Distribution Network Operators (DNOs) could then estimate how many heat pumps will need to run during peak demand times, although there are questions to be resolved in terms of practical implementation.

Efficiency: Existing EPCs are based on estimates of energy use, factoring in square meterage and how quickly the building loses heat (also known as the heat transfer coefficient (HTC).

We have developed methods to calculate the HTC based on in-situ measurements of temperature, and including other data such as solar gain and high-resolution smart meter data that will significantly improve the accuracy of EPCs. This has generated significant insights into their applications, the limitations in their accuracy and gaps in our understanding. This opens up huge potential to characterise buildings on their real performance and predict the energy, cost and comfort implications of building and heating system retrofit.

This work has been shared with DESNZ during their SMETER innovation competition and follow-on conversations resulting in a large impact on policy that has led to the SMETER programme being accelerated and further collaboration with DESNZ.

Performance gaps (the difference in energy performance between design and construction) can be addressed

EPCs are a key policy tool and their usefulness can be considerably enhanced by linking in-use data to obtain in-use heat transfer coefficients (SMETER) and to rate a buildings' flexibility. Whereas, on average, homes with better Domestic EPCs have lower energy use intensity, this is not the case with non-domestic EPCs and therefore poses a serious challenge to using EPCs as a policy instrument in the non-domestic sector.

Heat pump-ready homes

Modern boilers have up to 70 transducers. This provides a range of data that can be useful in understanding how energy is used in buildings, improving heating system performance and identifying if homes may have heat emitters which are suitably sized for lower temperature heat pumps.

Thermal imaging of buildings

It is now practical and cost-effective for infrared visualisation – using small, new generation cameras – to be undertaken on-site to identify building defects during construction. This helps to reduce the performance gap. Additionally, the experience of 'seeing' the construction in thermal view supports the construction professional's awareness of, and understanding about, critical thermal defects.

Health impacts of energy efficient homes can be considerable

UK homes have issues around being too cold, too hot and too damp. Hence, in planning for net-zero, emphasis needs to be on improving the indoor environmental conditions of our building stock. A substantial number of UK homes experience temperatures that are judged as too low (below 18oC) for the health of vulnerable people (which includes those under age five, over age 60 and those with ill-health). Older dwellings, detached homes, single occupancy and living in the North of England are all associated with the lowest share of hours at the recommended temperature threshold in the bedroom, living room and hallway. Living in cold, damp, and hard-to-heat homes is linked to lower wellbeing, as is struggling with affording heating costs.

However, greater attention is needed to avoid unintended health consequences, such as an increase in radon. Energy efficient homes (which are not leaky) in regions with high levels of radon need to have sufficient ventilation to ensure safe levels are achieved following retrofits.

Policies are needed to create equitable solutions for comfortable, sustainable homes. The UK Government and Local Authorities could support programmes that identify households who are at risk from low indoor temperatures and air pollution such as those with ill-health, the elderly or those who are unable to afford net-zero technologies. Housing associations can use this evidence to support their actions to invest and implement technologies that improve indoor environments and reduce the risks to vulnerable households.

Heat pumps are the key decarbonising technology for buildings

Decarbonising energy use in buildings will rely on the deployment of heat pumps. However, there are policy, technical, public acceptance and cost challenges to be overcome to achieve roll out at the level and speed required to meet net-zero goals. For example, target deployment rates of 600,000 per annum by 2028 are challenging given current deployment rates of around 35,000 per annum (2021) and the small number of installers with the necessary skills in the sector.

Getting heat pumps to work as efficiently as possible is one of the greatest opportunities and challenges to UK decarbonisation. During cold weather, improving the efficiency of heat pumps from 'average' to 'good' efficiency could save as much energy as insulating all solid walls in UK homes.

Heat pumps could be used flexibly to help manage peak electricity demand, but more standardisation of the heat pump stock would be required. By flexibility we mean providing electrical demand response from structural thermal mass. See EPCs for more information.

Hybrid appliances which combine a gas boiler with a heat pump in a single box that can replace a conventional gas boiler could facilitate a low disruption, low-cost pathway to net-zero. Energy demand could be reduced by 60% (compared to current gas boilers), but also reducing peak electrical demand by 10 GW (compared to air source heat pumps) which is important during a transition. Control and sizing of the hybrid are critical to its impact.

Heat pumps powered by renewable electricity challenge the 'fabric first' approach. With offshore wind and photovoltaic (PV) costs reducing, and with heat pumps needing only a quarter of the energy of gas boilers, it is becoming cheaper to generate decarbonised heat than to save it. This may limit the need for 'deep' retrofit, with insulation prioritised where it is particularly cheap (e.g. during normal refurbishment/extension) or where it is essential for health and comfort and for the efficient operation of heat pumps. Successful building retrofit and renovation for energy efficiency requires attention to be paid to timings, bespoke/building-specific requirements, and complementary objectives, i.e. more than just carbon reduction.

Buildings modelling as part of the Low Energy Demand scenarios – Positive Low Energy Futures

We examined a number of Low Energy Demand scenarios to explore how the buildings stock might reduce its energy demand to meet net-zero targets. We created 'simulations' of potential futures based on a well-developed narrative written by experts across a range of disciplines and fields.

For the residential sector we used the UK National Household Model (NHM) to explore the impact of various measures on future housing stock. The measures included in each of the LED scenarios explore incremental levels of technical ambition applied across the housing stock. They look at faster, deeper, and more widespread roll-out of building fabric retrofits; consider more ambitious heat pump, hybrid heat, and solar hot water programmes; and assume different requirement levels for new build housing apply as energy and infrastructure use in other sectors change.

For the non-domestic sector, we developed a bespoke energy model. The non-domestic sector includes a complex mix of buildings with a wide variety of different uses, from purpose-built retail and commercial spaces, through to storage and refrigeration, hospitality, health, education and public services. The energy demand reductions in the scenarios take a two-pronged approach. On the one hand, they include energy efficiency measures such as energy management systems, building retrofit, building system control, ventilation and cooling and more efficient appliances. On the other, they consider changes to the overall growth in the non-domestic stock itself. The latter results from changes in the wider economy, e.g. reduced retail and office space requirements due to a move to online retail and home-working, and leads to changes in growth expectations for non-domestic floor space.

The outputs of the modelling related to buildings (shelter and non-domestic has been combined with outputs from mobility, nutrition, land use and materials and products to create a narrative that is used to inform a bottom-up analysis of energy service demands in each sector). These are then used in an economy-wide model to construct "net-zero" scenarios for the UK. See the Positive Low Energy Futures report for more information.

Building energy modelling for estimating future energy demand

We have advanced the modelling of the building stock by improving our 3DStock and SimStock models to include representation of every building in the stock and at every level at the same address (geo-located), for example, shops at street level and flats above. We started with the non-domestic stock of industrial, commercial and public buildings, and have now included the domestic stock of houses and flats, as well as mixed-use buildings.

The Greater London Authority (GLA) and London Boroughs are now using the London Building Stock Model (constructed from the 3DStock method) to tackle fuel poverty and improve the energy efficiency of the capital's building stock. It was launched in September 2020, including a feature in the Evening Standard. LBSM covers around 3.5 million properties across the capital and its purpose is to help identify poorly performing buildings so that they can be prioritised for retrofit work to reduce their energy use resulting in money and emissions savings.

3DStock models are being used to support energy planning by other places, including in Sheffield and Wales, as well as in consulting work for DESNZ, and the NHS plan for net-zero. In addition, the team have also developed the London Solar Opportunity Map, for the GLA. It shows the potential output from solar electricity (photovoltaic) and solar hot water installations on all roofs and areas of open land. It suggests that installing PVs on warehouses may be preferential for achieving London's solar generation targets.

The cost-of-living crisis

The winter of 2022-23 has seen large increases in energy prices and the cost of living in the UK. Both smart meter data and self-reported data show a substantial increase in energy-saving efforts, including a one-degree Celsius drop in thermostat settings. About 40% of households in GB reported turning down their boiler flow temperature – an action that was heavily promoted in the winter of 2022-23 in public energy awareness campaigns – and leading to energy savings in those households that implemented it. However, other actions that householders reported doing most often were not the ones associated with the greatest possible energy or money savings, e.g. closing curtains at night and turning off lights. This emphasises the need for targeted and highly specific advice on energy saving. More than 10% of households were unable to keep comfortably warm in their living room and 15% struggled with affording heating costs.

3.2 Transport and Mobility

Our Transport and Mobility work clearly demonstrates that the amount of energy used in the UK for transport (vehicles, trains, aviation) can be reduced by 60% by 2050, compared to current levels.

This would make the task of reaching the government's net-zero target much easier, and would limit the amount of investment required for new energy and road infrastructure. Moreover, policies that carefully target high-energy personal travel (e.g. long-distance travel) are seen as the fairest, most acceptable solution. The predominant policy focus is on a transition to electric vehicles but this will be insufficient to achieve net-zero carbon by 2050. To meet the 2050 deadline, there must be an overall reduction in travel demand in the UK, alongside an increase in public transport use and a shift to active travel options.

Most high-carbon personal travel is done by a small number of individuals

We found that a very small number of long-distance trips is responsible for a large proportion of personal transport-related carbon emissions. Overall, 3% of trips are responsible for 60% of miles travelled and 70% of carbon emissions from personal travel (including flights).

Our research showed that carbon footprints for personal travel are so unequally distributed that policies targeted at 'high consumption' activities will affect relatively small proportions of the population, yet will have a greater impact than 'blanket' policy approaches. For example, just 11% of car users are responsible for 44% of miles driven, and the majority of flights (75%) are taken by 15% of people.

Targeting the highest-carbon travel behaviours is seen as fair

We show that public debate on fair and sustainable consumption is likely to be needed to establish the acceptability of any policies that target travel choices, particularly when we consider 'excess' travel consumption. For example, our work suggests that people and policymakers are not aware of the severity of the climate impacts of aviation and thus the importance of cutting demand for air travel.

Voluntary behaviour change has so far been ineffective and our research suggests that without structural change, regulation and economic signals, people will have no incentive to switch to lower-carbon travel options. It is clear that affordable access to low-carbon travel alternatives (notably public transport) will be need to support the public's switch to active travel and electric vehicles (EVs).

Our research used workshops to test options for reducing travel demand. Participants represented the full range of travel behaviours. Presented with relevant information and taking account of the trade-offs associated with different approaches, people gave their support to regulation and even rationing-with-choice, which were seen as the fairest options.

Business flights, excessive car mileage and the most environmentally damaging vehicles were seen as valid targets for policies options such taxation or regulation. However, any changes would need to incorporate protections for vulnerable groups.

Our research suggests that policies should clearly signal preferred travel behaviours that will enable the UK to achieve its net-zero goals. So, fares for high-carbon air travel and low-carbon rail journeys should reflect their relative contribution to net-zero ambitions.

Policy opportunities for greatest impact

Travel energy demand is much more unevenly distributed than housing energy demand. We argue that to achieve the UK's ambitious carbon reduction targets, in the short term, policymakers would have greatest impact by prioritising the reduction in long distance car use and frequent flying over reducing household energy use.

Transport emissions are concentrated in the wealthiest groups of our society, with the wealthiest 10% households being responsible for 25% personal transport emissions.

Carbon emissions from aviation are much bigger in absolute and relative terms than is typically acknowledged. Frequent flying has been normalised, but is largely undertaken by the wealthiest in society. Policy changes such as a frequent flier levy or air travel taxes would affect a small number of people, mostly those on higher incomes, but would have a significant benefit for carbon reductions.

CREDS' researchers made use of UK-wide survey data to assess travel demand and travel behaviours pre-, during and post-lockdowns associated with the Covid-19 pandemic. This has provided unparalleled opportunity to see the impact of reduced travel demand and to identify travel patterns that could be encouraged for the long-term for multiple benefits such as health, congestion, net-zero and air quality. Our analysis showed that the biggest and most sustained change was an increase in walking. There was also an increase in cycling during the pandemic, but largely for leisure rather than replacing car trips. Neither car travel nor the use of public transport had returned to pre-pandemic levels in 2022.

A focus on shifting short-distance trips to low carbon options will be insufficient, and misses the bigger prize of cutting the much larger carbon footprint of long-distance travel, particularly flying and long-distance car travel.

Helping communities to plan for change

CREDS was able to fund the development of the Place-based Carbon Calculator(PBCC). This free online, area-based carbon footprint tool for England takes data on household and travel energy use, and shows how the composition of carbon footprints vary from area to area. This can be used to help organisations like local authorities and community-based groups to understand the make-up of their local carbon footprint, and to plan the most effective ways to reduce carbon emissions.

Not all communities can contribute in the same way (rural areas are usually more car-dependent than urban areas, for example) and the PBCC provides information to help to develop appropriate place-based responses.

Mobility options from the sharing economy

We investigated how the sharing economy could reduce transport-related carbon emissions. At any one time only 15% of the private car fleet is in use, with around a third of vehicles not moving in a given week. Only 15% of cars follow a typical 'commuting' pattern, so there is scope to make better use of the existing car fleet. Our Commission on Travel Demand showed that we could meet mobility demands with a smaller vehicle fleet, with opportunities for innovative mobility services, such as shared ownership, but further work would be needed to demonstrate how shared mobility services could be developed, with the support of consumers.

