CREDS Mid-term review report

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Executive summary

The Centre for Research into Energy Demand Solutions (CREDS) was established in April 2018, as part of the UKRI Energy Programme, with funding of £19.5M over five years. Our mission is to make the UK a leader in understanding the changes in energy demand needed for the transition to a secure and affordable, zero- carbon energy system. This report is CREDS input into UKRI's mid-point review of the progress of the centre.

CREDS has brought together world-leading researchers from a wide range of disciplines. By building on the work of the End Use Energy Demand (EUED) centres, which preceded CREDS we have maintained the momentum of research excellence they developed. We have already developed a strong record of peer-reviewed publications, many of which are likely to have high impact, particularly in the context of the urgency of climate mitigation. We are confident that CREDS is becoming the largest single contributor in the world to high quality research on energy demand.

CREDS is UKRI's largest investment in energy demand research and acts as the hub for the UK research community in this field, giving us particular responsibilities for capacity building. We have paid particular attention to the needs of early career researchers (ECRs), giving them leadership roles in new projects. We also strive to be a beacon for equality, diversity and inclusion (EDI) through a consistent focus and some new initiatives set out in this report.

Our research agenda covers a wide range of energy demand issues. Three themes address energy use in the main energy using sectors: buildings, transport and industry. The other three themes are cross-cutting and address key drivers identified through consultation: flexibility, digitalisation and policy. Each theme has a well-established research and engagement programme and has already produced strong and influential research outputs, which we highlight in this report. Alongside these, we have funded three challenges, identified through a consultation process. The first, on decarbonisation of heat, began in 2018 and will end in 2021. It is producing important insights for the critical challenge of total decarbonisation of heating in buildings. The other two challenges, on fuel and transport poverty and on decarbonisation of steel, began in 2020, but are already delivering interesting findings.

In the 30-month period from the start of CREDS to September 2020, CREDS staff have authored over 180 publications, of which approximately 50% are peer-reviewed journal publications. The publication rate is increasing; in the last 12 months we have produced 91 publications, including 57 journal papers.

We champion the need for research on real world problems related to energy use rather than particular disciplinary approaches. All the themes and challenges are inter-disciplinary, and we work across themes where appropriate. In particular, we began the work of CREDS with a cross-theme project to assess the effectiveness of UK Government policy on energy demand. We have three ongoing projects on different aspects of the impacts of Covid-19. We are completing work on UK low energy demand scenarios, which has informed the recommendations of the Committee on Climate Change (CCC) on the UK's Sixth Carbon Budget.

Our first cross-theme project had the twin goals of promoting cross-theme working and producing a high-impact report by integrating existing knowledge from the energy demand research community. It led to a report on Shifting the focus: energy demand in a net zero carbon UK that was widely publicised in the media. It defines key aspects of our research scope: we cover both energy efficiency and how the demand for energy services changes, and we address demand reduction, flexibility and switching to decarbonised fuels.

Whilst our work is focused on energy demand, we use whole-system thinking. Aspects of our work, for example on heat decarbonisation, steel decarbonisation and flexibility also address supply-side issues. We have excellent links with other UKRI major investment in whole systems energy research, notably UKERC, CESI, EnergyRev, IDRIC and the Supergen hubs.

CREDS acts as the focal point for energy demand research in the UK. We have established the Energy Demand Research Network (EDRN) and consulted the energy demand research community on its needs for support with engagement and communication. We hold regular meetings for the network. We have a webinar programme, which we are seeking to expand internationally.

We work closely with other stakeholders in the energy demand community. We have involved stakeholders in the co-creation of research, examples of which are set out in this report. We have developed a communications and engagement strategy and associated plans to ensure we identify and engage key stakeholders. This enables us to work with them through a planned programme to use the best channels at the right time.

We have an Advisory Board drawn from key UK government departments, devolved government, the CCC, energy sector and energy saving businesses, trade associations, professional institutions, non-governmental organisations, independent experts and academics. We actively seek and use their advice and involve them in our meetings and other activities.

From the outset we have given the highest priority to ensuring that our impact matches the scale and quality of our research. The centre was designed to do this, as was each theme and challenge. Our whole leadership team is committed to this goal and we have succeeded in making it part of the culture of the centre. As a significantly larger centre than any of the preceding EUED centres, we have been able to recruit knowledge exchange professionals as part of the centre's core team. We use this expertise to ensure that our solution-focused research enables more impact for our work than has been the case historically for energy demand research. We set out the impact we have achieved in this report and it is illustrated with our 16 impact case studies..

The community of UK energy researchers does not fully reflect the diversity of the UK population and CREDS researchers are fairly typical of the wider research community. We recognise this starting point and are committed to change. We have given a high priority to equality, diversity and inclusion (EDI). We have a well-developed plan, which a cross-centre working group chaired by the Director is implementing. We undertake an EDI annual report on progress, drawing on a survey across the centre. We keep EDI on the agenda of Executive and Whole Centre meetings. We have helped other UKRI investments to develop their own plans. We recognise that there is more we can do, and therefore we are beginning recruitment of a part-time EDI Manager to increase our capacity to deliver our plans. We also plan to commission work to scope the need for research on energy demand and racial justice.

We have carefully considered our role in capacity building, and we have been successful in recruiting some mid-career researchers into leadership roles. We place a high importance on training of inter-disciplinary researchers, which our approach to research naturally enables. We have made support for ECRs the highest priority for use of our Flexible Fund, through a £1M call for research projects led by ECRs. This was a major exercise for CREDS, with excellent support in reviewing from the wider community and our Advisory Board. It has been a major success with eight new projects funded, led by a diverse group of potential leaders of the future. We have integrated these projects into our theme structure to ensure we provide appropriate support.

We review progress against our original aims in order to ensure that we identify areas of work that require further development. We currently have two such areas in mind: international engagement and business engagement. In both cases, our original planned activities have been detrimentally affected by the Covid-19 pandemic, and therefore we are developing revised plans.

We also review the external context for our research plans in order that we react appropriately to external change. Since we drew up the CREDS research programme in late 2017, there have been two major changes with potentially very large impacts on energy demands: the UK commitment to net zero, and the social and economic effects of the Covid-19 pandemic. Understanding the impacts of these on energy use is urgent. Subject to the recommendations of the Mid-Term Review, we therefore propose to use most of the remaining Flexible Fund to focus on these issues in the next two years.

In summary, CREDS is undertaking world-leading research and has brought together the energy demand research community to give it greater impact and develop new capacity. At the same time, the new context of a pandemic and ambitious climate goals has changed the context, and our research therefore needs to adapt. We have already shown that changes to energy demand will need to play a central role in the energy transition; without profound changes in the way energy is used, climate targets cannot be met. We are mapping those changes in more detail, as well as developing tools for key stakeholders, using insights from a wide range of disciplines across the physical and social sciences. Going forward, research will need to be strongly linked with the demonstration and deployment activities necessary over the whole period of the energy transition.

1. Introduction

The Centre for Research into Energy Demand Solutions (CREDS) was established in April 2018, as part of the UKRI Energy Programme, with funding of £19.5M over five years from EPSRC and ESRC. 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, zero-carbon energy system.

CREDS is UKRI's largest investment in whole systems, inter-disciplinary work in the area of End-Use Energy Demand (EUED) and is charged with acting as the hub of this area of research in UK universities.

The 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.

An overview of the governance structure is provided in Figure 1. The Director has responsibility for the operation of the centre, subject to oversight by UKRI, and draws on advice from an independent Advisory Board. The key decision-making body of CREDS is the Executive, which consists of the Director, theme Leaders and the Centre Manager. Each theme Leader has responsibility for delivery of their thematic research programme. The Centre Manager leads the administrative and knowledge exchange of the centre, supported by a small Core Team.

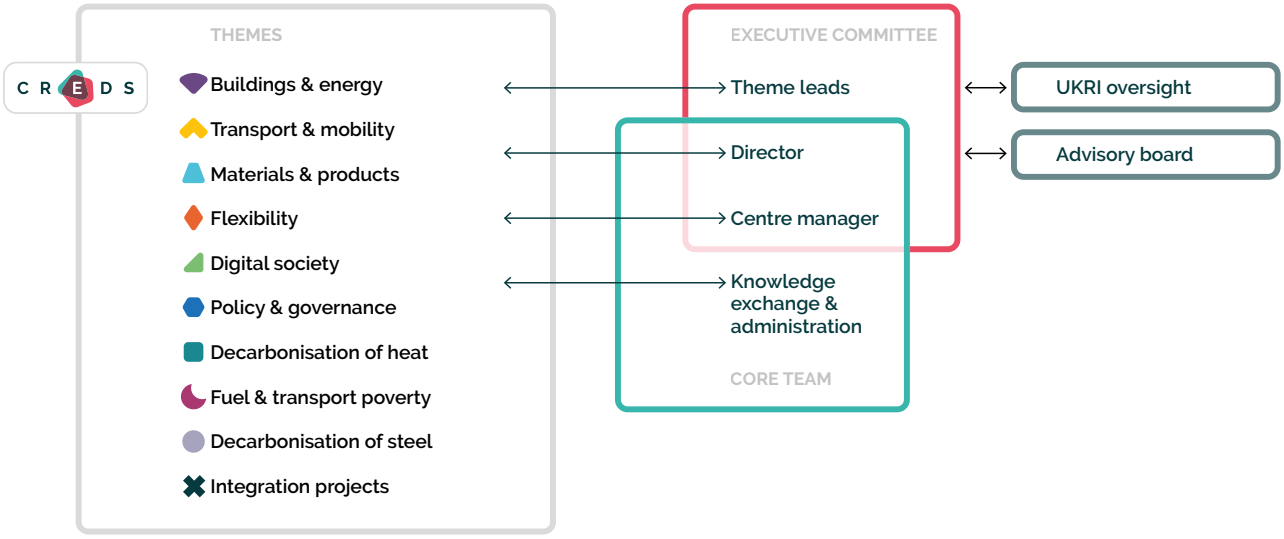

Figure 1. CREDS governance structure.

Appendix 1 lists executive members and roles. The Director is advised by an independent Advisory Board, which also has responsibility for oversight of use of the Flexible Fund. Current Advisory Board membership is set out in Appendix 2.

In addition to the research activities shown in Figure 1, CREDS has a Flexible Fund with which to respond to changing circumstances. The allocation and use of the Flexible Fund is overseen by the Advisory Board.

CREDS is a distributed research centre. The Director, Centre Manager and core team are based in the University of Oxford, but the whole centre consists of approximately 200 people based in 24 UK universities, each of which is required to sign the CREDS consortium collaboration agreement.