Methodologies

The findings described here are a result of several, diverse individual research projects conducted as part of CREDS transport and mobility theme. These projects used a suite of methodologies, including literature reviews, data analysis and modelling (e.g. Place-based carbon calculator, long-distance travel), surveys (e.g. Covid travel behaviours, high energy demand consumers) and stakeholder workshops (e.g. high energy demand consumers). This work generated several peer-reviewed outputs such as research papers (listed in the publications section of this website) and book chapters.

3.3 Materials and products

Our Materials & Products research has found that delivering net-zero in industry will require a combination of improved material resource efficiency, energy efficiency improvement and new zero-carbon industrial processes. In the short term, materials efficiency has the greatest potential, with new processes contributing more as we move towards 2050.

Our Materials & Products research focused on four research strands:

3.3.1 Industrial energy demand

The UK no longer has the opportunity to gradually introduce new technologies and allow for the moderate uptake of low-carbon options. Instead, the UK Government acknowledges it needs to take an active role in driving innovation and correcting market failures. Such an approach requires robust evidence to ensure that environmental, social and economic goals are met. Good quality data is vital to implement this transformation and inform credible decision-making.

This strand of research concludes:

- There is an urgent need for a public data strategy which gathers linked data on emissions, technologies, and related environmental, social and economic impacts.
- High-quality data and indicators for the monitoring and management of industrial energy should respond to the needs, both present and future, of stakeholders.
- This ideal dataset(s) should be readily updatable, open access, and independently managed, while ensuring consistency in concept, terminology and classifications.
- That the Department for Business, Energy and Industrial Strategy (BEIS) and the Department for Environment, Food and Rural Affairs (Defra) would be well-placed to help establish a central public body that works with key agencies (for example the Office for National Statistics (ONS) and Committee on Climate Change (CCC)) with the aim of delivering an improved evidence base on industrial energy, emissions and technologies.

In this strand of research our focus on exploring industry emissions from a consumption-based, emission perspective has fundamentally changed the methods of Government reporting, our understanding of progress and the policy options available to deliver global reductions in energy demand and GHG emissions. Coupled with this, our analysis of resource efficiency has provided key insights into an under-explored area of Government policy (we have provided support on a weekly basis to Defra, BEIS, Cabinet Office, the Treasury and the CCC using our MRIO model that is being continually developed with CREDS funding). In addition, this approach has been adopted by HM Treasury to analyse the distributional impacts of carbon footprints in their interim report of their Net Zero Review. We have formed a cross-governmental group to discuss monitoring energy/resources and economic implications, policy assessment and analysis and the interrelationship between all these issues that sit across a number of Government departments. The group includes Defra, BEIS, ONS and Innovate UK. It is now administered by Defra and meets on a two-weekly basis. The University of Leeds is the only academic organisation in the group to focus on how our research can be applied across all the departments.

Furthermore, this research has had a significant impact in relation to calculating the UK's consumption-based GHG emissions and formulating a policy response to address them. Over many years, the research team at the University of Leeds, led by Professor John Barrett, has both supported a number of Government departments and the CCC in relation to consumption-based GHG emissions. We have now made significant contributions to the past five major reports by the CCC that report progress to Government. This has involved giving the CCC access to our global MRIO model that tracks the GHG emissions associated with global supply chains. We have directly contributed to reports on multiple areas including measuring the UK's consumption impacts and the resource efficiency.

Alice Garvey completed a secondment to support the CCC in their analysis of industrial energy policy options for the Sixth Carbon Budget report. We provided an updated analysis of resource efficiency strategies for UK industry. We also provided information specific to Scotland to allow us to undertake a similar analysis for the Scottish Government. Without the development of the MRIO model, consumption-based emissions would simply not have featured in CCC reports. Our analysis of resource efficiency has provided key insights into an under-explored area of Government policy. The concept indicates that the total amount of resources (raw materials and process emissions) influences the scale of emissions and by changing the materials and process used, we can radically alter the emissions, but maintain the same function. The research from Leeds allowed the CCC to report to UK Government that resource efficiency was equally, if not more, important than the previous focus on energy efficiency.

A new report about resource efficiency, which was produced in collaboration with environmental charity WRAP, was launched on 26 March 2021. Through eight complementary strategies, the report sets out how changing the way we use materials as well as energy could deliver an additional 100 million tonnes (Mt) CO_2e reduction in territorial emissions between 2023 and 2032, boosting savings from the UK government's Ten Point Plan for a green industrial revolution by over 50%. It could also contribute over 10% (89 $MtCO_2e$) of the reductions required from the 5th to the 6th recommended Carbon Budgets. The report attracted a lot of activity on Twitter and coverage in a selection of media, including the Radio 4 Today programme, Business Green, Drapers Online, MRW Magazine, Resource Magazine, Sustainable Packaging News. And finally, a series of sector specific papers have been published in world leading journals, including Technology and material efficiency scenarios for net zero emissions in the UK steel sector, and Towards net zero nutrition: The contribution of demand-side change to mitigating UK food emissions.

3.3.2 Energy demand lifecycles

Changes in consumption patterns (e.g. transport modal shifts, energy use by households, choice of longer-lasting products, dietary shifts) to low-carbon alternatives present a great potential for emission reductions. This strand of research focused on consumption-based mitigation options across various end-use sectors, including food, housing, transport and other consumption.

What the work explored:

A systematic review entitled Quantifying the potential for climate change mitigation of consumption options was published in the special issue on the Focus on demand-side solutions for transitioning to low-carbon societies in Environmental Research Letters. Following on from this, an article entitled Household sharing for carbon and energy reductions: the case of EU countries was published in the special issue on Energy efficient cities of today and tomorrow in Energies. This work explored the differences and similarities in terms of household dynamics across EU countries and highlights their energy and carbon implications.

Further expanding this focus on distribution and sustainability, an article entitled The unequal distribution of household carbon footprints in Europe and its link to sustainability was published with gold open access in the Journal of Global Sustainability. Diana Ivanova has continued to explore themes of global distribution and household consumption in Future changes in consumption: The income effect on greenhouse gas emissions in Energy Economics.

A further project associated with this strand was the independent review of industrial decarbonisation policies to inform the 6th Carbon Budget recommendations of the CCC. The project (March 2020-December 2020) involved regular engagement with researchers in the committee as well as representatives from BEIS and the Energy Systems Catapult through weekly working group meetings. Extensive stakeholder engagement was carried out in the form of three steering group workshops (July, August, September 2020) as well as multiple individual consultations with representatives from the civil service, industry, trade organisations and the third sector (e.g. Green Alliance). A survey of stakeholders has also been completed (July-August 2020). The findings have been published in an independent CREDS report in December 2020 to coincide with the publication of the committee's recommendations. A policy brief and downloadable Industrial decarbonisation policy dataset were also published alongside the report.

This strand of research also engaged substantially with the construction sector. The team explored the science-based targets initiative which seeks to align corporate carbon reduction targets with global decarbonisation trajectories. Science based targets: On target? was published in Sustainability in February 2021. The team also brought this work together with a focus on distribution, wellbeing, and justice, publishing a briefing paper on the Ten principles for building back better to create wellbeing economies post-Covid (co-authored by Milena Büchs, Alice Garvey, Diana Ivanova from CREDS and others), and a journal article on the Global redistribution of income and household energy footprints: A computational thought experiments. Further research includes:

- Social outcomes of energy use in the United Kingdom: Household energy footprints and their links to well-being
- Achieving emission reductions without furthering social inequality: Lessons from the 2007 economic crisis and the COVID-19 pandemic
- Emissions savings from equitable energy demand reduction

Finally, this strand contributed to the application and critique of a new UK standard for whole-life carbon assessment in buildings, which was incorporated into the Green Construction Board Low Carbon Routemap. In November 2021 the UKGBC launched their Net Zero Whole Life Carbon Roadmap for the UK built environment. Jannik Giesekam worked with Arup and a range of industry stakeholders on the delivery of the roadmap. The roadmap, including a Pathway to Net Zero for the UK Built Environment, a technical report, a summary for policymakers and a set of stakeholder action plans were developed.

3.3.3 Energy demand modelling

This strand of research focused on producing a new version 2.0 of the MARCO-UK model, such that it can then be applied to CREDS research questions, for example giving new insights into the effects of different industrial futures on the economy, energy demand and employment. The aim of this strand was to provide a comprehensive assessment of energy and resource productivity options that have the potential to deliver a reduction in industrial energy demand. It considers the broader implications of these strategies through the quantitative lens of the improved MARCO-UK model by assessing the scale of energy rebound effects, conflicting outcomes between different strategies, and the broader socio-economic implications on employment and trade.

The project focused on developing improvements in relation to two key aspects of the MARCO-UK model:

- Improved granularity: industrial sectors: split energy (FEN_IND) to match BEIS sectors; split fossil fuels/renewables inputs; splitting OTHER into sub-sectors: commerce; government; agriculture; other; including transport; including digital/ICT use, and
- Constraints/feedback loops: Energetic constraints (efficiency limits and net energy inputs); energy cost share vs GDP limits; financial constraints: e.g. private and government debt; CO2 feedbacks (damage function); labour force availability.

This strand published two working papers, Socio-macroeconomic impacts of meeting new build and retrofit UK building energy targets to 2030: a MARCO-UK modelling study, and a report on the socio-macroeconomic impacts of the UK Labour Party's renewable and low carbon energy targets in the '30 by 2030' UK Energy Plan. In November 2021 a paper on Socio-macroeconomic impacts of implementing different post-Brexit UK energy reduction targets to 2030 was published in Energy Policy.

Another strand of this theme has focused on modelling energy footprints at a national and international levels. Notable publications include:

- Household final energy footprints in Nepal, Vietnam and Zambia: composition, inequality and links to well-being
- Three-scope carbon emission inventories of global cities
- Decomposing the drivers of residential space cooling energy consumption in EU-28 countries using a panel data approach.

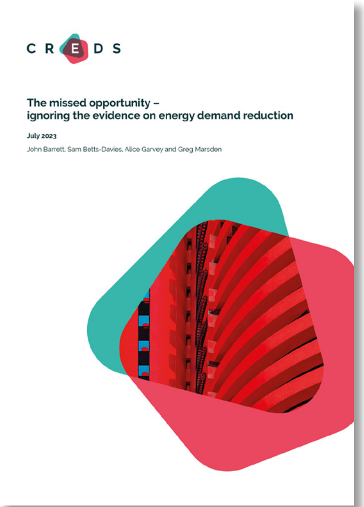
This has been coupled with a focus on UK level policies and interventions:

- Reducing inequality resulting from UK low-carbon policy
- Thermodynamic efficiency gains and their role as a key 'engine of economic growth'
- Untangling the drivers of energy reduction in the UK productive sectors: Efficiency or offshoring?

3.3.4 Low energy demand scenarios – Positive Low Energy Futures (PLEF)

Positive Low Energy Futures was a cross-centre, collaborative piece of modelling work aimed at plugging a vital gap in the UK national energy demand research landscape. The project was a flexible, iterative process, born out of the CREDS flexible fund, that allowed us to bring together 17 modelling experts from across several institutions to deliver the most comprehensive estimate for the potential role of energy demand reduction in the UK's climate mitigation challenge to date. The research culminated in results demonstrating that the UK could potentially reduce its energy demand by up to 52% by 2050, reduce the cost of the transition to net-zero and reduce our reliance on risky Carbon Dioxide Removal (CDR) technologies that are unproven at scale – all whilst improving social outcomes.

From its inception, the Positive Low Energy Futures project sought to ensure that the impact would reach a diverse set of stakeholders. By design, research findings were strategically publicised to multiple stakeholder groups, led by a communication and promotion strategy utilising a variety of mediums (digital content, animations, webinars, reports and high-profile academic journal papers) and platforms (online talks, conference presentations, media engagement), supported by the key skills in impact and engagement held by the CREDS core team.



To promote the research project's findings, CREDS hosted an online launch in October 2021, with a webinar, short animation, a microsite, a social media campaign and blogs. There have been 3041 views of the report and over 400 views of the accompanying policy briefing since its launch. It was attended by a variety of different stakeholders including academics, policymakers and politicians as well as private sector groups. Shortly after, we were contacted by the Government Office for Science, who attended the launch and were interested in using the modelling framework developed for Positive Low Energy Futures to generate their own scenarios for an upcoming net-zero Foresight project. This research looked to explore the role of societal and behavioural change within net-zero pathways and adopt a similar methodological approach to us. As a result, the CREDS modelling team were heavily involved in the development, modelling and write up of the subsequent GO-Science report, which found that pathways with little societal demand change will find it much harder to deliver net-zero emissions by 2050. A further report, The missed opportunity – ignoring the evidence on energy demand reduction considers whether the UK Government has recognised the wealth of evidence on energy demand reduction strategies provided by CREDS and GO-S in guiding the selection of policy options to achieve the UK's interim climate targets described in the 'Powering up Britain' report.

This collaboration also led to further opportunities to present the original PLEF scenarios to other stakeholders throughout government, including a breakfast meeting of the Government's Chief Scientific Advisors and several committee meetings hosted by the All Party Intelligent Energy Group and All Party Parliamentary Group for Renewable and Sustainable Energy and the Parliamentary and Scientific Committee. These opportunities were available thanks to the flexible approach taken to producing impact and a willingness to undertake further collaborative work with interested parties.

Furthermore, Positive Low Energy Futures was also presented to a European audience at the 2022 eceee (European Council for an Energy Efficient Economy) conference in Hyères, France. After the presentation, we engaged with attendants from Association négaWatt, a French research group that had also explored a low energy demand scenario for France, and were now looking embark on a more ambitious project – a low energy demand scenario for Europe. They were also keen to include the UK but had gaps in their data. As a result, CREDS was able to become a partner in the project, using the Positive Low Energy Future results to inform the UK portion of the European pathway.

An academic paper was published in Nature Energy on 27 June,2022. This added an international dimension presenting a framework that can be applied by other countries. The same overall message as the main PLEF report was communicated, namely that to fully exploit the potential of energy demand reduction, social changes, not just energy efficiency improvements are needed – changes to the way we eat, travel and heat (and cool) our buildings which could allow us to reduce our energy demand by 52%. We launched a new mini animation to go alongside the Nature Energy paper. There was extensive Twitter activity with over 2,200 views of the mini animation to date. A blog was also published in New Energy World on 13 July.

Since the launch of PLEF in October 2021, CREDS researchers have continued to build upon this pivotal piece of work and further explore the possibilities of low energy futures. CREDS researchers have engaged significantly with the EDITS (Energy Demand changes Induced by Technological and Social innovations) Network, who aim to identify gaps and potentials to enhance modelling, analysing, and communicating the demand-side solutions for climate mitigation. The team have joined EDITS committees, co-authored research, and organised collaborative events. John Barrett et al. published the results of PLEF in Nature Energy: Energy demand reduction options for meeting national zero-emission targets in the United Kingdom; and Joel Millward-Hopkins and Elliott Johnson explored safe and just low energy futures: Distributing less, redistributing more: Safe and just low-energy futures in the United Kingdom.

3.4 Flexibility

Less flexible electricity supply requires more flexible demand. In CREDS, we take 'flexibility' to refer to the capacity to use energy in different locations, at different times of day or year (via storage or by changing the timing of activity, including whether it takes place at all); to switch fuels; to smooth, move or create peaks in demand or, in the case of mobility, to re-arrange destinations and journeys in ways that reduce energy demand and/or congestion.

We contend that flexibility is constituted and limited by the interaction of social and technological/infrastructural arrangements including systems of storage and generation alongside social and institutional rhythms.

Research in this theme is informed by three key ideas.

- It should be grounded in an understanding of the timing of energy demand (domestic, non-domestic and in relation to the mobility of things and people) as an outcome of the rhythm, sequencing and synchronisation of activities.
- Interventions to mitigate peaks and increase flexibility in the timing of energy demand encompass a variety of technologies and pricing mechanisms which should not be studied in isolation.
- The wider societal impacts of harnessing flexibility, including the associated digitalisation and control automation in homes and work places, introduces new timings into people's lives which create new challenges for Demand Side Management (DSM).

How flexibility is conceptualised is important

The way the energy industry and energy research conceptualise flexibility 'fix' a particular interpretation of normality, supposing that particular needs exist and need to be met. We make no such assumption.

We explore the different ways in which we can think about what it means to be flexible, or to have flexibility, which opens up the space of possibilities for how flexibility could be unlocked and harnessed more effectively. Our work challenges the representations of time and society in the energy sector, and proposes innovative ways of Conceptualising flexibility. This work laid the foundation for further studying the Institutional rhythms that shape energy demand and its flexibility. We started by looking at 'organisational flexibility' in large UK high schools, asking whether such organisations can change the timing of their demand, how they might do this and what lessons (not necessarily energy-related) could be learned. Next, we examined the idea that adaptation in an organisation depends on a mass of intersecting temporal rhythms. For example, people responsible for caring for children are all too familiar with the punctuating nature that the timings of the school run play in the planning and unfolding of everyday life. And from a wider point of view, it is easy to see how the timing of school life is embedded in city and regional rhythms as it is connected to the timing of work, home, and everyday life.

Our research argues that flexibility is constituted beyond any one organisation, as we discuss in our paper on What is energy for? Social practice and energy demand, and in later work that investigates the Opportunities for and limits to temporal coordination, pdf. This research demonstrates that flexibility is a feature of how multiple practices hang together and of the changing relations between them. Flexibility exists in the intersections between organisational and institutional processes and so these define the scope for adapting and modifying energy use in either time or space.

Flexibility is not a win-win

Advocates of flexible technologies and tariffs argue that flexibility will benefit the whole system, including users. This is not necessarily always the case.

As our research shows, people's activities underpin peaks and drops in demand we observe. Thus, having the ability to make demand (more) flexible ultimately depends not only on consumers' willingness to change how and when they do things, but also on their ability to do so. Not everyone is able to; not everyone should have to.

Identifying those who might benefit and, more importantly, those who might be adversely affected by measures looking to harness flexibility is a complex task. To overcome some of the associated challenges, we have developed novel data analysis algorithms that allow for clustering of households with distinctive consumption patterns, as well as studying the long-term dependencies in their consumption behaviour.

Our work on demand-based consumer classification has enabled the analysis of the Distributional effects of Time-of-Use (ToU) tariffs on different types of consumers, on different income groups. That is, how much consumers will benefit from, or have to pay for, new tariffs looking to incentivise flexible demand. Our work goes a step further as we try to identify the specific activities likely to be responsible for gains or losses associated with the introduction of ToU electricity tariffs for the residential sector.

This research offers clear evidence to challenge the proposition that flexibility is a win-win. The findings, among other things, reveal that time-poor people such as single parent workers, are more likely to be worse off on an ill-designed ToU tariff compared to a flat tariff. This research was cited by Ofgem's final Impact Assessment on 'Electricity Retail Market-wide Half-hourly Settlement' and used as input for Ofgem's Electricity Network Access and Forward-Looking Charging Review. It also fed into a Parliamentary Office of Science and Technology (POST) note, which was published on their official portal in May 2023. Such regulatory reforms of tariffs have been estimated to bring about bill savings for UK residential customers of between £2bn and £5bn up to year 2045. The research shows that policymakers, industry and consumer associations should not have naïve views of flexibility as a panacea for an electrified future.

Learning from (flexibility) history

Infrastructural legacies and previous methods of balancing supply and demand are layered over time and in ways that matter for contemporary connections between social practices, the timing of energy demand, and for flexibility.

This interdisciplinary work on the Histories of Flexibility brought historians and social scientists together to look at selected cases using different approaches and scales of analysis to demonstrate this argument. This resulted in a special issue of the Journal of Energy History, in which we discussed the Legacies and lessons from the past when it comes to energy systems' flexibility, the history of balancing demand and supply in UK's gas networks, among many other interesting accounts that take a longer view of the concepts associated with energy demand flexibility.

In addition to these, more traditional academic publications, and with a view to sharing some of the most relevant findings and insights derived from this work as far and wide as possible, we produced a photo essay that takes us in a journey through time to explore the making of energy supply and demand.

Five main findings emerged from this work:

- Flexibility is positioned at the intersection of supply and demand.
- Flexibility is an outcome of political and institutional arrangements.
- Flexibility is a feature of service provision: this changes over time.
- Flexibility is a feature of how energy is distributed in space and time.

Flexibility is as an outcome of the changing relation between supply and demand, and of intersecting formations of legal, financial, social, governmental, and technical modalities.

Historical interventions in supply and demand – such as the transition from using gas to electricity for artificial lighting – have long(er) term consequences for flexibility. We should heed these historical lessons now in our present efforts to promote net-zero and to decarbonise: these too will have implications for resource consumption and of demand in future.

New flexibility metrics are needed – going beyond price elasticities

Pricing and tariffs are considered key tools to reduce energy demand and achieve net-zero. Price elasticity is meant to be a direct measurement of how increases in prices of the supplied good or service correspond to decreases in demand, and vice versa. Our research, however, argues that this is only part of the picture as it does not take into account how people's flexibility varies based on the time of day, location, work arrangements and social commitments. This is especially true for energy because people are actually consuming the services it enables – such as cooking, lighting and heating – rather than energy directly, and generally pay little attention to the amount of energy they consume.

Our aim was to develop alternative elasticity metrics to enrich our understanding of changes in demand in relation to price by asking some novel questions around changes in price elasticity across the day or between days, and thinking about the wider impacts of dynamic pricing and metrics for non-price elasticity. Preliminary findings show that new metrics based on time of day disaggregation provide accurate measurements of price elasticity of energy demand. We also found alternatives to the market and non-market values of time and compared changes in demand associated with ToU tariffs with changes before / after Covid-19 lockdowns and before / after price surges. Our clustering analysis reveals the variability of the 'response strength' of different types of consumers.

Our work provided evidence for a new Demand Flexibility Service which was launched in November 2022 by National Grid ESO; the results from the initial Demand Flexibility Service trials will be analysed in future work. Findings on new elasticity metrics may be used by regulators to evaluate the effectiveness of pricing measures and will inform energy economists on new ways to measure price elasticity of demand. This work was also informed by a joint meeting with BEIS/DESNZ which led to further research on the potential trading of flexibility certificates and a podcast on the Price elasticity of energy demand featured in the CREDS in Conversation series.

Technology-based flexibility harnessing is only part of the puzzle

Both in industry and academia, it is commonly taken for granted that technology-based strategies for harnessing flexibility are the main – if not the only – solution to the problem. This means that estimations of the flexibility provision potential are typically based on idealised, theoretical systems where flexibility is achieved only through the use of storage assets, energy efficiency measures, and automated control systems. What this widespread assumption fails to realise is that there is much more to the accurate estimation of flexibility potential, as it is people's everyday life activities what drives the demand for energy. This is problematic as it could, on the one hand, lead to over-engineered technology-based interventions that essentially limit the potential for demand flexibility provision to what can be achieved through such means; on the other hand, it could contribute to the preservation of narrow views of what flexibility provision entails, which fail to take into account the social dimensions of flexibility – for example, that the demand for energy associated with artificial lighting depends on activity and location, not simply time-of-day and levels of daylight.

Our research started with a review of the literature which explored the following:

- The translation of meaning of demand in relation to concepts of non-negotiable energy end use effects associated with technology efficacy/efficiency
- Issues of new fixities resulting from intended technological demand flexibility
- Addressing issues of determinism in accounts of new technology impacts.

Forthcoming outputs include the development and use of an agent-based model, adapted from Capel-Timms et al. (2020). The model performs accurate simulations of spatial and temporal variability of anthropogenic heat emissions (as a proxy to energy use) across Greater London. It looked at the activity and movement of people (in a city context) and how capacity constraints, service scheduling and energy-demanding technologies inform the timing and location of energy demand. The model combines time-use survey, census, work-day population, travel routing, and urban meteorological data. Further model development has led to a more flexible approach that allows for easier modelling of different city contexts and is now set to run for Greater London and Berlin and is being set up for modelling of Paris and Bristol.

The key findings for this work were:

- Introducing new technologies results in new interactions with it which, in turn, changes the pattern of energy demand.
- Findings from the model show that it is able to simulate the variability of energy consumption in time and space across London better than some other models.
- The model also explored the connection between transport and building-centric energy use, highlighting that choice costs energy (e.g. being able to take different types of transport at different times of day using different routes, or responding to different weather conditions) and creates pollution. This will be the subject of further work.
- When generating power load profiles for occupant-driven appliances, an approach based on sequence of activities occurring at the same location enables capturing more variability and proves to be more scalable compared to a probabilistic occupant-based approach.

These findings are of relevance to electrical distribution systems and urban planners, policy makers, national and regional travel operators and planners, DSO network operation planners, and academics.

3.5 Digital society

Our digital society research has found that digital technologies have the potential to enable large energy savings in three ways:

- Firstly, by substituting information for material goods and services,
- Secondly by enabling sharing of material goods, and
- Thirdly by using digitalisation to optimise energy control of buildings, industrial processes, logistics and other systems.

However, the digital economy has a large and rapidly growing energy footprint, and the continuing improvements in the energy efficiency of individual devices have been offset by continuing increases in the number, power, complexity and range of applications of those devices – encouraged in part by the efficiency improvements themselves. Digital technologies influence energy consumption in a variety of ways and their overall impact remains unclear. Hence, policy interventions will be needed to steer digitalisation in directions that have an overall reduction in energy use.

The world is currently facing two socio-technical transitions: shifting to a low-carbon society, and a digital revolution. Despite some claims to the contrary, evidence suggests that spread and adoption of ICT does not automatically lead to reduction in energy demand, if this stimulates new energy-using practices or, wider economic growth. Despite this policy challenge, the two transitions are often considered separately.