This report seeks to synthesise and self-evaluate CREDS work to date as an input to the independent panel conducting the Mid-Term Review of CREDS. There is more detail on CREDS work in the published annual reports for 2019 and 2020 and on the CREDS website.

The structure of this report is based on guidance from UKRI. The next section sets out the research achievements to date, both for CREDS as a whole and each research theme. Section 3 sets out how we have built on the previous Research Council investments in EUED; Section 4 summarises the other (non-research) activities; Section 5 sets out our relationships with other stakeholders; and Section 6 outlines our outputs and the resulting impacts. Section 7 explains the use of the CREDS Flexible Fund; Section 8 outlines our approach to managing the centre; and Section 9 sets out our plans for the future of CREDS. Appendices provide background information.

2. Research achievements

2.1 Research consultation and planning

Both the Research Council guidance and broader considerations of good practice point to engagement with relevant stakeholders in designing the work of research centres. Such consultation was enabled by the decision of the Research Councils to appoint Nick Eyre as EUED Champion for a 9-month period in advance of the proposed CREDS start date of 1 April 2018. During this period there was extensive consultation with the existing EUED centres (see Section 3), the energy demand research community in the UK, and other stakeholders including in Government, business and civil society organisations.

The outcome of this process was a consensus that CREDS thematic structure should reflect both the diversity of types of energy use in the UK and the pressures that might lead to change. The CREDS core research themes agreed were:

- three themes focused on the main energy using sectors of buildings, transport and industry; to emphasise the importance of considering energy service demand as well as efficiency, these are called buildings, transport and mobility, and materials and products respectively.
- three themes based on stakeholder assessment of new pressures: flexibility, digital society, and policy and governance.

This broad structure of the research programme – six themes and the first research challenge on decarbonisation of heat – was set out in the CREDS proposal.

In addition, we consulted on the priorities for other challenges, with broad agreement that there should be a call for proposals around three topics: decarbonisation of difficult sectors, equity and justice, and co-benefits. This led to the funding of the second and third challenges: on transport and fuel poverty, and decarbonisation of steel.

The research programme is designed to make a major contribution to many of the strategic priorities of UKRI. In particular research in:

- the whole consortium directly contributes to the **climate change** priority, as we expect changes to energy use to be the main contributor to climate policy goals.
- the Buildings and Transport and Mobility themes contribute to improving knowledge of the priorities for **21st Century products** that will be needed to meet energy and climate policy goals.
- the Materials and Products theme, and the Decarbonisation of Heat and Decarbonisation of Steel challenges directly address the net zero carbon issues within **sustainable industries** and **new industrial systems**.
- the Buildings and Policy and Governance themes, as well as the Transport and Fuel Poverty challenge, contribute to understanding the major changes needed in the priority area of **housing**.
- the Materials and Products and the Digital Society themes will elucidate the important role of energy in **productivity** and **understanding the macroeconomy**.

In designing the research programme, we were concerned about two particular risks arising from the nature of a large, multi-institution centre: first, that new research projects might not produce impactful results for a number of years; and secondly that the separate themes might not interact adequately. To address these we included an early integration project, bringing together people from all themes to focus on the energy demand aspects of overarching UK government policy as set out in the Clean Growth Strategy.

2.2 Cross-theme activities

We strive to promote a research culture that values inter-disciplinary approaches and avoids siloed thinking. This was a key criterion for the selection of the Director and design of the centre. Similar criteria have been applied to the selection of themes, challenges and their leaders; and then to research projects and researchers. We have been successful in recruiting a team committed to inter-disciplinary research and whole-systems thinking. This greatly assists with identification, design and management of cross-theme activities.

Cross-theme activities have arisen in four ways:

- through strategic decisions to use the Flexible Find to support cross-theme projects,
- through the core team putting researchers in touch with each other as a result of their overview knowledge based on their theme liaison role,
- through bottom-up collaborations, where individual researchers identify questions best addressed through inter-theme working, and

- through immediate feedback from one researcher to another, for example through interactions at CREDS Whole Centre Meetings or research webinars.

2.2.1 Integration Projects

The Flexible Fund (through a process described in Section 8) has funded projects that integrate findings across themes, in three broad areas:

- our completed opening project on the UK Government's Clean Growth Strategy project Shifting the Focus,
- ongoing work to develop quantified Low Energy Demand Scenarios for the UK, and
- a cluster of projects on impacts of and responses to Covid-19, including on energy use in homes and travel, and the role of demand side measures in economic recovery.

2.2.1.1 Shifting the focus – CREDS' response to the Clean Growth Strategy

For the reasons set out above, the twin objects of the project were to produce an early output with high impact and to promote joint working within the centre. We were confident that we could make a useful contribution quickly, without the need for primary research, by drawing on existing research and the expertise of staff in the centre.

The project was led by Nick Eyre, with excellent engagement from across CREDS. The analysis involved 22 members of the centre, from all themes, with internal reviews by another 12. The report quickly achieved our goals of establishing joint working across themes.

Although the Clean Growth Strategy was the starting point for our analysis, subsequent developments made net zero plans a better framing of the findings, and therefore the final report was entitled Shifting the focus: energy demand in a net zero carbon UK.

The critical intellectual output was an expanded approach to thinking about the role of energy demand change in the energy transition, as more than just energy efficiency improvement, as shown in Figure 2. This now forms the guiding approach to the breadth of the research programme and our explanation of its importance.

The Shifting the focus report secured high media attention (see Case Study 04: Shifting the focus towards energy demand) and has informed the work of other organisations, notably the Green Alliance report Balancing the energy equation: three steps to cutting UK demand.

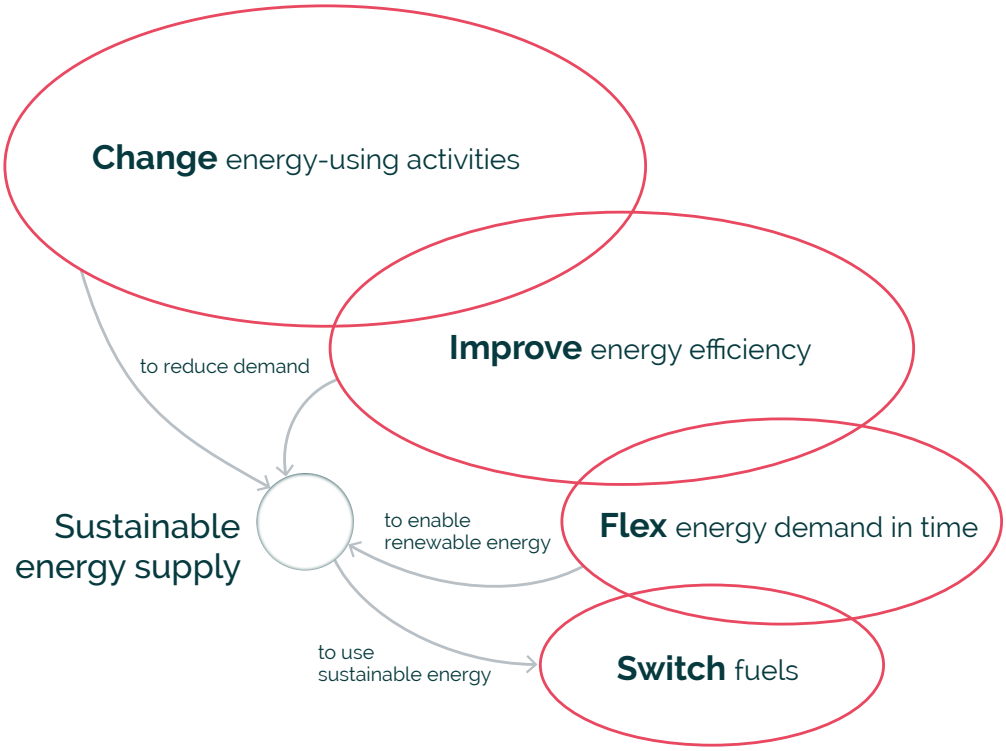

Figure 2: Energy demand in the zero carbon energy transition

2.2.1.2 Low energy demand scenarios for the UK

Work is now well-advanced on our next cross-cutting report on low energy demand scenarios for the UK, led by John Barrett (theme lead for Materials and Products, University of Leeds). The project is developing quantified low energy scenarios for the UK, involving staff from six themes. The immediate target audiences are UK Government and the Climate Change Committee (CCC), as they develop their thinking on rapid decarbonisation, but we also see the report as a distinctive input to debates around COP-26, which risk being over-focused on supply side change and negative emissions.

The analysis starts from a consideration of the fundamental energy services of shelter, nutrition, mobility and products and the energy needed to provide these, incorporating measures to avoid demand and shift systems of provisions as well as improve efficiencies. It will be the most advanced and detailed low energy demand scenario ever produced at the national level. The intention is a publication in Nature Energy. The majority of the modelling and narrative for each sector is complete and teams from the Department for Business, Energy and Industrial Strategy (BEIS), the Department for Environment, Food and Rural Affairs (Defra) and the Department for Transport (DfT) have offered to review the results.

2.2.1.3 Impacts of and responses to Covid-19

Although the Covid-19 crisis has raised a number of operational challenges for CREDS, it has also changed our research agenda. This was apparent from day one of lockdown: energy demand changed radically, particularly in transport, providing an opportunity to research a natural experiment in the impact of changing practices on energy use. As time has progressed, interest has moved towards the longer-term implications of Covid-19: both how energy using practices will change and the potential for energy demand reduction through the economic recovery package. During the early period of the pandemic, we quickly developed three projects in this area.

The first looks at The effect of Covid-19 on energy use in homes, working with the Smart Energy Research Laboratory (SERL) and is led by Tadj Oreszczyn (theme lead for Buildings, University College London). The research involves a survey of 1700 people already participating in the SERL analysis of domestic smart data, with a focus on the periods of lockdown and recovery from them. This allows combination of qualitative responses about the impacts of Covid-19 with quantitative smart meter data. Analysis is ongoing.

The second is The effect of Covid-19 on travel and socialising adaptability, led by Jillian Anable (theme lead for Transport and Mobility), and co-funded by a number of partners including Transport Scotland, ClimateXChange and Liverpool City Council. In this work we are leading a UK-wide forum for sharing results on Covid-19-mobility related datasets, including health data. The project aims to do a three-wave survey looking at how behaviour in travel has changed as a result of the pandemic. There has been a quantitative survey of 9,600 participants in ten city regions, followed up with 110 interviews in five locations and interviews with policymakers and academics. Further survey and interview work is ongoing.

The third is on The contribution of energy demand in the economic recovery package post-Covid-19, led by Clare Downing (Centre Manager, University of Oxford) and involving staff from five CREDS themes. This study is user-needs led, in that we have consulted policymakers in BEIS, DfT, the Ministry of Housing, Communities and Local Government (MHCLG), the Scottish Government and the Local Government Association (LGA) on their information needs. We are then applying existing analysis, coupled to macroeconomic modelling to evaluate the impact of different policy options on key economic and energy indicators. We have already responded to a request from BEIS for rapid analysis of the ability of the housing retrofit supply chain to scale up, in preparation for the Chancellor's announcement of the Green Homes Grant in the July mini-budget.

2.3 Buildings

The Buildings theme was able to make a prompt start to research in 2018, with high levels of staff continuity from the EUED Centre for Energy Epidemiology. This benefitted CREDS as a whole, as the theme was able to make important progress and generate outputs and impact, while some other themes were still recruiting.

The theme's research on co-benefits includes work on health and comfort. The health project has already published several papers, including one on radon and energy efficiency that finds a positive association between air tightness and radon levels. Work on a major evaluation of the relationship between health and energy performance of housing was delayed by data availability during lockdown, but is now proceeding. Research on comfort and control is examining the empirical evidence for energy savings from improved controls. As the opportunities emerged for research on the impacts of lockdown on energy use in buildings, we decided to prioritise research in this area and shifted some research onto Covid-19 specific tasks (see description under cross-theme working above).

An important part of the theme's research is to analyse the performance gap – the discrepancy between modelled energy ratings and the actual performance of buildings. The research is taking advantage of new opportunities enabled by access to smart meter data and additional resources from the BEIS-funded SMETER project. The theme has published a paper on the incorporation of solar gains into dynamic thermal models and brought together novel data sets and algorithm development to produce digitally generated in-use building efficiency certificates. The aim is ultimately to allow this approach to improve the unreliable current system of Energy Performance Certificates and create a rating consistent with the 'as built' performance. Results from this work are feeding into the evaluation of the Green Homes Grant, the proposals for SAP-11 and the Green Finance Institute's Metered Energy Savings project.

Research on future energy use pathways in buildings model has made significant advances through the development of the 3Dstock model. Its London version, The London Building Stock Model (LBSM), has been completed and launched by the Greater London Authority (GLA), as a tool for the decarbonisation of the building stock in London. The GLA and London boroughs are using LBSM to identify poorly performing dwellings and other buildings. This supports the boroughs' work to enforce Minimum Energy Efficiency Standards. Development of the 3DStock model has continued, with publication of a journal paper and an animation. There is ongoing work to extend use of the model to other areas, and 3DStock is also being used with metered data to provide BEIS with insights into the impact of EPCs on buildings' energy use. 3DStock is also being used as part of the Active Building Centres refurbishment work programme, including the development of a model of Sheffield (see Case Study 06: Taking 3D stock: modelling the building stock and its use of energy).

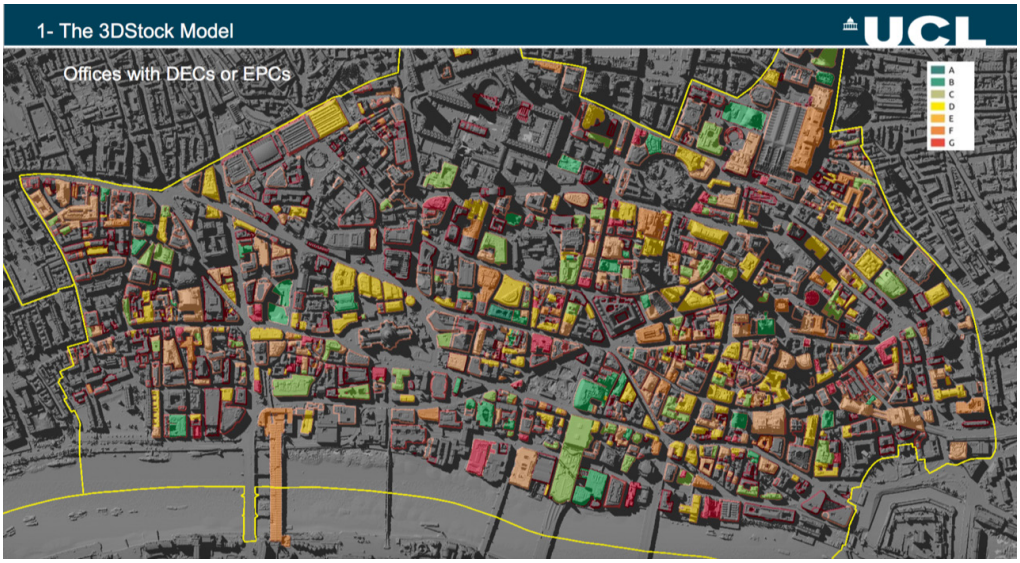

Figure 3: The London Building Stock Model (LBSM) is being used by the Greater London Authority (GLA) as a tool for the decarbonisation of the building stock in London.

Collaboration with the research on decarbonisation of heat has produced an award-winning paper on the effects of carbon dioxide on human cognitive performance. This is described under Decarbonisation of Heat, below.

The theme has made considerable policy impact. It makes a key input to the globally influential Lancet Countdown on climate change and health, and it has participated in the Government's input into the Mission Innovation initiative. Theme members are central to CREDS development of closer working relationships with the evidence and policy teams working on buildings in BEIS. One early career researcher provided oral evidence to the House of Commons Science and Technology Select Committee. Another is currently seconded part-time to BEIS's Science and Innovation for Climate and Energy team, providing technical and policy support on heating systems performance and future clean heat strategies. Theme members have provided advice at senior levels in Government and business, including to a roundtable on decarbonisation of home heating, where the audience included the Chief Executive of Scottish Power, the BEIS Minister of State, and to a Council of Science and Technology meeting devoted to retrofitting of homes.

International impact has included the launch of the Global Roadmap for Buildings and Construction, co-authored with the International Energy Agency and the UN Environment Programme, and The Lancet Countdown on Health & Climate Change 2019 Report. Theme members have also been active in a number of international collaborations, including with the Mexican government and the Costa Rica Green Building Council.

The initial plan for the theme front-loaded expenditure into the first 3 years of CREDS, with the aim of securing additional funding for follow-up work. This has been a successful strategy with funding secured from the Mexican Government, GLA, BEIS and other UKRI projects. It is planned to continue seeking this type of leverage.

The CREDS Building theme has developed a world-leading set of models, tools, methods and building stock databases which are now being refined to help plan the building stock's transition to net zero at the scale of building, local authority and nationally. With the government's £ multi-billion commitment to mass deployment of building insulation and heat pumps this research is proving timely. It is essential that this deployment meets the required performance standards; is appropriate and cost effective while maximising co-benefits; and yet does not result in unintended consequences. This is the focus of the buildings theme work to ensure high-quality and timely impact.

2.4 Transport and mobility

In the first few months of CREDS, the theme appointed a team of high-quality research fellows, discussed project plans with stakeholders – notably the CCC, DfT and key transport operators – and began work on initial projects in the three sub-themes: high energy use, flexible mobility and accelerating deployment. Work is now ongoing on all projects with an increasing output of papers, blogs, briefings and responses to consultations. There have been some delays in fieldwork due to Covid-19, but the pandemic has produced major changes in transport practices and energy use, leading to the development of additional work looking at travel and social change (see section on Covid-19 research above).

The project on high-energy using consumers is undertaking interviews and deliberative workshops online. Recruitment of high-end consumers (who are difficult to define and reach) is more challenging online. The research team has submitted a journal paper on air travel inequality in the UK, drafted a policy briefing on concepts of excess and will deliver a book chapter on social divisions in transport energy use for the Research Handbook on Energy and Society. There are good links with the theme on Fuel and Transport Poverty, which is studying very different consumers.

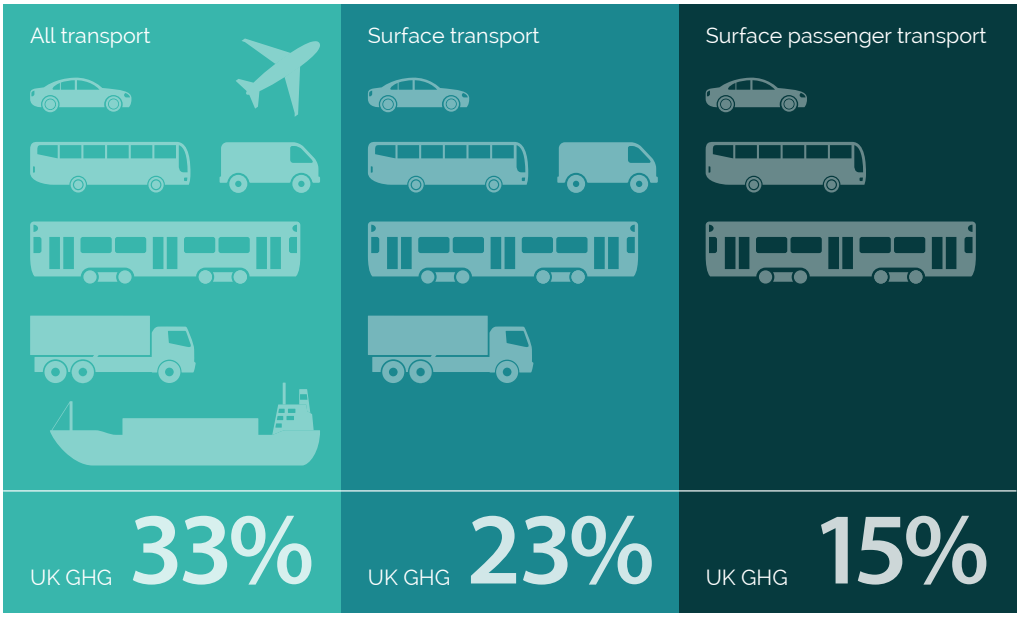

Figure 4: Proportion of UK greenhouse gas emissions per transport type.

The outputs on high-energy using consumers are feeding into the sub-theme on flexibility in mobility, which is focusing largely on passenger mobility. Work to assess the potential for e-bikes to substitute for car use produced a briefing note that gained widespread media and policy attention, including in the CCC recommendations for the UK's Sixth Carbon Budget. The research team completed a series of seven briefings on transport decarbonisation for the Local Government Association in England, covering: ambitious action plans, buses, climate smart parking, electric vehicles, growing cycle use, online opportunities; and accessibility). These provide practical guidance to councils developing strategies that have declared a climate emergency (see Case Study 09: LGA guidance on actions for transport in the climate emergency).

The planned phase out of petrol and diesel vehicles, and the Government's recent decision to advance this to 2030, will continue to make vehicle electrification a major issue for all of our audiences. Our modelling capability makes CREDS well-placed to assess quantitative effects of technical change, but also on complementary issues of mobility change, which gives us a distinctive focus. It has allowed the research team to act as critical friend to the Government's Electric Vehicles and Energy Taskforce, and provide input into a consultation on the phase out date of internal combustion engine vehicles, as well as generating high-impact outputs.