Energy impacts vary widely

The energy impacts of digital technologies vary widely between different applications, contexts and users.

The use of digital technologies and services to substitute for material goods and services, termed e-materialisation, is now widespread, for example e-healthcare, e-music, e-books, teleworking and video-conferencing. Our research finds that there is no strong evidence that substituting physical goods with digital services delivers significant energy savings. While energy savings can occur under certain conditions (e.g. if user devices are energy efficient, long-lived and intensively used), these savings are highly sensitive to user behaviour, socio-economic context and other variables. Many digital services (e.g. e-books) provide only a partial substitute for their material equivalents and the lower cost and higher utility of other digital services (e.g. video streaming) encourages large rebound effects (Court and Sorrell, 2020) where any savings due to efficiencies are used to increase other services resulting in less energy savings than expected.

The most robust historical evidence for remote working (teleworking) suggests that it delivers only modest energy savings or, contributes to increased energy consumption (Hook et al, 2020). Our analysis of English households between 2005 and 2019 shows that the majority of teleworkers travel farther than non-teleworkers each week owing to greater distances between the home and workplace and additional non-work travel. In addition, total household travel is greater in households with teleworkers. However, teleworking three or more times a week is associated with a small (~7%) reduction in distance travelled. The environmental benefits of teleworking are contingent upon broader progress in sustainable travel and land use planning, e.g. encouraging modal shifts from using a car to active travel, like cycling, and avoiding the spreading out of residential housing 'tele-sprawl' (Caldarola and Sorrell, 2022).

Evidence suggests that energy efficiency improvements of 5G mobile networks could enable stable or falling energy consumption in these networks, despite rapid growth in mobile data use. However, most studies focus upon operational energy use and neglect embodied energy (from production) and indirect effects, including network infrastructure and raw material extraction, i.e. the whole-network level. Falling data costs are encouraging more data-intensive services (e.g. unlimited data plans), stimulating the demand for new services (e.g. virtual reality, mobile gaming), and facilitating the integration of 5G with other applications (e.g. Artificial Intelligence, Internet of Things), which are offsetting the energy savings from improved efficiency (Williams et al, 2022).

Looking back through history shows that transitions in communication technologies appear to be faster than energy transitions, suggesting there may be a challenge in achieving the twin goals of decarbonisation and digitalisation and highlighting the importance of encouraging interlinkages between information and communication technologies (ICTs) and the energy sector (Fouquet and Hippe, 2019).

Energy consumption is not a priority for users

Energy consumption is not the priority for users and there are trade-offs to negotiate.

New digital platforms can facilitate the sharing of material goods, for example by car sharing, ride-sharing, bike-sharing, peer-to-peer exchange of goods and food-pairing apps. However, the success of community-based sharing initiatives rests upon the desire of users to contribute to the development of their local community. The potential for sharing to reduce energy use, emissions and waste is a secondary concern that remains largely invisible for most users.

A variety of technologies are coming on-stream and we investigated the possible effects on energy use of these technologies and this revealed that factors other than energy consumption are the priority for users. Both professionals and laypeople recognise the potential for energy and emission savings from automated vehicles (AVs). However, there are likely to be substantial direct rebound effects e.g. more vehicle miles (Hopkins and Schwanen, 2022).

Most users who have smart home technologies (SHTs) such as doorbells, consider convenience, security and time savings to be more important than energy and cost savings, and many SHTs support wasteful and energy-intensive practices (Sovacool et al, 2021).

An analysis of the diffusion of smart meters in four countries suggests that their transformative effects – including their potential for energy savings – are oversold. Smart meters are a complementary rather than a disruptive technology and do not challenge the dominant practices and roles of electricity suppliers, firms, or network operators (Sovacool et al, 2021; Geels et al, 2021).

Data from smart heating trials reveals trade-offs between comfort, value and cost; diverging preferences for the level, duration and area of heating; conflicts between different users (e.g. parents versus children, hosts versus guests) and the importance of considerations other than thermal comfort (e.g. social signaling, parental care, preventing damp, caring for pets and plants) (Sovacool et al, 2020; Sovacool et al, 2020b; (Sovacool et al, 2020c.

Technologies have positive and negative effects

Digital technologies can have both positive and negative effects.

Digital technologies have made a major positive contribution to increasing economic growth and providing benefits to consumers. However, it is important to consider the trade-offs between these benefits and the negative effects of additional energy consumption. Digital technologies also have negative effects for users (e.g. the security implications of smart devices) and to society (e.g. generation of e-waste) that must be anticipated and managed going forward. Policymakers are paying increasing attention to the potentially adverse social impacts of digitalisation, such as concerns about data privacy and the lack of accountability of large firms. However, there is insufficient attention to the energy and environmental impacts of digitalisation, and a tendency to accept optimistic appraisals of those impacts that lack supporting evidence and these issues need addressing with improved regulation of firms. A review of low-carbon scenarios found that they highlighted the potential of digitalisation to both increase and reduce energy demand, depending on specific direct energy use effects of ICT; indirect and rebound effects in transport and home energy use; and wider effects via economic growth. This analysis implies that the future pathways adopted for digitalisation will have a significant impact on future energy demand and hence on the feasibility and acceptability of achieving net-zero goals (Bergman and Foxon, 2022) .

Potential for large energy savings, but also rebound effects

Digital technologies have the potential to enable large energy savings but are associated with large rebound effects hence policy steering is needed to capture the benefits

Digital technologies can enable energy savings in multiple areas.

Emerging business models for energy services (e.g. smart tariffs, electricity storage, peer-to-peer trading) offer potential benefits to electricity consumers (e.g. affordability), electricity systems (e.g. flexibility) and the environment (e.g. decarbonisation). A 'Ladder of Innovation' was developed according to environmental, social and economic value at the local level compared to the national level and also integration with the energy system. Our review of UK trials of such business models suggest that they are primarily driven by the needs of the electricity system (e.g. extending aggregation capabilities to facilitate the balancing of local demand with local supply), and deliver only modest benefits to users, whilst often failing to deliver on local environmental and social goals (Hiteva and Foxon, 2021). Policy needs to develop a set of regulatory and market incentives which aim to address these failings.

Our research concluded that efficiency improvements can encourage greater consumption of goods and services. Continuing improvements in the energy efficiency of digital technologies, coupled with broader improvements in performance and utility can encourage large direct and indirect rebound effects. Evidence from a number of applications (e.g. teleworking, video streaming) suggest that these effects may lead to a net increase in energy consumption (Court and Sorrell, 2020).

However, for autonomous vehicles (AVs), many of the scenarios project a net reduction in energy demand (Hopkins and Schwanen, 2022). But, these effects are likely to be larger in freight than in passenger transport, and cancelled out at least to some extent by greater vehicle mileage, more car trips at the expense of other modes of transport, and greater distance between home and work. Policy should concentrate on minimising the direct and indirect rebound effects linked to AV adoption and use, particularly in passenger transport.

With the right policy and market mechanisms in place, digital solutions can deliver significant energy savings and social wellbeing and local environmental benefits, not just economic gains. Suggestions for policy interventions include energy efficiency regulations, consumer protection, technical and marketing standards for SHTs and devices, default settings, reuse and repair requirements for direct energy consumption and land use planning to avoid tele-sprawl to encourage indirect energy savings. In particular, policy-makers should ban the practice of planned obsolescence and enshrine a 'right to repair' in law in order to prolong the average lifespan and recyclability of SHTs and devices. Policy-makers also need to carefully consider whether stimulating and catering for seemingly ever-growing levels of digital data traffic is a sensible and sustainable long-term strategy, despite the industry's optimistic assertions that the energy use implications can continue to be managed through further energy efficiency improvements.

3.6 Policy and governance

What were we trying to do?

The research aimed to contribute to understanding of current UK energy policy and governance. We investigated mainstream and innovative cases, developed new theoretical understandings, concepts and policy ideas, and worked with stakeholders to demonstrate the potential for reformed policy and governance to help deliver a fair transition to a zero-carbon future.

How did we build on what had been done before?

At the start of CREDS, different aspects of the theme's work had different starting points. Our work on building retrofit, for example, built on a considerable tradition and literature, to which we have contributed further, whereas our work on 'policy asymmetry' is exploratory and novel. Our research on new policy ideas (e.g. Retrofit Salary Sacrifice), engagement methods (e.g. Watts the Deal) or practices (e.g. off-site construction) is creating new areas of inquiry.

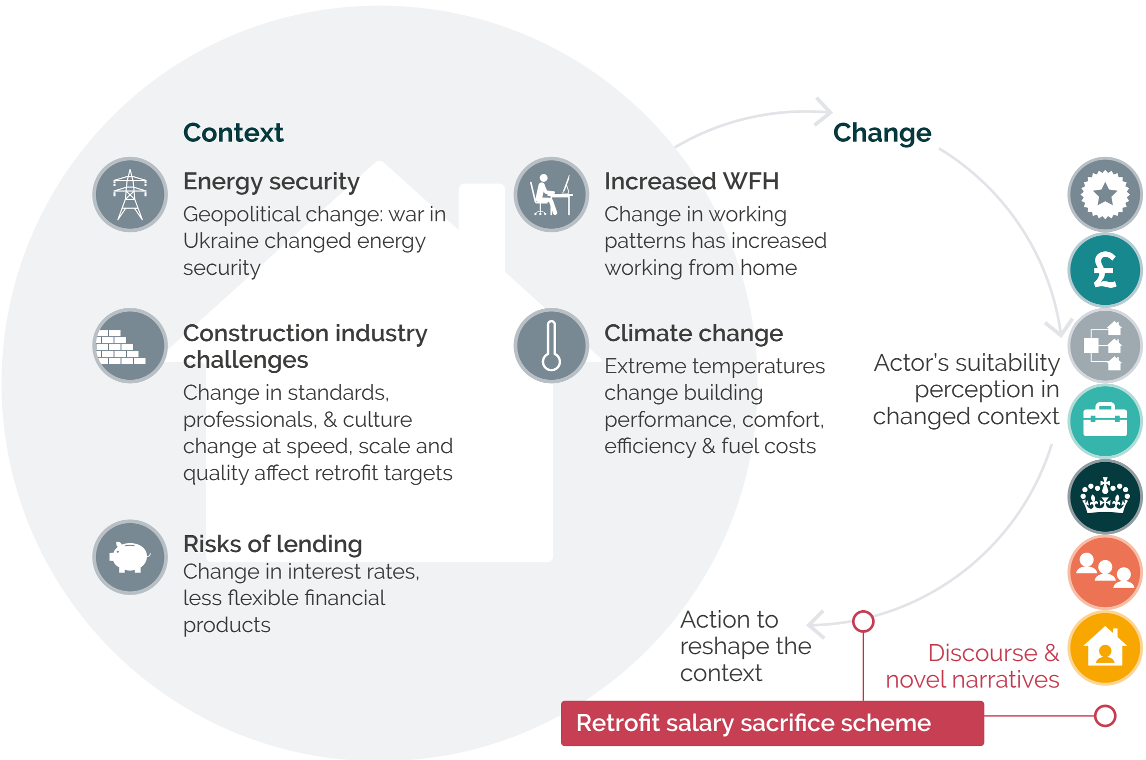


Figure 2: Changes in the context of home efficiency as described in the Retrofit Salary Sacrifice scheme.

Main findings

Contribution of energy demand policy to the net-zero transition

The agenda for energy demand change is much bigger than marginal efficiency improvement, and is critical to the low carbon transition. There is a significant resource of untapped energy-saving opportunities in UK homes: specifically, our estimates suggest that one quarter of the energy currently used in UK households could be cost-effectively saved by 2035.

The contribution of demand-side and other modular options will remain crucial, as mass-produced technologies tend to improve more quickly than those requiring large construction projects. The energy transition will include a systemic shift from heat-producing to work-producing energy sources. This enables very large improvements in the conversion efficiency of final energy, through the use of electricity and hydrogen, in particular in heating and transportation. A reduction in final energy demand of up to 40% is likely from this effect alone.

Energy demand appears to receive less policymaking attention than energy supply, even where demand side change could secure similar policy objectives more cost-effectively. Target setting, technologies and market-based instruments receive most policymaking attention while energy demand solutions, changing practices, regulation and finance do not receive the attention they deserve.

While shifting the focus to energy demand solutions and policy support for existing technologies are within the remit of energy policy, regulatory and institutional change for more human-focused energy system operation, and, most importantly, education and public awareness, are not. These require systemic transformation of policy and practice to achieve a just transition to net-zero.

Retrofitting buildings for energy efficiency and climate change

Current UK buildings policy and governance – for both domestic and non-domestic buildings – are insufficient to meet the challenge of climate change. Significant changes in governance, policy, culture and practice are required.

We concluded that successful retrofit and renovation for energy efficiency requires attention to be paid to timings, bespoke/building-specific requirements, and complementary objectives – retrofit is more than just carbon reduction.