The theme's work on accelerating change is continuing the work of the Commission on Travel Demand begun by EUED Centre DEMAND. The Commission held four inquiry sessions on Shared Mobility, with very good engagement from local and national policymakers, NGOs and transport operators. We launched the final report at the Smart Transport conference in September 2019, which has influenced the CCC recommendations for the Sixth Carbon Budget.

Transport and mobility research in CREDS has a high visibility and impact. The bulk of media coverage of our Shifting the focus report concentrated on its transport chapter, particularly the need for demand reduction alongside electrification. This led to an invitation to meet the DfT Minister of State just after the 2019 election and subsequent support to DfT officials preparing the Transport Decarbonisation Plan. The Scottish Government is incorporating advice on travel demand reduction from the theme's work into its climate change strategy. Work on fairness and tackling excess travel and energy demand has been used in presentations to inform local deliberative process and the UK Climate Assembly. We also submitted evidence based on CREDS research on aviation and long-distance transport to the Environmental Audit Committee Inquiry on Sustainable Tourism.

We keep under review the major implications of the pandemic for transport and its energy use. This is already changing our research plans. For example, the Commission on Travel Demand originally intended its next enquiry to focus on leisure travel, but has now decided to prioritise work on the more urgent issues of travel adaptations due to the pandemic. The Commission is now holding monthly evidence exchanges with a range of key transport providers, planners and policymakers.

Energy and transport research communities usually have limited interaction. The work of the theme is internationally recognised for its application of cutting-edge research on mobility change to the agenda of rapid decarbonisation. It has a strong focus on the areas of passenger transport where growth is happening most quickly, including long distance, leisure and air travel and where there are the most opportunities for rapid change, including due to Covid-19.

2.5 Materials and products

The Material and Products theme consists of three sub-themes that explore energy efficiency opportunities in UK industry, the impacts of consumption patterns and resource efficiency, and broader links between industry, energy use, the economy and society.

Work on industrial energy efficiency and demand has been plagued by poor data quality, consistency and coverage for many years. CREDS coordinated a series of workshops and interviews with BEIS, Defra, devolved countries and the Office for National Statistics to outline the industrial energy data needs to evaluate the pathway to net zero from the perspective of energy demand reduction, as well as assessing over 70 existing datasets. A report entitled A data strategy to promote the clean growth of UK industries, was produced with input from the data specialist consultancy Aether, identifying the urgent need for high-quality industrial energy data that is readily updatable, open access and independently managed. The report has opened up lines of communication with the Director of Industrial Energy in BEIS where discussions on how to implement the plan are ongoing.

In addition to this, the work package has produced detailed sector level net zero pathways for the food and steel sectors, filling important gaps in current UK Government knowledge about available mitigation options. Our modelling includes a wide range of options including production efficiency, product light-weighting, reuse and recycling, material substitution, lifetime extension, product switching and service changes. Both pathways demonstrate not only energy efficiency options but also how the same services (structure for steel and nutrition for food) can be provided with less energy and resources. Defra have evaluated our pathway and are using our evidence to support their scenarios following our response to Government consultations. A similar dialogue is underway with BEIS in relation to the steel analysis.

Research on household consumption drivers of energy use has included a major systematic review on consumption-based mitigation options across various end-use sectors, many countries, regions and social groups. It provides a uniquely comprehensive analysis in a field of increasing interest. The key journal paper has been widely cited and is proving internationally influential, including with the IPCC. The study was launched in May in collaboration with a BBC article attracting over 500k online hits within a week (see Case Study 10: Top ten tips for reducing your carbon footprint attracts international attention).

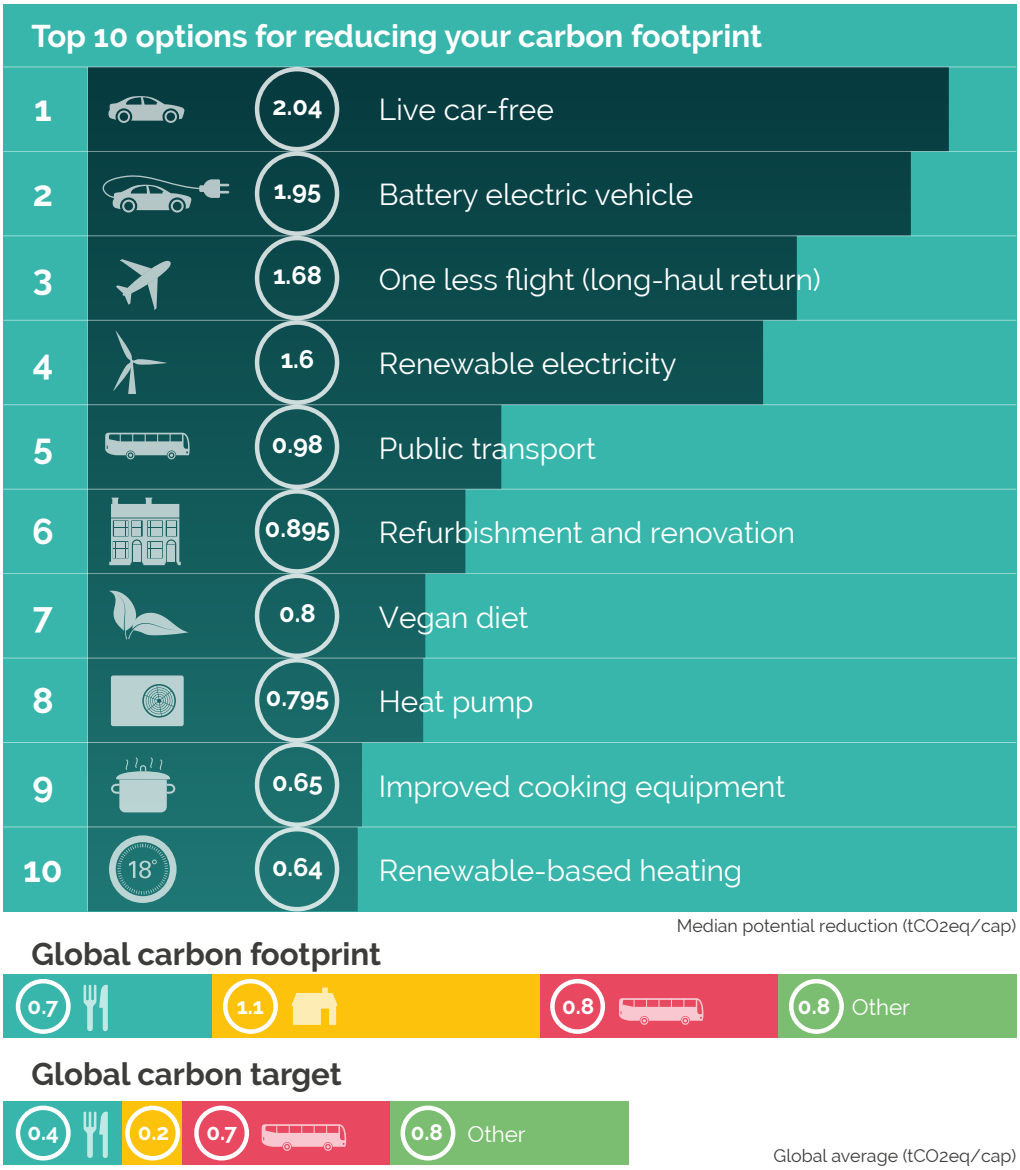

Figure 5: The most effective ways to reduce household carbon emissions.

The key conclusion, although not understood by all social media commentators, is that consumption energy and carbon impacts must be dealt with at a systemic level and it is not just an issue of behaviour change by households. The research on household consumption has had both a UK and international impact leading to the lead author (Diana Ivanova) collaborating on the role of lifestyle change in the UNEP Emissions Gap report, an international report with Oxfam and a major publication with WWF on our consumption and emissions. We also collaborated with Gumtree, the online second hand market website, who have used our data to show the carbon savings of buying second hand products as opposed to new ones on every item on their website. Finally, we have been advising other countries on how to assess the impacts and energy demand implications of consumption.

Our research demonstrates the link between industrial energy demand and different social and economic futures. Demand for an understanding of these linkages is unprecedented, resulting in the team having weekly calls with UK Government departments to feed our research directly into scenario planning, strategies and policies. While no individual is responsible for the one policy, it is our research that has been exclusively used by the UK Government to introduce a legally binding target to double resource productivity (see Case Study 11: Transforming UK Government energy and resources policy). John Barrett is now a member of a UK Government Committee to oversee this target. In addition, we have worked directly with a number of teams from the Climate Change Committee on resource efficiency, translating strategies to policy and consumption based GHG emissions to inform their Sixth Carbon Budget report. This also involved a secondment to the CCC for an ECR, Alice Garvey. Finally, working directly with the Treasury and Cabinet Office, our method to assess the distributional impacts of UK climate policy was adopted for their net zero carbon review following the publication of our approach in a journal article.

Our next steps and future impacts include:

- Greater engagement with UK industry through partnering with Innovate UK, High Manufacturing Catapult and the Energy Systems Catapult. Our approach to supporting systemic change in UK industry will be to work through these boundary organisations. Our project with Innovate and the Catapults will co-create industrial pathways to net zero with industry considering the role of re-manufacturing and new business models. The project starts in February and continues for the remainder of 2021.
- Having produced substantial empirical data and analysis, we will balance our publication of policy reports with more academic papers. We therefore plan to publish 20 academic outputs in the next 18 months, with ECRs being the lead author on each paper to improve their career opportunities.
- With Government, we intend to continue with our extensive engagement to ensure that CREDS research directly feeds into key decision-making processes.

Overall, work on the energy and carbon implications of products and materials is having increasing impact. The direct influence of our research on UK Government has resulted in a new legally binding target on resource productivity. We have extensive engagement with BEIS, the CCC, Treasury and the Cabinet Office, as well as broader impact through collaboration with the BBC. International impact on household consumption issues has resulted in collaboration with the United Nations, Oxfam and WWF.

2.6 Flexibility

The theme is divided into two sub-themes: one on defining, conceptualising and measuring flexibility, the other on intervening to enhance flexibility. The theme is progressing according to plan with five live projects.