At the household level, opportunities for household retrofit should be supported by policy at key points, such as change of ownership/tenancy, or as part of other planned construction work. Working from home, particularly during the pandemic, has been identified as a new trigger for a specific subgroup of salaried homeowner employees to undertake retrofit works. Researchers developed the concept of a Retrofit Salary Sacrifice scheme, building a single process to link finance, project appraisal, management and delivery, and engaging employers as a new actor supporting retrofit. This would overcome a significant deployment barrier by increasing consumer confidence and trust in retrofit delivery.

This idea has attracted considerable interest from national and local government, employers and the finance sector, amongst others, and continues to be developed further.

Specifically for commercial buildings, lessons from the successful Australian performance-rating model could be applied in the UK for both retrofit and new build.

Construction skills for net-zero buildings

The UK construction sector currently operates in a low-skills equilibrium which makes it difficult to produce low-energy buildings. Current policies have failed to stimulate an effective retrofit sector. CREDS' work with the Federation of Master Builders proposes changes that would increase skills to enable the delivery of high-quality zero-carbon retrofit and construction. Meaningful educational and training reform (including higher levels of accreditation and professionalisation) requires industry reform at the same time to create appropriate demand pull.

CREDS commissioned economic modelling work that indicated how buildings and industrial policies could support a net-zero post-pandemic recovery. This included a skills and retraining programme for construction workers to include re-training of gas installers, so that they could develop appropriate zero-carbon technology skills as part of the energy transition.

Multi-level governance

Attention is increasingly turning to subnational institutions and actors (particularly local government) and the potential roles which they could play in driving climate action at local and regional levels.

For city-level action, only 19 of the 35 City Deals we assessed include measures on climate change mitigation, with one also addressing climate change adaptation. Most City Deal climate measures build on existing initiatives or focus on individual projects or specific issues; there is a lack of joined-up approaches. Policy innovation will be needed as sub-national governments are increasingly seen as a significant driver of climate action, including energy demand reduction, at local and regional levels.

There is policy uncertainty and contestation over responsibilities for heat and energy efficiency across scales of government, and policy divergence between Scotland and England. There is a more comprehensive, planned approach to energy efficiency in Scotland than England, with specific policy institutions and funding.

Existing governance institutions are unlikely to support a collective ability to respond to the challenge of net-zero emissions from buildings, and there is growing awareness of the need for institutional innovations. The institutionalist perspective has highlighted the significant contrasts between Scottish and English policy strategies, where Scotland takes a more planned approach with specific policy institutions and funding. Despite these differences, all current developments lack the urgency needed to meet ambitious legal carbon budget commitments, with major governance innovation for heat and energy efficiency policy still required.

New imperatives and new actors

Real world events have highlighted new imperatives in energy transition as well as significant research gaps. The climate emergency requires broadening our understanding of actors in the energy system, and a research focus beyond 'the usual suspects'.

In responding to Black Lives Matter, CREDS recognised a research gap in understanding the relationship between racial justice and energy demand and developed a scoping project to derive a research agenda. A guide to racially just energy research, arising from that work, has been produced. It assists researchers in being more thoughtful and deliberate about their research.

The exceptionally high energy prices of winter 2022-23, and fast policy response, prompted reflections on how research could match the speed of change in policy and governance. The output was a research agenda and guidelines on practical aspects of executing research in a hurry.

Research has focused on actors in the energy system who are typically overlooked. This includes findings on the value of energy communities as demand-side innovators, and demonstrates that small and medium enterprises are important not only as energy users and producers of energy-using goods and services, but also as influencers of their customers and supply chains.

Novel policies for energy demand reduction

A series of projects in this theme have explored the use of innovative policy options for energy demand reduction. By expanding the scope of energy policy, introducing new policy tools, finding 'non-energy' policy opportunities and by transforming multi-level governance & policy evaluation, faster and deeper cuts to carbon emissions can be achieved.

- Heat as a service: has the potential to pay a key role in the electrification of heat. The hurdles faced by energy service-based business models have a longer history than is usually recognised, and there is much to learn from the relative failures of the past.
- Local authority energy service models: local initiatives provide different retrofit mixes, with differing potential for effective change. Policy and market changes needed to empower local authorities to contribute systematically to net-zero carbon buildings have been identified.
- Peer-to-peer trading / distributed ledgers as a disruptor of energy retail markets: peer-to-peer (P2P) energy trading – where energy prosumers transact directly between each other – could help enable transition to a low-carbon energy system. Peer-to-peer communities can enable optimised supply and demand of locally generated electricity as well as an active participation of citizens in the energy transition.
- The role of clothing in the transition to low carbon heating: the thermal content and style of clothing is an overlooked but important consideration in the sustainability of the fashion industry, and an area where it could make a positive contribution to reducing carbon emissions.
- Personal carbon allowances: personal carbon allowances (PCAs) could play a role in achieving ambitious climate mitigation targets. PCAs could be trialled in selected climate-conscious technologically advanced countries, mindful of potential issues around integration into the current policy mix, privacy concerns and distributional impacts.
- Energy sufficiency: energy policy based around access to sufficient services will involve questioning expectations and norms about what 'enough' means and who gets to decide. Moving to a sufficiency framing will involve challenging social and political debates, and technological advances will not allow us to side-step these.
- Evaluation in the climate emergency: failing to observe, share, and act on policy-based learning risks wasting public money and slowing the response to the climate emergency. Appropriate and timely evaluation can ameliorate these risks, helping to increase the pace and scale of innovation, accelerate energy policy making, and improve delivery.

Methodologies

- **Supply chain actors and local traditional and off-side modular building retrofitting strategies** – social network analysis to map the skills and communication networks of supply chain actors.
- **Clothing and heat demand reduction** – exploring future scenarios of clothing-related reductions in heat demand and by a review of current evidence.
- **Multi-level governance** – comparing policy decision-making and implementation for energy efficiency in buildings in England and Scotland; analysing different local authority business structures for investing in the energy performance of buildings and low carbon heat; and testing the robustness of the typology against emerging developments in 26 City Deal regions.
- **Deep refurbishment of buildings** – an evaluation of the evidence base on what works (and what does not), and in which contexts, to distil lessons for future policy design and implementation.
- **Distributed Ledger Technologies (DLTs) as a disruptor of retail markets** – using a realist review approach to identify and synthesise evidence from research in the energy and other sectors; to better anticipate what impacts could come about, how, and who might stand to gain or lose.
- **Policy asymmetry in market design** – considers the policy paradigm of levelling the playing field by explicitly considering demand-side policy as an alternative to supply within a regulatory process. Drawing on international experience, and detailed analysis of the economics and institutes in the UK, the project investigated how the principle of the level playing field might be applied and the problems in doing so.
- **Drivers of policy asymmetry** – the work draws on theories in political science including agenda setting and policy windows. Decision-making processes are tracked through a combination of process tracing and interviews with relevant stakeholders.

3.7. Decarbonisation of Heat

Our work on heat decarbonisation aimed to investigate the potential benefits of adopting a System Architecture framework to help structure the development of energy system decarbonisation strategies and deal with the complexity of the energy system.

This perspective, with its focus on the spatial, topological, and functional organisation of the system and its components – is likely to be particularly valuable in the context of rapid expansion and transformation of the existing system. Events over the last three years have reminded us that uncertainties can arise from wider geopolitical, economic and supply chain contexts. Impacts of such uncertainties are difficult or impossible to model explicitly. System Architecture provides a framework and battery of techniques to analyse trade-offs and support decision making in the presence of such uncertainties.

Methodology and data collection

A wide-ranging review of models highlighted that no single modelling approach captures all the emergent system features investigated, such as evolvability, flexibility, robustness and feasibility which are key to effective decision making under real world conditions.

Stakeholder engagement formed a key strand of our work, linking modelling to policy making. We explored stakeholder requirements using in-depth Q interviews and a Pugh Scoring exercise in a workshop with expert energy system stakeholders including high-level policy makers, regulators and industrialists. We also conducted wider stakeholder engagement and dissemination through a webinar. These activities enabled us to investigate stakeholders' expectations and visions of the future energy system and their prioritisation of the current decarbonisation policy goals. Interviews generated significant feedback on energy models and modelling practice.

All of the above supported a two-pronged modelling programme. We used the UK TIMES (UKTM) model to explore the concept of evolvability and how different system architectures respond to emerging opportunities and challenges. The former include technical developments that allow reductions in cost. The latter would include unexpected increases in technology and energy costs (The last year has also reminded us of the potential for abrupt reorganisation of supply chains, oil and gas markets, energy supply infrastructure, the global financial system and geopolitics). UKTM was also used to assess the goal of robustness of technology choices, using a probabilistic approach, running multiple scenarios and using Monte Carlo Analysis (MCA) to analyse model output.

In parallel, we used the Energy Space Time Integrated Model Optimiser (ESTIMO) to investigate the flexibility requirements for mid-century, high renewable, zero emission energy systems, in terms of installed capacities of wind and solar generation, storage and interconnectors. Methodologically, the work involved physical simulation of hourly energy flows within the UK economy and, at reduced detail, the EU27, using up to 35 years of historic meteorological data. Both models were used to compare three different heat supply options dominated respectively by individual heat pumps (HP), district heating (DH) and electrolytic hydrogen (EH2). An assessment of the economics and role of hydrogen made from natural gas (GH2) was also undertaken. A global logistic substitution model was also developed to understand the global implications of the growth of PV and wind generation at rates broadly consistent with historic trends. The core methodology in this work was logistic extrapolation of historic trends for global wind and PV deployment, coupled with analysis of the extent to which physical, economic, land, resource and climate constraints might limit growth.

Since 2018, members of the Heat Theme have also engaged in a number of cross-theme and wider collaborations, supporting the production of a series of research papers and other outputs.

Main findings

- Although models are intended to inform policy decision-making, our findings suggest that they struggle to satisfy multiple, emergent and dynamic policy goals. This constitutes a powerful reason for adopting an overarching System Architectural perspective on energy system transformation. It also means that conceptual development, and empirical and qualitative research should form prominent parts of the energy research portfolio alongside energy modelling.
- Our work on heat decarbonisation highlights the need to move away from the current dominant focus on cost of the energy system towards consideration of a wider range of system properties including evolvability, flexibility, robustness and feasibility.

Findings in detail

Technologies to achieve heat decarbonisation in the UK

- Our work suggests three major technologies that could be used to achieve heat decarbonisation: hydrogen boilers, individual heat pumps, and district heating, each with different implications for energy system architecture. All are technically feasible, although 'high hydrogen' systems appear to be the most expensive. This is due to the availability of more energy efficient and cost-effective alternatives, and the need for high value hydrogen in other parts of the energy system, such as industrial processes.
- **The energetics of green hydrogen are a major driver of the higher cost for this technology. Green hydrogen requires about four times more electricity per unit of heat output. As a result, the total cost of heat is about 80% more compared to individual heat pumps and to heat pumps deployed in conjunction with district heating.**
- Use of blue H_2 for heating substantially increases CO_2 and methane emissions, and places additional pressure on natural gas supply, limiting its value as a zero-emission heat supply technology. There may however be a role for a residual contribution from natural gas-fired electricity generation systems operating at low load factors in future net-zero carbon systems, to cover exceptional combinations of demand, weather and plant availability.
- Technological diversity in the near-to-mid term (2030-2050) may contribute to a more evolvable system, facilitating switching to alternative pathways.
- Climate change will reduce heat load and increase cooling load by about 20%. Reversible heat pumps, which are relatively easy to retrofit, can cool as well as heat. Other options for heat supply would require separate provision for cooling.
- Modelling with ESTIMO shows that 40-50% of wind and solar generation are spilled in near-optimal energy system designs. This is because this results in lower total energy system cost than would be achieved if storage and/or interconnector capacity were increased. It is not cost effective to attempt to eliminate spillage by building additional energy storage and interconnector capacity.

- The largest impacts on energy demand are likely to arise from the electrification of heat, which will increase the exergy efficiency of heat production and delivery by a factor of approximately 3 compared to hydrogen (Exergy is a concept that measures both the quantity and availability of energy. Its adoption, at least qualitatively, in analysis of heat supply, becomes unavoidable as exergy efficiency rises from the very low levels associated with combustion of fossil fuels (≈3%) to levels associated with heat pumps and fuel cells (≈30%). Fuller definitions can be found online).
- Flexibility will be key to system resilience and costs. The integration of 10s of TWh of flexibility and storage into the energy system could be aided by encouraging the deployment of storage and hybrid energy conversion systems within the design of heat networks in "the Last Mile" (A hybrid system is one in which two or more energy conversion technologies are bundled and controlled in a way that enables a wider range of functionality than would be achievable with a single technology. Examples range from hybrid heat pumps, to the electricity grid). Such a development would have the capacity to reshape the whole UK energy system, buffering ordinary consumers from variations in renewable energy generation, and decoupling dwellings from subsequent developments in energy conversion and storage technologies deployed upstream. We note that much existing research on demand-side flexibility fails to acknowledge both the scale of the flexibility required to operate mid-century, zero carbon energy systems, and the extent to which this is likely to be met upstream of energy consumers.