In the first sub-theme on conceptualising flexibility, we recognise that demand side flexibility includes both using energy storage to allow temporal decoupling of supply and demand, but also the flexibility of energy using practices and systems of provision. The research aims to conceptualise this whole system flexibility to better understand the synchronisation, periodicity and duration of energy demand. It is building on the work of the EUED Centre DEMAND. Ideas developed from that work form the core of a book now published on Energy fables: challenging ideas in the energy sector. The project has published a paper on how flexibility and time are represented in the energy sector and a commentary in Nature Energy that argues for a paradigm shift in research on energy and time.

In the same sub-theme, work on flexibility in the past, present and future seeks to inform how social and institutional rhythms might fit with variable energy supplies. It has begun by looking at flexibility in the past, and has recruited historians and others to a 2-day workshop, which will be the basis of a special issue on Flexibility in the past in the journal Energy History.

Measuring the flexibility of demand poses challenges. The project addressing this issue is developing innovative ways of measuring demand side flexibility and its value. Working with an international visitor, Max Kleinebrahm, a collaboration on flexibility and machine learning produced a conference paper, which is leading to a journal paper. Two other potential visitors have started taking part in theme online meetings, with the aim of collaborating remotely. The work has also led to a paper on hot weather and electricity demand in Italy.

In the sub-theme on intervening to enhance flexibility, a project on flexible demand side technologies is researching how existing demand side technologies can change patterns of demand. Storage and control technologies, e.g. household batteries, vehicle-to-grid electric vehicles and demand side response platforms, aim to enable more flexible management of demand. As part of this work, the operational constraints on technologies, both alone and in combination, are modelled in relation to how, where, and when people use energy. The work is linked to research on air pollution and health supported by both UKRI and DfT.

The second project in this sub-theme concerns the impact of pricing on time of use. It is moving beyond the traditional approaches of time-averaged price elasticities used to understand total demand. Instead, it considers how price-elasticity varies in time, and through this, the barriers to demand response and the societal impacts of dynamic pricing. It aims to understand elasticities across different energy uses as a function of time of the day, weather and occupancy levels. The work has already generated a book on Appraising the economics of smart meters and journal articles on time of use tariffs, time use methodologies for residential electricity demand, and barriers to demand side response.

The work of the theme has impact through presentation at high-profile events, including the International Energy Agency Demand Side Management Day, a World Bank conference on evidence-based policymaking, in an Ofgem seminar series, and commercial and NGO conferences.

Research has informed advice to Ofgem on various issues, including the impact assessment of the RIIO-2 price control, the Competition and Markets Authority price transparency remedy, the reform of black start restoration, the literature on demand side response, the forward-looking charging review and distributional impacts of half-hourly settlement reform (see Case Study 13: Winners and losers in energy policy reform). Policy advice has also been provided to Defra on resource efficiency, waste reduction and consumption emissions, to the British Standards Institute on smart electric vehicle charge point standards, and to BEIS with regards to storage as a separate asset class. The theme led CREDS' responses to the BEIS/Ofgem consultation on Flexible and responsive energy retail markets, and to the Energy Networks Association consultation on flexibility.

Part of the theme's work is to promote dialogue within CREDS on timing of energy demand and flexibility, so that they are taken into account in other streams of work. A CREDS conference on Flexibility, time and energy demand was planned for April 2021, but has been postponed until 2022 due to Covid-19. Instead, the theme is holding a series of online events, aiming to attract internationally excellent flexibility researchers and facilitate collaborations. The first of three flexibility reading rooms was held in July 2020 on Conceptualising flexibility and was well-attended by a multi-disciplinary audience. Future events in the second half of CREDS are attracting international participation.

Overall, the theme is undertaking internationally leading research through a unique combination of technical, social and economic insights into the variation in, and flexibility of, energy use in time to enhance knowledge on demand side flexibility, which is increasingly critical to a net zero carbon future, but also grounded in everyday lives and energy use. Empirical findings have already informed policy, especially with regard to distributional impacts of time of use tariffs. Moving forward, the theme is expected to set the research agenda on flexibility with conceptual innovation in how the value of flexibility interacts with social practices, and ground-breaking ideas on how flexibility is measured and implemented. The theme will continue to inform policy design and stakeholders from industry and civil society by providing a credible source for information on various aspects of flexibility and pointing to novel flexibility opportunities.

2.7 Digital society

The research in this theme is guided by three overarching questions:

1. What are the historical and potential future impacts of information and communication technologies (ICTs) on sectoral and economy-wide energy consumption?
2. What factors and mechanisms explain those impacts?
3. How can the future energy-saving potential of ICTs be maximised?

The research is organised under three sub-themes that address macroeconomic, business and user perspectives respectively, namely: ICTs and energy productivity; Business models in the digital economy; and Smart systems and user practices.

Research in the energy productivity sub-theme is investigating the aggregate impact of ICTs on economy-wide energy consumption. We began by undertaking systematic reviews of the evidence on ICTs and energy consumption, in relation to: e-materialisation (the use of ICT to replace physical goods), e-working (teleworking) and e-sharing (platform-enabled sharing of physical goods). Papers on e-materialisation and on teleworking have been published as part of a special edition of Environmental Research Letters on the use of systematic reviews for climate and energy policy. The teleworking paper attracted significant media attention and generated interest from BEIS and the IPCC (see Case Study 15: Is working from home better or worse for the environment?). Further work is now underway to analyse evidence on the impact of teleworking on UK energy use and carbon emissions over the period 2002–2019.

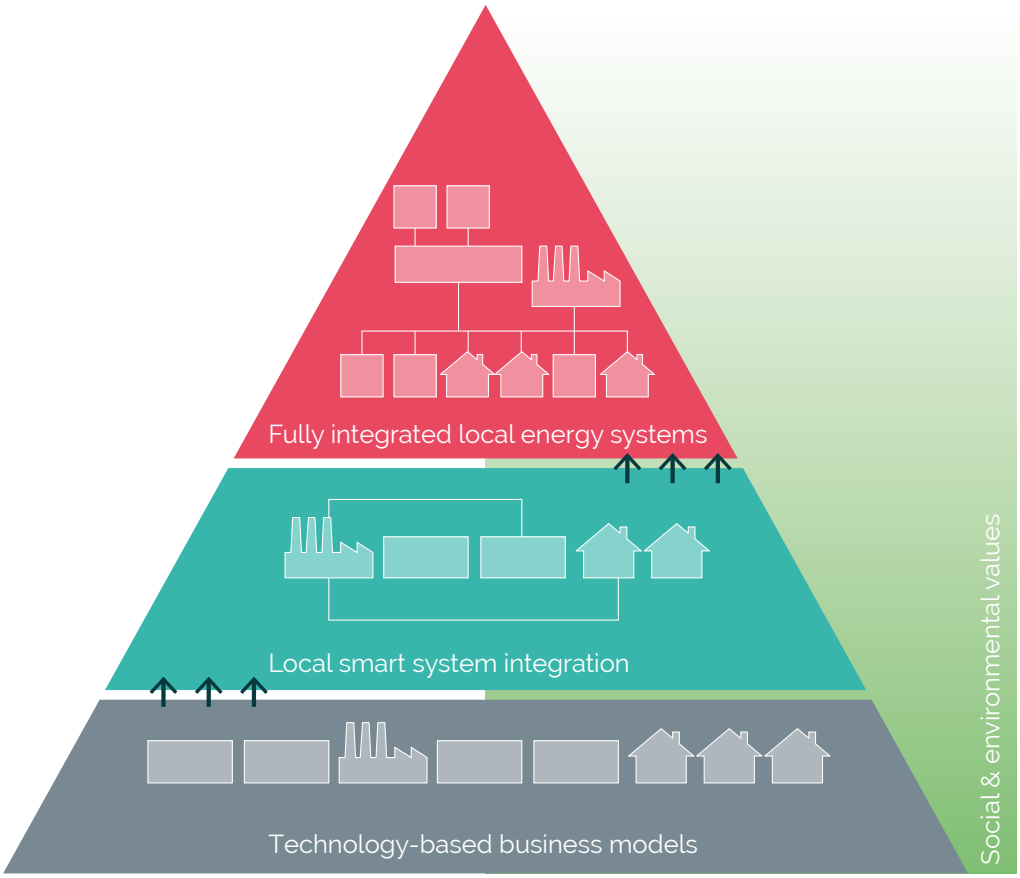

Figure 6: Digital energy services business models in the UK build upon each other to create a Ladder of Innovation.

We have also estimated the historical impacts of ICTs on energy consumption in 28 sectors in 17 countries over the period 1995 to 2007. This project uses econometric analysis of the EU KLEMS database and other sources, and the results suggest relatively modest energy savings.

Further work is exploring the long-term trends in the price and consumption of communication in the UK, and used this to estimate income and price elasticities for communication. This work is now being extended to other countries.

We have also begun two new projects: the first investigating the future impacts of digitalisation on energy demand and economic output; and the second exploring the potential impacts of 5G wireless technology on energy demand.

In the business models sub-theme, initial work focused on examining ICT-enabled energy service business models. This involved interactions with stakeholders, including the Ofgem Innovation Link team, and included a workshop on business models. This research is now complete, with a first journal paper published on creating value for users and the energy system through new business models. The research team has also produced an innovation briefing and secured further funding from Sussex University to establish a series of Innovation Forums on decarbonisation in the Greater Brighton region (see Case Study 14: Innovation Forums to tackle the climate emergency).

Further work in this theme is examining the impact of digitally-based sharing economy business models on energy demand. We are conducting a case study of a community-based sharing economy business, and we are currently analysing the results of interviews and surveys with both staff and users.

Research in the smart systems and user practices sub-theme has included projects on smart homes, smart meters and vehicle automation. We undertook a household survey and review of technologies and business models for smart homes, which led to the publication of four academic papers. We secured a further collaboration with the Energy Systems Catapult to analyse data from their smart homes living laboratory and this led to the publication of four academic papers on home heating practices and behaviours and the challenges of smarter controls.

Our research on the accelerated diffusion of smart meters has involved comparative case studies of smart meter roll-outs in Norway (a clear leader with a state-led rollout), Portugal (a moderate leader with a distribution company-led rollout) and the UK (with a supplier-led rollout). A paper summarising the results has been submitted and the second phase of the project is ongoing.

Our project on the expectations about the future impact of automated vehicles has completed a Delphi survey of professionals in the field, together with three Delphi surveys of members of the public. This project focuses on three revolutions that could potentially reduce transport energy demand, namely electrification, sharing and automation. The results show wide variations amongst both professionals and public about the potential timings and benefits of automated vehicle adoption, including the implications for energy use and emissions.

Overall, research under the Digital Society theme is at the cutting-edge of research into the impact on energy use of the large social changes resulting from digitalisation. It has already demonstrated that the adoption of digital technologies and related new business models will not automatically lead to reductions in energy consumption. The achievement of energy savings will depend on the institutional context for this adoption and on the responses and expectations of users. Further research will explore how these factors could influence delivery of future energy savings from ICTs.