Findings for modelling and modelling practice

- A novel outcome of this work is a set of clearer conceptual distinctions between flexibility, resilience and evolvability, and descriptions of how each can be operationalised using energy system models.
- An understanding of stakeholders' views on system requirements helped modelling teams to improve modelling practice through the review of existing assumptions on issues such as inclusion of hydrogen as a vector in ESTIMO, and developing the concept of evolvability in UKTM.
- UKTM currently tends to underestimate impacts of operability for net-zero carbon systems, on storage and interconnector capacity, and fraction of wind and solar energy spilled; this limitation of the model may introduce significant bias into results.
- UKTM currently does not model supply chain dynamics explicitly. This limitation is likely to become more significant as rates of deployment of new technologies rise.
- ESTIMO is not designed to model the evolution of technology mixes over time. But by focusing on operation and operability of future, largely-renewable energy systems, ESTIMO complements work undertaken with models such as UKTM.
- Work to systematically combine estimates from the two separate models is still to be done. Key issues, such as supply chain dynamics, currently lie outside the combined capabilities of both models.

Insights from stakeholders

- Policy makers and other stakeholders' do not have a unified or a single perspective on the selection of technologies in the light of system goals, particularly, the goal of equity.
- Our work with stakeholders shows that two broad strategies for decarbonising the UK energy system exist. The Adaptive Strategy, which tends to represent the supply side, holds that system resilience is a priority that should drive technological selection. The Transformative Strategy, which tends to represent the demand side of the system, holds the view that the use of available technologies in creative combinations and configurations maybe key to the transformation of the energy system.
- **There is an over-emphasis on cost as the primary driver of technological selection and factors such as supply chain dynamics, consumer acceptability and equity are neglected**. As the energy transition accelerates these other factors are likely to become more salient and the ranking of energy system goals is likely to change. It is therefore important that sustained and structured stakeholder engagement between the energy modelling community and policy makers/energy system stakeholders is maintained.
- The complexity of the energy system and the practical impossibility of including all issues in energy system models that are relevant to the objectives of policy makers and other energy system stakeholders, necessitates the adoption of an overarching System Architectural perspective. The System Architecture discipline, with its extensive literature, wealth of historical examples, methods and tools, can help energy researchers to focus their work, enable articulation and prioritisation of system goals (evolvability, equity, resilience, costs), and bridge the gaps between different models, and between policy-makers and energy system modellers.
- It is is unlikely that cost will be the main factor in determining the future of heat and of the UK's energy system as whole. Other factors including supply chain dynamics, judgements of political risk and feasibility, and the current dominant position of natural gas in heat supply will also be in play.
- **Although models aim to underpin policy decision-making, our findings suggest that they struggle to satisfy multiple, dynamic and evolving policy goals. This constitutes a powerful reason for adopting an overarching System Architectural perspective on energy. It also means that empirical and qualitative research should form a prominent part of the energy research portfolio alongside energy modelling.**

Implications for global trade and reaching the 1.5˚C target

Decarbonisation and transformation of the UK will take place in a global context. It would have been remiss of us to have overlooked the latter perspective.

The work on the global logistic substitution model revealed no insuperable physical or, economic barriers to a transition from today's fossil-fuelled global energy system, to one based largely or, entirely on wind energy and solar photovoltaics (PV). It therefore appears that a process is under way which, if continued, has the potential to displace fossil fuels from almost all markets between 2050 and 2070. However, such a transformation of energy supply will both require, and drive, a deep reconfiguration of global energy demand toward electricity and derived products, itself dependent on multiple other technological substitution processes across sectors and geographies. Reflection on historical transitions, first from biomass to coal, and then to oil, suggest that such a process would profoundly impact patterns of global trade, and ultimately geopolitics. Failure to achieve such reorganisations could delay or, curtail the substitution process, with the consequence that mid-century CO_2 targets and the 1.5°C warming target would not be met.

We conclude with a comment on the impacts of the war in Ukraine. These extend well beyond the energy sector and include higher prices for agricultural fertilisers and grain, a partial breakdown in the global financial system, disruption of markets for metals and other resources, and disruption of supply chains associated with technical equipment for all parts of the UK energy system. It is likely that prices of energy and associated commodities will remain high for many months, if not years. More general disruption of global markets also now appears to be under way, as trading blocks and manufacturing supply chains reorganise themselves, and as the dominance of the US Dollar in international trade wanes. The consequences are likely to take years to resolve. The impact in the UK is likely to be a sustained period of reduced real incomes, which will inevitably hit people on low incomes hardest. It appears that what we face is not short-term fuel poverty, but long-term impoverishment. While the larger ambition to align energy demand reduction with energy security, affordability and climate policy goals is essential, a more considered community development approach akin to the one that has been adapted and adopted with great effect in health in the UK and internationally is also likely to be necessary to support the hardest hit.

3.8 Fuel and Transport Poverty – FAIR

Our work on fuel and transport poverty in the UK energy transition (FAIR) set out to examine the intersections of fuel poverty (energy poverty) and transport poverty in the UK's transition to a net-zero society.

The aim was to identify:

- who could potentially be vulnerable (the overlapping socio-demographic and spatial factors)
- how it impacts them
- where these people are and
- which policies could help.

Methodology and data collection

We examined the literature on energy poverty and transport poverty, specifically focusing on the socio-demographic groups that are vulnerable to both problems, that is, those which face 'double energy vulnerability'. We interviewed 59 households in all four nations of the UK, investigating their lived experiences of fuel poverty and transport poverty. The interviews were carried out in partnership with the Energy Saving Trust and their local networks which were key to finding research participants, some of whom were hard-to-reach and previously less researched people. To provide quantitative and statistically significant evidence on double energy vulnerability in the UK, we collected data via a national household survey (approximately 1,400 participants).

We developed a Geographically Weighted Regression (GWR) model to create maps to explore the spatial variation of both fuel and transport poverty patterns across the UK. To examine the implications (distribution, fairness and pros and cons) of different policy options from various policies, Cambridge Econometrics applied its macro-econometric model E3ME to model three alternative policy pathways for the UK to meet net-zero by 2050. As part of our wider policy work, we also undertook public focus groups to get the general public's view on fuel poverty and transport poverty. We held eight online focus groups in early 2022, two in each nation with a total of48 participants. Our final data source was 42 interviews with experts to get their views on fuel poverty and transport poverty and related policy measures.

Key findings

People living in fuel and transport poverty

Fuel and transport poverty is caused by a mix of reasons, including financial and infrastructural inequalities such as low incomes, poor housing quality, use of expensive technology such as prepayment meters, lack of access to or high cost of public transport and 'forced' ownership of expensive personal cars.

Many of the people and places identified at greatest risk of energy and transport poverty are the same groups who experience discrimination, disadvantage and exclusion in multiple other facets of social life (including, in some cases, greater vulnerability morbidity and mortality from Covid-19). This suggests that vulnerability to fuel and transport poverty is deep-rooted in the structure of societies, extending beyond the fuel and transport domains.

The effects of fuel and transport poverty on peoples' lives

Lack of sufficient fuel and transport services is detrimental to quality of life, causing stress and missed opportunities, like cutting out certain foods or leisure trips. Affordable energy and transport services that are available to all, would reduce the need for people to cut back on essentials and improve peoples' quality of life.

The lived experience of someone in fuel and transport poverty is a daily stress and cause of worry over choosing between different fuel and transport services: e.g. when to use the heating or electricity at home and how to travel to work, school, the shops or medical appointments.

Geographic modelling to map the distribution of double energy vulnerability

The availability of data on energy and transport poverty statistics varies significantly across the four devolved nations with inconsistent definitions and limited disaggregated data. This lack of harmonised data on energy and transport is a severe impediment in understanding socio-spatial variants of energy and transport poverty.

We developed an original method for analysing energy and transport poverty in the UK and constructed two unique metrics:

- The fuel poverty metric combines data on heating burdens, energy efficiency and social vulnerability
- The transport poverty metric is constructed on the basis of access and social vulnerability.

Energy and transport equations:

Energy Poverty Index

Central Heating [0.25] + Energy Cost [0.25] + Energy Performance Certificate [0.25]+ Income [0.25]

Transport Poverty Index

Accessibility [0.33] + Car Ownership [0.33] + Income [0.33]

When we map both energy and transport poverty the results show a clear north-south and urban-rural divide. In the fuel poverty domain, one of the surprising findings was the high degree of poverty in peri-urban areas, possibly due to higher energy costs and lower Energy Performance Certificate (EPC) values.

The transport poverty map showed high values in inner-city areas outside of London, possibly as a result of poor accessibility and car ownership scores. The greatest vulnerability to double energy poverty can be found in isolated rural communities that have a high proportion of residents who are disadvantaged in socio-economic and demographic terms.

Policies which could help to reduce fuel and transport poverty

We have used a macroeconomic model to assess three policy scenarios, based on GDP and employment outcomes across the whole of the UK economy.

1. A Net Zero Strategy scenario (NZS): replicating policies from the UK government's Net Zero Strategy, published in autumn 2021, with no predefined emissions outcome
2. A market-based instruments scenario (MBI): UK net-zero achieved through a carbon tax only
3. A regulation scenario (Regulation): UK net-zero achieved through a range of regulatory policies.

The results demonstrate two important high-level findings:

1. Implementation of climate policy generates positive outcomes for the environment, economy and society as a whole, creating a win-win situation in which emissions are reduced, while at the same time the economy grows and new employment opportunities are created. All the modelled net-zero policy pathways lead to better outcomes for GDP and employment compared to the business-as-usual scenario.
2. There are significant differences in the distributional impact on real disposable income between the Regulation scenario, which produces the 'fairest' outcome (lower-income groups benefit more than higher-income groups) and the MBI scenario. The MBI scenario leads to increased real income for all if 100% of the tax revenue raised from carbon pricing is recycled, but if no revenues are recycled it is the worst outcome across all the scenarios. This demonstrates that it is important that carbon revenues are put back into the economy to avoid strongly negative outcomes, and that the way the Government chooses to do this has an impact on distributional outcomes.

Focus group ranking of policy options

The focus group participants tended to mistrust landlords and large energy firms as intermediaries intended to deliver policy mechanisms: they are not perceived as neutral actors, but self-interested ones and part of the problem. However, when asked to rank energy poverty policy options, focus group participants gave first priority to requiring landlords to improve the energy efficiency of their homes. They gave second priority to increasing the level of support given under the Warm Homes Discount scheme; and they gave third priority to ensuring that new homes are much more energy efficient.

In terms of transport poverty, focus group participants gave first priority to making bus and train fares and ticketing simpler and cheaper. Restoring bus services post Covid-19 was a second priority, followed by resourcing local authorities so that they can install electric vehicle charging as a third priority.

3.9 Decarbonisation of the steel industry

Our decarbonisation of the UK steel industry research has found that key policy options for the government to drive green steelmaking include lowering industrial electricity prices (the UK has the highest in Europe), removing discrepancies between the cost of carbon emissions for steelmakers based on the level of their emissions associated with electricity consumption and implementing a carbon border adjustment mechanism.

We have found that:

- In the steel sector, retrofit options have the most short-term mitigation potential.
- The most likely option for complete decarbonisation is hydrogen direct reduction of iron, with a subsequent process step involving electric arc furnaces, which has lower carbon emissions and costs than carbon capture and storage-based options. This would already be a lower operational cost option than blast furnace relining if steel producers were exposed to the full cost of their carbon emissions.
- Even longer-term options need short-term attention to develop and demonstrate them. Increased scrap use in steelmaking allows greater use of electric arc furnaces, but requires better quantification of its benefits and process options.
- Unless government provides significant financial support to the UK steel industry and improves the policy environment around green steelmaking, UK steel manufacturers will struggle to decarbonise their operations while maintaining international competitiveness. There is a serious risk of UK steel production being moved overseas, considerably reducing the control that we have over decarbonisation and security of supply. If this occurs, the costs of reaching net-zero emissions from UK steel consumption could be needlessly high in terms of stranded assets and job losses.

Description of strands

We undertook three strands of research:

- Assessment of current techno-economics options
- Stakeholder engagement
- Policy options

Before our project, there was little understanding of the likely interactions between the energy system and green steelmaking technologies, expectations of stakeholders within the UK steel industry, and policy options to drive green steelmaking in the UK. When the proposal was developed, it was recognised that these were all crucial areas to address in order to decarbonise the UK steel sector.

Assessment of current techno-economics options

We investigated the available technology options for decarbonising the UK steel industry, considering the technical barriers and conducting cost-benefit analysis. This work involved a combination of computational modelling of advanced steelmaking and heating processes, energy system analysis, and the determination of levelised costs of several technologies relevant to green (or at least greener) steelmaking (i.e. steelmaking with lower carbon intensity than currently).

What we found:

Hydrogen direct reduction of iron (H2-DRI), with a subsequent process step using an electric arc furnace (EAF), is the most appropriate approach for iron and steelmaking in the UK, with near-zero emissions. In this approach, hydrogen is used as a reducing gas to convert iron ore (mainly hematite, Fe_2O_3) to "sponge iron" (Fe) in a shaft furnace, at temperatures of around 800-1000˚C. The hydrogen reacts with the oxygen, resulting in an off-gas of steam (H_2O). An electric arc furnace is used to convert the sponge iron to steel by adding a small percentage of carbon and any alloying elements that are required for the particular steel grade. Scrap metal can also be added to the electric arc furnace to reduce the sponge iron requirement and hence reduce energy requirements.

The hydrogen used in H2-DRI can come from a range of sources. Of interest in green steelmaking are "green hydrogen" and "blue hydrogen". Green hydrogen is hydrogen that has been produced using water electrolysis powered by low carbon electricity, such as that from renewables or nuclear power, and the carbon intensity of green hydrogen can potentially be negative. Indeed, the National Grid ESO project that the average electricity grid carbon intensity in the UK will be negative from around 2035 as a result of biomass power with carbon capture and storage (known as BECCS). It is also possible to produce hydrogen using a gas reforming process such as steam methane reforming or autothermal reforming. Gas reforming splits the hydrogen from natural gas (mainly methane, CH_4), leaving carbon dioxide in the off-gas stream. If this carbon dioxide is captured and stored (for example, in aquifers or disused oil and gas reservoirs), then the hydrogen is known as blue hydrogen. The carbon intensity of blue hydrogen is generally higher than that of green hydrogen as not all of the carbon dioxide is captured from the off-gas stream.

Early on, we recognised that there had previously been very little attention given to the energy system requirements of the H2-DRI + EAF approach when deployed at large scales. We developed a new long-term energy system planning tool covering both electricity and green hydrogen and applied it to the UK case to find the lowest cost combination of electricity generation, hydrogen conversion, and energy storage technologies in a range of future scenarios.

We have also developed a model of recuperated water-source heat pumps and have used it to determine the economics of providing high temperature process heat using renewable electricity. This work also covered the potential to use mine water and latent heat pumping (i.e., partially freezing the water source to extract more energy, thus reducing water requirements).

Stakeholder engagement

We examined how stakeholders' expectations can shape the steel decarbonisation agenda and which conditions are involved in the idea of a future decarbonised industry. We also identified elements for and future paths towards decarbonising the industry through qualitative reasoning where stakeholders share their thoughts and feelings on decarbonisation, without involving measuring by one-to-one interviews and path ranking and development, where they would have to rank order different and preferable options regarding decarbonisation.

What we found:

We have shown how actors tend to shift the locus of agency (the capacity to act). By this, we mean that actors argue that they cannot act unless another actor, typically the Government, provides supportive conditions. In other words, the normative expectation is that this nominated prime actor should provide those conditions, and until they do, the original actor should not be expected to act. We see this as a form of strategic sense-making and action with rhetorical policy value, in the sense that it seeks to be persuasive while minimising regime actor commitment.

The conditions and expectations referred to by actors all have plausible, material bases concerning regulation, investment, technology development, the creation of markets and public procurement. Yet regime actors remain crucial to action on all of these. At issue is how to incentivise economically and commercially viable steel decarbonisation. This is likely to involve approaches to value creation that reduce operational and infrastructure costs for commercial actors, indeed supported by governmental action. At the same time, discursively shifting responsibility for the sector's decarbonisation to the UK Government is not in itself helpful and is a situation in need of change.

Policy options

We have identified the best policy, or combinations of policies, to support decarbonisation based upon the synthesis of work in other strands. Our goal is to analyse policy solutions identified across the strands and recommend appropriate policy choices and solutions to support decarbonisation of the UK steel industry. We have examined the techno-economic modelling results and common proposed solutions for industrial decarbonisation, with an eye toward UK specific solutions and the relevant role of the international policy community, if at all. We have used stakeholder engagement and feedback to shape analysis, as well as identified a number of routes for future research and policy engagement.

What we found:

Our research concludes that the government should consider socialising the cost of renewable levies and network maintenance, or moving them from electricity to gas, and lay out steps to expose industry to the full cost of its greenhouse gas emissions while preventing carbon leakage (such as developing a carbon border adjustment mechanism, to be phased in as emissions trading scheme free allowances are phased out). There is a need to foster internal demand for steel produced by decarbonised routes and work towards consensus between the stakeholders involved in the process, rather than government expecting industry to act and vice versa.

Our research also concludes that the government should provide funding towards the development of a zero-emissions steel plant based on green hydrogen, direct reduction of iron, and electric arc furnaces. This could be a collaboration between the public and private sectors.

Methodology and data collection

To provide quantitative evidence around the costs and emissions of low-emissions steelmaking, we integrated a model of the key processes in low-emissions iron and steel production (including hydrogen direct reduction of iron and electric arc steelmaking) with a long-term energy system planning tool featuring key low-carbon electricity generation technologies, electrolysers, and energy storage in the form of underground hydrogen storage and underground compressed air electricity storage. The energy system planning tool was formulated as a linear programming problem and solved using CPLEX via the CPLEX Connector for MATLAB. Twenty years of historical wind and solar capacity factors for Great Britain were taken from renewables.ninja, and time slicing was used to preserve the variability in renewables availabilities while ensuring reasonable runtimes.

We developed a spreadsheet tool to compare a wider range of key options for low-emissions steelmaking, including advanced ironmaking processes and carbon capture. We examined the literature to find inputs to these models.

These tools were used to assess the importance of several factors relevant to decarbonising steel production in the UK, including electricity prices, carbon prices, and compensation towards the costs of carbon emissions.

We conducted expert interviews with around 20 industry stakeholders to identify stakeholders' expectations about the most plausible decarbonisation routes and the conditions that they consider necessary to achieve their expectations. The stakeholders represented organisations including steel manufacturers, trade associations, environmental NGOs, and central government departments. Interview content was developed based on literature review and informed by the techno-economic analysis conducted by other members of the research team. Multiple-criteria decision analysis (MCDA) was used to understand the stakeholder preferences, with a set of four decarbonisation routes developed for this.

Each of these routes included a technological preference, market actions and policy changes. The stakeholders were also provided with six criteria to consider in a comparative assessment of the decarbonisation pathways.

The potential to reduce heating demands in steelmaking was assessed by developing a thermodynamic process model of heat pumps operating on the reverse Joule-Brayton cycle (in which the working fluid remains as a gas throughout the cycle) and considering the economics of such heat pumps when used to preheat furnace gases, including hydrogen produced via water electrolysis. Enthalpies were calculated at each point in the heat pump using CoolProp (an open-source thermophysical property database), and heat pump designs were optimised by using multivariable nonlinear optimisation tools in MATLAB to find the temperatures and pressures that maximise coefficient of performance. Heat exchanger designs were optimised separately to minimise cost while ensuring that pressure drops were within acceptable limits.

4 Approach to Equality, Diversity and Inclusion

4.1 EDI Action Plan

CREDS adopted a policy and action plan on Equality, Diversity and Inclusion (EDI) that was published in April 2019. Our aim is to foster an inclusive culture within the Centre, which promotes equality, values diversity and maintains a working and social environment in which the rights and dignity of all our staff, students, partners and stakeholders are respected. This achieves our legal obligations under the Public Sector Equality Duty but also goes further than the legal requirements.

The Plan contains 12 specific commitments covering legal responsibilities, recruitment, bullying and harassment, flexible working, career progression, communications, researcher-led activities, and monitoring and reporting. It has influenced our practices on a number of issues, including use of the Flexible Fund, recruitment to funding panels, event planning, remote access to meetings and mentoring. The Director led the development of the plan, and this reflects the importance we place on EDI issues. It was discussed and agreed by the Executive Management team, Advisory Board, CREDS EDI Working Group and professional guidance from the Equality Officer of the School of Geography and Environment in the University of Oxford.

4.2 EDI Working Group

The CREDS EDI Working Group is a voluntary group of staff members from the consortium who meet three times annually. They progress the plan and discuss EDI issues as they arise. We interpret 'staff' broadly, seeking to include in our decision-making staff with responsibilities for administration, communications and knowledge exchange, as well as those identified as researchers. Due to resource constraints, as the EDI working group are voluntary including those within the Core team, we established an EDI post (one day per week – 0.2 FTE from 2021 and 0.4 FTE from 2022 onwards). It was agreed by the Executive Committee and Advisory Board and is funded from the Flexible Fund.

The EDI Manager provides us with additional capacity, specialist expertise, monitors and develops the EDI plan, runs the EDI working group, and carried out specific projects – developed and presented the Inclusive language guide and the Recruitment guide. The Recruitment guide has been shared with the HR team in Oxford and many of the other CREDS Universities. The guide has been adopted by the department and division at Oxford University and will be sent to staff who are involved in recruitment and this work is the subject of an impact case study – The CREDS EDI Recruitment Guide: an impact case study.

4.3 Activities undertaken to implement the plan

A year after publishing our EDI plan we reviewed the progress in implementing it and published the EDI Annual report and briefing paper in June 2020. Further evaluation in 2023 on the male/female split of speakers at CREDS events and a consortium-wide survey into attitudes about EDI has revealed interesting insights and data. This has been summarised in a blog called Evaluating the impact of Equality, Diversity and Inclusion (EDI) research. We recruited a researcher to scope the agenda on the intersection of racial justice and energy and to help us advocate for funding which has resulted in a Guide to racially just energy research.

The main challenge to CREDS is that many aspects of EDI are determined at the institutional level, which means the Centre's influence is limited, although we are sharing what we have learned with the institutions that are part of the consortium.

We keep EDI visible in the consortium with sessions at every Whole Centre Meeting (WCM) of which there have been 9. EDI related topics have included Unconscious Bias and Responsible Bystander training, career progression, presentations on progress from the EDI working group, and staff surveys. We share information about what is happening on EDI in CREDS with articles in the internal newsletter (the Consortium Update) and external newsletters, items on the website and EDI working group meetings.

We have published significant content on our website related to EDI – Our blogs, guides, tools and podcasts have included:

- Women in energy
- Equality, Diversity, Inclusion and Energy
- Feedback on the Amplify Project, our anti-bullying forum
- Inclusive language guide
- Recruitment Guide
- The long and winding road of research funding
- The intersections between racial justice and energy demand research
- EDI Podcast
- Navigating knowledge exchange and research impact as an early career researcher
- The EDI Cube.

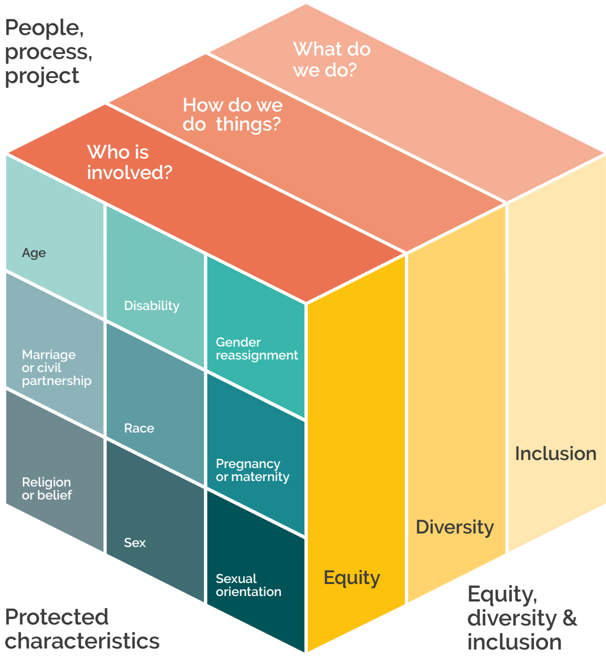


Figure 3: The CREDS EDI cube.

The EDI cube has been presented and used at several events, including internally within the University of Oxford and externally at the UKERC Summer School and the C-DICE National Post-doctoral Conference.

EDI has helped us engage outside of CREDS in many ways – we have influenced the strategies of at least 9 energy consortia. We have also actively engaged with other consortia on EDI. For example, last year we collaborated on the Net Zero Cross consortium ECR Conference. Wider engagement on the topic of EDI has included cross-consortia engagement meeting 2022 (summary of EDI work), which has led to a collaboration with Warwick University and the Faraday Institution to produce a proposal for the EPSRC EDI Hub call.

We have also started to influence the institutions that are part of the consortium, with several of the EDI working group being involved in EDI-based initiatives such as departmental working groups. In addition, we submitted evidence to the All Party Parliamentary Group on Diversity and Inclusion in STEM inquiry on Enquiry on Equity in STEM workforce that was referenced six times in the final report (published July 2021) and was cited as an example of good evaluation practice.

Our EDI work is one of our impact case studies: We are the ones that we seek: Equality, diversity and inclusion in CREDS. This extensive EDI and ECR work was also presented as one of four major impact case studies of CREDS at CREDS in Celebration final event.

EDI has been central to the planning of all our events including for the consortium and the Energy Demand Research Network (EDRN). For example, we try to ensure diversity and a gender balance amongst speakers and promote ECRs contributions where possible. In addition, a guide on Planning effective, inclusive and sustainable events has been developed to check the environmental and social performance of venues, and to make events as inclusive as possible.