2.8 Policy and governance

The research of the Policy and Governance theme is organised into three broad sub-themes: policies for demand reduction, multi-level governance and policy asymmetry between energy supply and demand.

Work in the first sub-theme has focused on building refurbishment policy, as this is well-known to be a major challenge. The research aims to bring together insights on the timing of refurbishment opportunities, the roles of professionals, intermediaries and the supply chain, and multiple benefits of energy efficiency. It has produced journal articles on the role of manufacturers and merchants, construction sector education, retrofit metrics and SME energy efficiency policy, as well as several conference papers.

Work on multi-level governance began with a comparative review of English and Scottish policy frameworks for energy efficiency in buildings and decarbonising heating. The project leader (Jan Webb) is a Commissioner on Scotland's Infrastructure Commission and has provided expert input to UKRI's planning of work on heat. The project has produced articles on laggards and leaders among UK local authorities, energy efficiency in self-build housing, and a conference paper to the International Social Innovation Research Conference. Work on energy demand issues in City Deals is continuing.

Figure 7: Watts the deal board game has now evolved into an online option to explore P2P trading.

Research on policy asymmetry has largely focused on distributed ledger technologies and peer-to-peer (P2P) trading in energy retail markets. Surveys on consumer demand for P2P energy trading have been delayed, but will be undertaken in the next year. The project has already generated a number of outputs ranging from three journal articles to a P2P trading game, Watts the Deal?. Originally a board game, it has been developed into online version, with positive responses from communities, regulatory bodies, local authorities and NGOs (see Case Study 16: Watts the deal?).

The project on market design has been re-framed to place greater emphasis on the scope for aggregation and novel financing in integrating energy efficiency into energy markets. It is collecting data using an online survey and in-depth interviews.

Overall the theme has a high academic impact through conference papers, book chapters and journal articles. Three of the team are co-editing a forthcoming Research Handbook on Energy & Society, which will bring together contributions from across the theme, including chapters on local energy efficiency and heat policy in England and Scotland, social impacts of P2P energy trading, and energy policy for future buildings. This theme is hosting three international visitors from Pakistan, Israel and The Netherlands.

There are high levels of engagement with policymakers, including through meetings with Ofgem and government, and as speakers and panellists at conferences and workshops. The research team supported the BEIS review of heat networks and has been invited to give a seminar to the Scottish Government Heat and Energy Efficiency Team. It contributes to renovation quality standards development (PAS 2035 and PAS 2038). The team is undertaking new work around training for the construction industry, which includes contributions to the Construction Leadership Council Industry Recovery Plan, and is feeding ideas into HM Treasury for economic recovery, including housing retrofit. Other engagement with policymakers includes contributions to several calls for evidence such as BEIS' consultation on energy-related products.

In response to Covid-19, we are involved in new initiatives and finding new ways to do research and to engage audiences with that research. For example, the theme leader is co-editing a journal special issue on personal carbon trading with our Israeli visitor remotely. A paper on the validity of social research during and after Covid-19 has also been published.

Much energy demand research, including elsewhere in CREDS, can inform policymaking. The unique feature of this theme is the focus on the impact on energy demand of governance systems and policy design. In addition to continuing to work on specific research topics, the theme will highlight our contributions to theory and new methods (integrating work across the three current sub-themes) and extend work on more ambitious policy ideas including personal carbon trading, sufficiency, reform of construction training, and new energy governance and market arrangements. We will also work increasingly with other teams in CREDS to create new insights and higher quality outputs and engagement by integrating our policy and governance expertise with their specialisms.

2.9 Decarbonisation of heat

The Decarbonisation of heat challenge is focuses on the role of energy system architecture in the decarbonisation of heat, and on integrating this into energy system modelling. A key insight is that energy system architecture plays a powerful role in the selection and deployment of individual technologies. The Challenge as a whole aims to integrate and build on the system architecture literature that has emerged as a framework for organising highly complex engineering programmes. It is highly novel, with the potential for significant impact on research, regulation, governance and policy. It is organised into three sub-themes: a systematic review of the decarbonisation literature, development of existing whole energy system models; and social, regulatory and governance implications.

The systematic review of existing proposals for heat decarbonisation and of the way in which energy system modelling has supported energy and decarbonisation policy over the last 15 years is complete. It has resulted in a journal article article on heat decarbonisation modelling approaches in the UK. Several other papers are in preparation. This work suggests that key requirements of future energy system are not well represented in existing models. These requirements include resilience, and the ease with which systems can be deployed and evolve.

The model development sub-theme addresses the metrics for these requirements with a view to implementing them in energy system models. It has made significant progress in developing the UK Times model, which has played a central role in UK Government energy policy. This has been developed to better represent policy-making in an uncertain world and the potential for different energy system architectures to respond to unexpected events. Using the ESTIMO model, the research has simulated half-hourly UK and European energy systems with different shares of individual building heat pumps, district heating heat pumps and electrolytic hydrogen boilers. ESTIMO allows exploration of weather impacts over long time scales, and developments in continental scale energy trade. Based on our analysis, we believe that improved representation of space and time in energy systems models is required.

The work of the challenge team is already having impact. It co-authored a report to the Heating and Cooling Forum held by UKRI in March 2020. Following a meeting of the Council for Science and Technology in May 2020, in collaboration with the Buildings Theme, the challenge team produced a reflection on Building Decarbonisation Transition Pathways. It has also made input to consultations by BEIS. The BEIS Parliamentary Select Committee and the Environmental Audit Committee. Papers on innovation in deep retrofit and on heat pump performance have been published. The development of a special issue of the journal Energies on decarbonising heating and cooling is under way. Results from the ESTIMO model have contributed to a Royal Society report on long-term energy storage, which is expected to be published shortly. Work on social and regulatory issues has been presented to the 2nd International Conference on Energy Research and Social Science. A paper published in collaboration with the Buildings Theme on the possible impacts of elevated levels of CO2 on human cognitive performance was awarded the CIBSE Napier Shaw Bronze Medal for best paper published in CIBSE's research journal in 2018.

The work of the challenge has been supported by a series of learning events. Presentations have been made to BEIS, the International Conference on Sustainability in Energy and Buildings, a workshop on heat decarbonisation organised by the Edinburgh Centre for Carbon Innovation with support from the Scottish Government and the Danish Energy Agency, to the built-environment think-tank The EDGE, and a keynote presentation to the energy policy session of the MIT 2020 Online Conference. We have consulted and collaborated with other energy modellers and their policy users, notably in BEIS and the Energy Systems Catapult.

Information about the work was shared with stakeholders in a CREDS-organised workshop, in which participants reviewed the results from our two modelling teams and from stakeholder interviews. Other engagement has included representation at the All-Party Parliamentary Group for Energy Studies on the impact of net zero and energy infrastructure.

Further development is ongoing and future funding has been sought for 3 years' funding from the UKRI Decarbonisation of Heating and Cooling 2020 Call.

2.10 Fuel and transport poverty

The fuel and transport poverty challenge is CREDS second challenge project. The work began in January 2020. It is therefore less advanced than research in themes and the first Challenge project, and relatively, has been more affected by the Covid-19 pandemic than earlier projects. The research is investigating who may be vulnerable to both fuel and transport poverty in the UK, and how this impacts on their well-being, participation in society and wider life chances. The challenge aims to understand systemic and spatial drivers for both forms of poverty. Research includes interviews and surveys with households who are already vulnerable or who may be affected by the energy transition, and spatial analysis of locations that are impacted. We also will also conduct interviews with experts and policymakers. Stakeholder engagement throughout the project provides an understanding of where fuel poverty and transport poverty policies overlap, and which solutions for an energy transition could promote a more just society.

We have made good progress with a systematic review literature and development of a conceptual framework based on the principles of energy justice and energy vulnerability. We are comparing literature on fuel poverty/energy poverty with transport poverty, specifically examining the socio-demographic groups that are vulnerable to both forms of deprivation. This review informed a meeting with HM Treasury, and has led to a policy briefing and a journal article, as well as informing the recruitment strategy for household interviews.

The research team and partners had initially developed a step-by-step recruitment plan for face-to-face interviews. The interviews themselves were delayed as the priority partner organisations were occupied in helping vulnerable people with the initial pandemic response. An online platform has been used as an alternative route to recruit study participants, enabling the start of the household interviews.

We have developed engagement plans, a stakeholder map and a communications plan and adapted this to address issues raised by Covid-19. There are regular meetings with the Transport theme researchers working on high energy users, with a plan for collaboration on publications. We have engaged with policymakers in all four UK nations and have begun interactions with both officials and some MPs, as well as NGOs, for example taking part as a panel member in an event within the National Energy Action Warm Homes Week.

Key outcomes from the challenge include the following:

- We hosted a stakeholder engagement event with 30 policy representatives from the four governments in the UK. This was organised to highlight the overlaps between fuel poverty and transport poverty to officials who mainly work in one of the policy fields. Through the engagement work with policymakers, we have also highlighted the need to consider that transport poverty is an issue in the UK. We also delivered a CREDS webinar on identifying those who may be vulnerable to fuel and transport poverty, attended by 109 policymakers, practitioners and researchers.
- The research team has published blogs and papers, including a commentary piece published in the high-impact factor journal Joule, making the case that both fuel poverty and transport poverty need to be considered together when moving to increasingly electrified and connected net zero energy and transport systems.
- We have engaged with other researchers in the field both in the UK and the rest of Europe. This has included meetings and events with the European Energy Poverty Observatory, and acting as reference group members for a transport poverty project led by the Energy, Transport & Climate Directorate of the European Commission.
- Our plans for the future include continued ongoing policy engagement, completion of data collection and writing of results in the form of academic papers and more digestible policy briefings. Our data collection for the coming year includes finalising interviews with households, undertaking expert interviews and conducting a national survey. All of these will lead onto further specific policy modelling later in the project, with a view of making specific recommendations both to future research and policy.

2.11 Decarbonisation of the steel industry

The third CREDS challenge is on decarbonisation of the steel industry. The work began in January 2020. It is therefore less advanced than research in themes and the first challenge project. It is researching strategies to eliminate the dependence of iron and steel production on fossil carbon. Various routes for decarbonising steel production have been designed, including approaches that use hydrogen, carbon capture and storage (CCS) and biomass. There has been some roadmap development, but the research aims to provide an integrated strategy that incorporates technologies, policies, stakeholders' opinion and their interaction. The work involves two main areas: expert interviews in the steel industry (now to be held online) to develop stakeholder visions; and modelling to investigate the optimal combination of energy system technologies to decarbonise the steel industry.