Following the survey of CREDS staff that 4 (of 50 who completed the survey) people had experienced bullying or harassment 'rarely' or 'occasionally' since being at CREDS, we undertook an awareness-raising campaign about this issue called the 'EDI spotlight series' in 2021 and 2022 with:

- A webinar on inclusive leadership (15 November, 2021) and a second webinar about personal stories of diversity, called 'Fitting in and Standing out' on 18 November, 2021. This was co-ordinated with National Anti-Bullying Week in November 2021, the theme of which was One kind word.
- This theme inspired the Amplify Project – a confidential forum for members of the energy research community to share their own stories of workplace bullying and harassment. Collecting and sharing these accounts has helped raise awareness and create a safe and honest way to examine working cultures. The learning points from these stories are available as a blog.
- A second webinar completed the series on 12 May, 2022 with a Neurodiversity Spotlight as part of mental health awareness week covering issues such as diagnosing neurodiversity (e.g. ADHD, autism and dyslexia), living with energy-limiting conditions, how to adapt work and workplaces to be more suitable for neurodiverse people and working with a neurodiverse team of people.

We provided information to the consortium on the CREDS anti-bullying and harassment procedure and key contacts. The survey of institutions that had recruited staff indicate that 3 institutions made staff aware of the bullying and harassment procedures of their employing institution included information on flexible working during induction. Clearly, this could be improved.

In terms of supporting career progression, we ran a dedicated call and mentoring scheme for researchers to lead projects, the Early Career Researcher (ECR) Flexible Fund call (See section 5.1). Although this was called an ECR call the staff that became PIs were mostly mid-career. We also provided two induction meetings to bring the new PIs up to speed, covering topics such as project management, staff management and invoicing and the core team were available for individual advice. The ECR funding call has had a big impact on the careers of those that received it – three have new jobs (one in central Government, one in energy consultancy) and two have been able to stay in academia and successfully apply for further funding. Nishatabbas Rehmatulla secured his promotion to Assistance Professor, it enabled his researcher to become established in this academic space and apply for his own grant as PI and the work has seen international recognition at the UN.

Faye Wade received a Chancellor's Fellowship and a Co-I role in the Energy Demand Research Centre, and Janine Morley received further CREDS funding and other projects too and has written a blog about her experience in CREDS.

Support to ECRs within CREDS included a dedicated event in 2019 to bring CREDS ECRs together to get to know each other and provide some training and mentoring and funding for a small project within their own research area. CREDS also supported (funding and speakers) the ECR cross-consortium Net Zero conference 30 November-1 December 2022 in Manchester and many of the CREDS ECRs and students attended.

5 CREDS use of Flexible Funding

5.1 Challenges call

We had funding allocated to a further 2 challenges of up to £1million each within the proposal and we held a 2 stage funding call process to select projects. The call was live for 10 weeks on our website and was the 4th most popular page with 1949 views. We held a webinar on 13th December 2018 that was attended by 36 people and the presentation and Q&A from the webinar were made available on the website and had 106 page views. There were 24 proposals that applied in Stage 1 and of these, 7 were selected for Stage 2. The process involved 2 reviewers for each proposal and a score was allocated, the combined score from the 2 reviews were used to rank the proposals which were then debated in a panel forum. One proposal was contentious and hence further new reviews were gathered before it was accepted.

The two projects that were funded as a result of the call were:

- Fuel and trAnsport poverty In the UK's energy tRansition (FAIR) | Mari Martiskainen at Sussex University. This involves partners in Sussex, Oxford, Manchester, Edinburgh, Ulster, Liverpool John Moores, Energy Saving Trust, Cambridge Econometrics and Green Alliance.
- Complete decarbonisation of the steel industry — how do we get there? | William Gale, University of Leeds. This involves partners in Leeds and Sheffield.

These projects have been monitored in the same way as the existing themes, with the PIs on the Executive Board of CREDS and the research teams as full members of the consortium

5.2 Flexible Fund allocation

The Flexible Fund is now fully committed with nearly 50 projects within this fund.

5.2.1 Early Career Researcher (ECR) Flexible Fund call

The eight ECR awards that were funded in 2020 were integrated into the themes, so their results are reported in Section 3.

The EDI plan committed to reserving at least 30% of the Flexible Fund (this was increased from £750,000 to £1m) to allow researchers to lead projects to enable them to gain proposal writing and project management skills and PI experience. The call was open and ECRs were defined as 'people active in energy research in the UK who have not previously led a project with funding exceeding £100k' and this criteria was thought to be appropriate according to the evaluation. We put additional support mechanisms in place during the call to support capacity building for researchers, such as providing a long window for proposal writing (call published 25/7/2019 – call closed 17/12/2019), offering a webinar to explain the call scope and conditions on 26/9/2019 (49 people attended) and offering a group mentoring scheme (66 people were offered mentoring provided by seven members of the CREDS Executive). Finally, feedback was offered to all applicants: individual written feedback to the 19 shortlisted candidates and individual mentoring sessions (phone calls) to 50 unsuccessful candidates.

The projects were integrated into our existing thematic areas of work and therefore come under the same governance processes as the rest of the consortium. We held two induction training sessions for the new PIs and the core team were available for individual questions and advice. The eight projects are:

1. Using electric vehicles as distributed energy storage systems: a digital twin-based approach, Senthooran Balasubramaniam | University of Coventry
2. Adding another layer? A future for clothing in heat demand reduction and decarbonisation, Janine Morley | University of Lancaster
3. CoCo hybrid project, George Bennett | University College London
4. Decarbonisation of coastal shipping, Nishatabbas Rehmatulla | University College London
5. Social entrepreneurship at the grid edge, Charlotte Johnson | University College London
6. Old for new? Mapping skills and communication networks for traditional and off-site building energy retrofit, Faye Wade| University of Edinburgh
7. DeViz (Defect visualisation via thermography), Julie Goodhew | University of Plymouth
8. Facilitating policy change for low carbon mobility: the role of multilevel governance, Louise Reardon | University of Birmingham

There was a small amount of budget remaining from the ECR call that we have used to fund an additional two ECR projects for staff within the CREDS consortium– one was to write a paper on clothing, comfort and energy demand and one is carrying out a two-way learning process between ECRs and practitioners on sensitivity auditing to scrutinise a model's uncertainty.

5.2 Core Team resourcing

We allocated additional funding for the core team from the Flexible Fund to recruit a Knowledge Exchange Manager for Business because we recognised that the business audience did not have sufficient attention within CREDS. This role mainly liaised with the key themes involved with the business audience Materials and Products and Steel and interested trade bodies such as CIBSE, ADE and IMechE. We also allocated additional funding for an EDI manager within the Core team to provide expertise to the consortium.

5.3 Data and research quality project and support for archiving

The data and research quality project led by Sarah Higginson has produced a six video series to support learning on improving the transparency, reproducibility and quality of research (TReQ tools), reviewed and summarised the preprint policies of 20 top journals published in by CREDS researchers and summarised a few useful reporting guidelines.

All projects' data will be archived on the UKDS website. To enable the data to be found more easily, a collaboration between UKERC and CREDS has resulted in UKERC harvesting archived CREDS data from UKDS by AI and listing it on their database according to IEA categories.

5.4 Final Project on 'from crises to net-zero'

As expected, new opportunities for research have arisen during the course of the project and the final project is taking advantage of the rich changes that have happened as a result of the pandemic and the affordability crisis and the effects these have had on energy demand to draw lessons for the longer term. It is structured into five work packages:

- WP1: Heating and comfort to understand changes to heating practices during lockdown and subsequently
- WP2: Commuting and business travel – undertaking additional waves of surveys and interviews to understand post-pandemic travel patterns
- WP3: Space, time and infrastructure: linking a number of existing models and demand scenarios based on other CREDS work to investigate the scope for flexibility using EV batteries
- WP4: Local responses to zero-carbon strategies in two contrasting city region areas of England
- WP5: Stakeholder engagement and synthesis of findings from across the work packages.

The findings were shared in a public webinar 'From crises to net-zero' on 4th July 2023.

5.5 Impact Acceleration Awards

We have had an IAA fund to extend the impact of CREDS' research since November 2019 and it has funded 9 projects.

1. In partnership with the Local Government Association to develop seven decarbonising transport briefs (Transport)
2. In partnership with Transport for the South East to develop a place-based carbon calculator for transport for local authorities (Transport)
3. To extend our relationship with central government and to enhance our impact on policy, we funded a Government Affairs Manager to reach BEIS, MHCLG and the Treasury. (Core)
4. Two policy workshops to increase academic presence in the public conversation on Fuel Poverty Evidence (FPE) with MPs, Citizen's Advice and OFGEM and material developed for the Fuel Poverty Research Network (FPRN) and CREDS websites. (FAIR)
5. Working in partnership with the Federation of Master Builders to transform how energy retrofit needs to be embedded in the everyday practices of builders working in the repair, maintenance and improvement (RMI) market (Policy)
6. Energy and economic scenario modelling for a future residential retrofit programme to understand the impact of a suite of policy interventions on delivering the UK's net-zero targets with the report promoted in a series of dissemination events. (Digital)
7. In partnership with IIASA (Austria) and NTNU (Norway) to share primary-final-useful stage energy data from the MARCO-UK modelling work and create international impact. (Materials)
8. Working on a test area in Manchester, the model aims to integrate the building stock, heat pump flexibility and EV charging patterns to identify the potential for increased, local heat and transport flexibility. (Buildings and Transport)
9. To create Citizens Panels on mobility linked to PLEF and bridging across to work in the Energy Demand Research Consortium. (Transport).

Progress on the IAA projects is reported in section 3 within their related themes.

5.6 Integration Projects

The Flexible Fund funded five integration projects where staff from many themes within CREDS worked together on a project.

Shifting the Focus report and major cross-theme activity

In July 2019, CREDS launched its first report, based on existing research, called Shifting the focus: energy demand in a net-zero carbon UK. The report proposes actions to strengthen and deliver the commitments in the Government's Clean Growth Strategy, although the emphasis was changed during the project to reflect the altered policy landscape and the shift to Net Zero. This was the first CREDS cross-theme activity, with the aims of developing collaborative working across CREDS, producing policy relevant outputs, providing early impact for CREDS and helping identify gaps in our research plans.

The overall conclusions were that demand side change should be a major part of the strategy for an affordable, secure and net-zero carbon energy system. Delivering it will not be easy, as it is a broad agenda, but delivering the transition without doing demand side change would be much more difficult. It is available as the full report or as a summary version. The media coverage was exceptional with the BBC doing an exclusive and Nick Eyre was interviewed by Mishal Husain on the BBC Radio 4 Today programme on the morning of the launch.

In the first 5 days after the launch, the CREDS website news item and report publication page were viewed more than 1,100 times and the report PDF was downloaded 873 times. Since then, it has been viewed 7,104 and downloaded 3,062 and is our most popular publication. More details are available in the CREDS Annual Report 2018-2019, section 2.1 National Impact Case Study.

The short and long-term impact of COVID-19 on building energy demand and future decarbonisation, led by Tadj Orecsczyn. Data analysis of the questionnaire and meter data from 1,000 properties has been completed, leading to a full paper on energy use behaviour change during lockdown. Further papers focus on the change in measured energy use and its relationship to the self-reported behaviour change.

The contribution of energy demand in the economic recovery package post-Covid-19 led by Clare Downing. A range of green policies for buildings and Industry and estimated investment values provided inputs into the E3ME macro-economic model scenarios and Cambridge Econometrics ran the scenarios against a BAU baseline of current policies. The results indicate that investing in 'green' rather than 'brown' recovery measures would benefit the economy, have better employment outcomes, drastically improve environmental performance and have important distributional impacts, with low-income households seeing greater relative welfare improvements from these policies. The report Macroeconomic impacts of green policies in the Economic Recovery Package post-Covid was published in December 2021, and was promoted in co-ordination with the communications team at Cambridge Econometrics with a blog: Energy-demand reducing measures can play a major role in helping the economy to bounce-back from the long-term impacts of Covid-19.

The **Positive Low Energy Futures** (PLEF) project led by John Barrett, provides the most comprehensive assessment to date of the role of reducing energy demand to meet the UK's Net Zero climate target. Further information is provided in Section 3.3.

Covid-19 Transport, Travel and Social Adaptability Study (TRANSAS) led by Jillian Anable and Greg Marsden, and co-funded by many partners including CREDS Theme 2, Transport Scotland, ClimateXChange and Liverpool City Council. Six waves of data have so far been collected and there will be a webinar to present the results on 4th December. Results of the surveys, including blogs and news are published on the and the results are published on a dedicated website.

C R E D S

About CREDS

The Centre for Research into Energy Demand Solutions (CREDS) was established as part of the UK Research and Innovation's Energy Programme in April 2018, with funding of £19.5M over 5 years. Its mission is to make the UK a leader in understanding the changes in energy demand needed for the transition to a secure and affordable, net-zero society. CREDS has a team of over 140 people based at 26 UK universities.

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