In the expert interview work, we have begun by developing a framework and guidelines for the semi-structured interviews and data analysis. The interviews seek to capture data in five main areas: expectations, interests, and strategies; policy; potential impacts on the organisation; technological development; and perceived obstacles. Research ethics approval has been received. Prior to commencing the semi-structured interviews, we held informal initial discussions with a trade body, a materials institute and a variety of UK and international industry, plus an organisation focused on driving forward sustainability. These have been followed by more formal, anonymised semi-structured interviews with staff from a manufacturer organisation, structural steel company representatives, a national trade body, an international trade organisation, government officials and an environmental NGO. Initial results indicate stakeholders see a need for interventions in the market and a focus on the supply chain. Concerns were expressed over potential government overreach and the need to promote sustainable domestic production of steel, as opposed to reliance on imports. The extent to which decarbonisation costs would be bearable remains the largest concern for stakeholders, who feel that the necessary investment would have to come from government. Indeed, a need was seen for a more active government role, clearer regulation and promotion of sustainable public procurement. The preference was for policy packages that address decarbonisation of the steel industry as a whole.

In the modelling work, an energy system model has been developed to account for various options to meet the energy requirements of fossil-free primary steelmaking, using hydrogen direct reduction and electric arc furnaces. The model now includes dispatchable generation (as combined cycle gas turbine + CCS and biomass + CCS), along with energy generation and storage costs, and BEIS projections of fuel and carbon costs. The results are being written up into a journal paper. We are currently re-checking the validation of the model, prior to releasing the findings, but it appears that the energy requirements for decarbonising the steel industry will be challenging to meet, but are within the bounds of achievability.

Looking ahead, the formal stakeholder work will be paused until October 2021, due to maternity leave, but informal engagement with stakeholders will continue and we will focus on a detailed analysis of the policy environment for decarbonising the steel industry. This will encompass, what policy levers are available, are these fit for steel industry decarbonisation purpose, if not what needs to change and to what, how and when? Given the importance of both direct imports of steel and steel embodied in imported manufactured goods, we also hope to look at how the international policy and trade environment might impact the sustainability of steel used in the UK. Our modelling work will continue to connect plant models with broader energy system models, to consider co-evolution of decarbonisation of the steel industry with the broader energy system. We expect to both deepen the resulting connected model(s) and expand our coverage of decarbonisation approaches. By the time the stakeholder engagement work recommences, we will be in a position to present stakeholders with realistic, costed decarbonisation scenarios and to gauge their reaction to these. This would then feed back into which approaches we investigate in the third year of the theme.

3. Building on the work of the EUED Centres

3.1 The End Use Energy Demand Centres

CREDS seeks to build on the work of the End Use Energy Demand (EUED) Centres, which were funded by UKRI predecessor organisations in the period 2013-2018. There were six EUED Centres:

Centre Name	Lead University	Director
Centre for Energy Epidemiology (CEE)	University College London	Tadj Oreszczyn
Centre on Innovation and Energy Demand (CIED)	University of Sussex	Benjamin Sovacool
Centre for Industrial Energy, Materials and Products (CIEMAP)	University of Leeds	John Barrett
Dynamics of Energy, Mobility and Demand (DEMAND)	University of Lancaster	Elizabeth Shove
Interdisciplinary Centre for Storage, Transformation and Upgrading of Thermal Energy (i STUTE)	University of Warwick	Robert Critoph
Centre for Sustainable Energy Use in Food Chains (CSEF)	Brunel University	Savvas Tassou

The Directors of the first four Centres listed are actively involved in CREDS, along with many other investigators and researchers. One investigator from iSTUTE is also a CREDS investigator.

3.2 Energy Demand Research Champion activities

Although CREDS began formal operation on 1 April 2018, the activity to ensure effective development of the work of the EUED Centres began a year earlier with the UKRI call for an EUED champion to develop the CREDS bid. The timeline of this period before the start of CREDS is set out below:

- **April 2017** — Research Council call for End Use Energy Demand Champion
- **July 2017** — Appointment of Nick Eyre as EUED Champion

July – September 2017	Open consultation on CREDS research themes
July – November 2017	Meetings with EUED Centre Directors
August 2017	Expressions of interest in CREDS theme leadership
September 2017	Appointment of theme leaders for CREDS bid
September 2017	Research community and stakeholder meeting
September – November 2017	CREDS proposal development and bid submission
January 2018	Reviews, review response and RCUK Panel meeting
February 2018	Post-bid processing
March 2018	Invitation to CREDS Advisory Board members
March 2018	Consultation on CREDS research challenges
March 2018	Announcement of CREDS

The timeline shows that the meetings with EUED Centre Directors were an early priority, as part of the consultation that ran concurrently with development of the CREDS bid. All the EUED Centre Directors were invited to bid to lead themes within CREDS and most did. Theme leadership appointments were made through a competitive and transparent process. The extent to which EUED Centre personnel form part of the CREDS team therefore depends on their engagement with the research priorities identified through consultation.

As part of the Research Champion activity, we also developed a database of all outputs from the EUED Centres to ensure that CREDS would be able to make this available should the EUED Centres close their websites (which none yet has).

Following the commencement of CREDS, the Director and core team met with staff from each of the EUED centres. These meetings had two purposes. The first was to discuss the key research outcomes of the individual EUED centres and how these might be taken forward in CREDS. The second was to discuss and agree that the CREDS launch event would double as a final dissemination event for the EUED centres. CREDS was formally launched at a well-attended event in London, on 20 September 2018. Joint design with EUED Centres allowed them to showcase key aspects of their work together, in a way not previously achieved.

There remain strong links between the previous work of the EUED Centres and CREDS ongoing research programme. In particular,

- The work of the CREDS Buildings theme draws heavily on the approaches and methods of energy epidemiology developed in the CEE Centre.

- The work of the CREDS Transport and Flexibility themes on energy using practices draws on the theoretical foundations developed by the DEMAND Centre.
- The work of the CREDS Materials and Products theme has a strong focus on resource efficiency, developing ideas and methods from the CIEMAP Centre.
- The work of the CREDS Digital Society theme draws on the outputs of the CIED centre and the ideas it developed on energy transitions.

In all these cases, CREDS seeks to develop and apply the work of the EUED centres and to give it greater impact, through cross-cutting work and a professional approach to knowledge exchange.

4. CREDS activities

4.1 Centre start-up

The CREDS consortium was developed in the nine-month period from the appointment of the Director as UKRI Energy Demand Champion in July 2017 to the centre start date on 1 April 2018. The timeline is set out in the previous section. The process was highly consultative. There were detailed discussions with the EUED Centres as set out above, but also a series of meetings with other key stakeholders agreed with the Research Councils, as well as the High Level Group that oversaw the work of the EUED Centres for UKRI. We held an open consultation on ideas for key research themes, through an on-line process, followed by an open meeting for the energy demand community at the Royal Society on 28 September 2017. We subsequently held a consultation on key challenges through a similar process, with an open meeting in London on 13 March 2018.

Following discussions with UKRI, we agreed a transparent process for recruitment of theme leaders. Two of these were appointed on the advice of the EUED Champion Grant panel. With the CREDS Director they acted as the panel for appointment of other theme leaders through a competitive process. The whole team then developed the details of the proposed research programme and bid documentation, through an intensive process in Autumn 2017, with the bid submitted on 27 November. Responses to reviewer comments were made over the Christmas break and the panel meeting was held on 19 January. CREDS was announced on 26 March 2018, with a start date of 1 April 2018.

As part of the funding award UKRI specified some conditions recommended by the panel, relating primarily to management, communications and the start-up phase. We addressed these comprehensively, reporting progress to our Advisory Board and UKRI.

The short period between the announcement of CREDS and its start date notice inevitably meant that research, administrative and knowledge exchange staff were not all in place immediately. We benefited substantially from the research continuity with the EUED Centres, but recruitment was the major priority in the first six months of the centre.

We recruited a Centre Manager, Clare Downing, who began work on 1st May, followed by two Knowledge Exchange Managers and a Website and Communications Manager. The CREDS Core team was therefore largely in place by the summer, allowing planning of the CREDS launch event. The centre was launched, at a very well-attended event in London on 30 September 2018. The event was combined with an exhibition of the work of the EUED Centres, allowing them to promote their findings to an audience of 200 people. The feedback was positive and the event secured good publicity and impact for energy demand research.

4.2 Centre operations and governance

CREDS is managed on a day-to-day basis by the Director, who is the Principal Investigator, and the Centre Manager. The CREDS Executive is collectively responsible for resourcing and strategic decisions. In the early months of the centre, the Executive met monthly, face-to-face. We established strong working relationships, as we developed the key policies of the centre, considered early uses of the Flexible Fund and began the research programme, including the first cross-theme activity. In this period, we adopted the key policies for the centre, including our Communications and Engagement Strategy, EDI strategy and plan, and Risk Register.

After a year, we reconsidered the Executive meeting frequency and moved to two meetings per quarter, of which one was one face to face, primarily to review quarterly progress reports and their implications, and the other by teleconference to address other issues. Since the beginning of the pandemic, we have retained the same schedule, but met by video-conference. The CREDS consortium agreement allows for voting, but to date, we have been able to proceed by consensus on all issues.

Details of the management philosophy and approach are set out in more detail in the later section on Centre Direction and Management.

CREDS Whole Centre meetings (WCM) have no formal status in the governance of the centre. However, they have played an important part in developing a CREDS community, across the universities in the consortium, especially to enable cross-theme interaction. To date we have had six Whole Centre Meetings. The first was held within a month of the centre starting, and the second on the day after the formal launch. Subsequently we have had three face-to-face meetings in Oxford and Leeds, with the sixth meeting moved from Edinburgh to a video-conference format in June 2020. At each meeting, we have had sessions concerning overall progress of CREDS and EDI issues. All the initial six themes and the first challenge have presented their work interactively at a WCM. We are now moving into a phase where selected research findings are presented and discussed.

The CREDS Advisory Board is charged with providing independent advice and overseeing use of the Flexible Fund. The Board meets twice annually, initially in person, but in 2020 virtually. The Advisory Board has also agreed procedures that allow urgent decisions on use of the Flexible Fund to be made by email discussion and, for minor funding decisions, by Chair's action.

The work of each of the initial six themes and first challenge has been presented separately to Advisory Board meetings. We have adopted an approach in which specific issues for advice are explicit on the agenda and each meeting receives a report back on the action taken as a result of advice at the previous meeting. In addition, members of the Advisory Board have played an active role in decisions on the Challenges Call and the Early Career Researcher Fund. Levels of participation by Advisory Board members, all of whom are busy people, have been excellent. At their request, we invite them to WCMs and several have made the significant time commitment to attend.

The Director and core team meet twice annually with the relevant portfolio managers in EPSRC and ESRC, currently Edward Jones and Helen Rogers respectively. Despite changes in personnel over the period of CREDS, the portfolio managers have been engaged and supportive. We value their advice, especially in identifying links to, and likely developments of, UKRI programmes.

4.3 The hub role and the Energy Demand Research Network

Our mandate from UKRI includes acting as a hub for the energy demand research community. We have done this through the formation of the Energy Demand Research network (EDRN). There is no exact definition of energy demand research. Projects identified as EUED within the UKRI Energy Research programme form an important nucleus, but are not the complete list. We therefore developed a database by trawling lists of UK and EU-funded research programmes. We invited the PIs (or nominated substitutes) of energy demand research projects in the UK to an open one-day meeting in Birmingham on 9 May 2019, along with some members of the UKRI Energy Programme SAC and other selected stakeholders. We are confident that the EDRN communicates with UK-based researchers who self-identify as working on energy demand.

At this launch meeting of the EDRN, we introduced the hub role of CREDS and the Network, and then held a facilitated and highly interactive event, focussing on different areas of engagement (policy, business and international) and data management. We provided an extensive meeting report. Feedback from the meeting was good and asked for more specific meetings, with an aim of involving a wider group of researchers than just PIs. This essentially now defines the mission for the EDRN.

We have developed a forward programme for the EDRN. The next event in April 2020 focused on research in the climate emergency bringing together academic researchers and their counterparts in the NGO community who work on the same issues, but often at different timescales and different levels of detail, with the aim of discussing how, in our research, we might learn from each other. It was moved on-line, due to the Covid-19 lockdown, but was still successful in bringing together these groups with parallel interests. There were speakers from CREDS, the Centre for Climate and Social Transformations (CAST), Oxfam and Citizens Advice. Over 70 people attended and the feedback was very positive.

As it became increasingly clear that on-line communications would be the norm for a significant period, we redesigned the EDRN programme to be a series of webinars for the network. We have now run webinars on:

- How to influence the Sixth Carbon Budget,
- Demand side flexibility: Beyond price and technology,
- Energy efficiency in a post lockdown world: Earthshot not moonshot
- Policy and impact: how does research make a difference?

The webinars attract good audiences, including overseas participants. We are therefore planning a regular series to support the network, but also to take the opportunity of developing our international engagement under the new constraints.

We remain open to new ideas for the network and actively canvass for these through the quarterly ECRN newsletter. Given the huge range of disciplines and content under the broad umbrella of energy demand research, a tightly knit network is not a sensible goal. Instead, we aim to encourage diversity, build links and support engagement activities.

4.4 Capacity building and early career researcher support

We identified support for early career researchers (ECRs) in the original proposal as a key element of the work of CREDS, recognising the lack of clear career structure facing many ECRs in inter-disciplinary research environments. This has been the highest priority for the early use of our Flexible Fund, and so our second major funding call (after the call for new challenges) was dedicated to supporting projects led by ECRs. We felt it was important to act early within the five-year period to CREDS to give successful ECRs the opportunity to maximise their project length and engagement in CREDS. More details of the process and outcomes are set out below in the section on the use of the Flexible Fund.

We are also committed to supporting ECRs within CREDS. At our Whole Centre Meeting in January 2019, we consulted on our plans for ECRs. We drew on the views of ECRs in the centre during a two-day event on 22-23 October 2019. This has generated a researcher-led programme of cross-institutional events. The event also included training on How to write a good funding proposal, and information on funding opportunities. These resources were made available on a dedicated ECR area of the CREDS website and through our internal and external newsletters. We have subsequently agreed to use the underspend from the Flexible Fund call to support ECRs in a number of ways they have identified as being important, particularly to have time to complete academic paper writing. More details of CREDS work to support ECRs are in Case Study 02: The leaders of tomorrow: our work with Early Career Researchers.

Whilst the remit of CREDS does not include support for doctoral students, we interpret our goals as a hub for the research community and capacity building to include working constructively with those tasked more explicitly with doctoral student education. The last round of EPSRC doctoral training support refunded the most relevant CDT to CREDS work – at University College London and Loughborough University, now called the CDT in Energy Resilience and the Built Environment (ERBE). This has strong input from staff in the CREDS consortium, which enables good links between CREDS and the doctoral training community.

4.5 Equality, diversity and inclusion

We made development and agreement of the centre's policy for Equality, Diversity and Inclusion (EDI) an early priority. 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 we respect the rights and dignity of all our staff, students, partners and stakeholders. The Director led the development of the plan, reflecting the importance we place on EDI issues. We consulted with the CREDS Executive, our Advisory Board, UKRI and other staff, and took professional guidance. This fulfils the EDI specifications of UKRI and our legal obligations under the Public Sector Equality Duty, but goes also further than these requirements.

We are treating the Plan as a living document and have an EDI Working Group to take it forward, to make it concrete through specific initiatives and to monitor delivery. The Plan has been revised overtime to adopt changes recommended by the EDI Working Group. It has been discussed at Whole Centre Meetings of CREDS. It covers 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, remote access to meetings, and mentoring.

The EDI Working Group completed a report on EDI in CREDS in 2019, including a survey of all CREDS institutions' recruitment processes. In some areas, such as EDI training in recruitment, the results are encouraging. In others, e.g. induction and awareness of the gender pay gap, the picture is more mixed. Recruitment numbers in individual institutions are too small to allow statistically significant conclusions, but across the CREDS consortium, in 2019, we predominantly recruited men into research roles and women into non-research roles. We have provided this feedback to each institution. Our impression is that recruitment in 2020 has been more balanced, in part due to the success of proposals into our ECR Flexible Fund from researchers in under-represented groups. We have also undertaken a staff survey on EDI issues. The results are encouraging in terms of perceptions of CREDS commitment to EDI. Our work in this area is the subject of Case Study 01: We are the ones that we seek – EDI.

We also evaluated the ECR Flexible Fund call, on a number of aspects of EDI, through a survey of 110 people involved in the call. The report has been shared within the consortium and other UKRI's Energy System projects. It concludes that the call was "successful, well-run and well received". We have supported other consortia, including UKERC, on the development of their own ECR plans.

There is more to do. As part of our Covid-19 impact monitoring, we are keeping under the review the EDI implications. Using savings made in other budgets, we will recruit a part-time equalities manager to strengthen our work in this area. In addition, following the Black Lives Matter campaigns in mid-2020, we have taken stock of our performance on issues of BAME equality and racial justice, identifying that people from Black, Asian and minority ethnic communities are under-represented within the consortium. Having considered various options, with the support of our Advisory Board, we have agreed to allocate funding from the Flexible Fund to a project to scope research opportunities on energy demand and racial injustice. We are seeking a partner organisation with expertise in race equality with whom to work on this.

4.6 International engagement

Within the first half of the CREDS programme, we have given the highest priority to our own research programme and UK stakeholders. Our academic publications are largely in international journals, giving us international intellectual impact. CREDS researchers and others in the UK energy demand research community also have significant direct international engagement, and some areas of leadership, notably through UKRI-funded work with specific countries such as India and Mexico, UK input to the European Council for an Energy Efficient Economy (eceee), authorship of some chapters of the IPCC sixth assessment report and the International Energy Agency (IEA) Technology Cooperation Programme on User Led Energy Systems.

As in other areas of energy research, we are at a disadvantage compared to other countries with established national research institutions, such as Fraunhofer Institutes and national research laboratories, in terms of ability to plan and commit resources over periods of longer than 5 years.

CREDS has taken international initiatives, in particular through our International Visitor Programme. We launched this at the eceee conference in France on 6 June 2019. The call lasted three months, resulting in nine applications. Following reviews, we offered visits to six people. Of these, two visited in early 2020, with positive outcomes. The remaining four were deferred as the pandemic made international travel an unrealistic option. At the mid-point of CREDS, there is significant uncertainty about how long that will last.

Our current plan Includes making a big input to the major European energy efficiency conference, eceee, in June 2021, but it is now clear this will be on-line and smaller in scale due to Covid-19. At the same time, there is an obvious risk that, although access to EU research funding will be maintained, UK withdrawal from the EU will disrupt other European collaboration. So our institutional engagement outside the UK risks being limited by forces outside our control, which is clearly a problem.

Our assessment of our international engagement is that there are many activities within the consortium and the wider energy demand research community, including through UKRI-funded projects, IEA Implementing Agreements and the IPCC.

However, these rely largely on long-standing links and individual initiatives. Overall, UK energy demand research international engagement is quite strong, but we have not yet achieved the full benefits to which we aspire from the concentration of research in CREDS. Our attempts to take forward international cooperation have been largely frustrated by Covid-19.

If the transformed situation with respect to international mobility persists, we need to revise our thinking substantially. We are considering a number of options including:

- developing more formal research partnerships with other organisations,
- aiming to play a bigger role in IEA Technology Cooperation Programme activities,
- strengthening our presence in academic and non-academic social media platforms,
- inviting high-profile international researchers to speak at CREDS-hosted webinars.

5. Relationships

5.1 Communications strategy and brand

The UKRI Panel that considered the CREDS bid recommended we reconsider the name and branding of the centre, using professional advice. Based on advice from energy efficiency marketing professionals, we appointed an experienced consultant, Sara Marshall, who worked with the CREDS Executive team, in April and May 2019, to develop our vision, mission and an overarching statement for the agreed aims of the centre. We then commissioned a branding agency, Tayburn, to develop the CREDS visual identity. Based on this, we developed the CREDS website, using a consultative process to ensure it serves the needs of our main stakeholders. We launched the website and prepared other materials in time for the full launch on 20 September 2018.

This initial work also underpins our Communications and Engagement Strategy. We developed the strategy in the early months of CREDS, using input from across the consortium and an early Whole Centre Meeting. It builds on contacts and activities of the EUED centres and other previous work. It was submitted to UKRI in December 2018. The strategy sets out our key audiences, in business, policy, research and the media. Our Communications and Engagement Plan develops more detailed activities for each of the Knowledge Exchange managers, as well as the Director, Centre Manager and research themes. We have established a system of core team links, so that each theme has a lead contact in the core team with whom to plan engagement activities. Internally, we treat the Plan as a living document. Progress is monitored and evaluated, and the Plan is updated annually. More details on the content of CREDS engagement work is provided under "CREDS outputs and impact below".

5.2 Stakeholder engagement

Our stakeholder engagement activities build on existing strengths. The EUED centres and other research in which CREDS staff have previously been involved had developed varied stakeholder portfolios. Many of us have work experience outside universities, and bring these experiences to CREDS. Our work plans and recruitment priorities emphasise stakeholder engagement, and therefore we do not recruit ivory tower researchers.

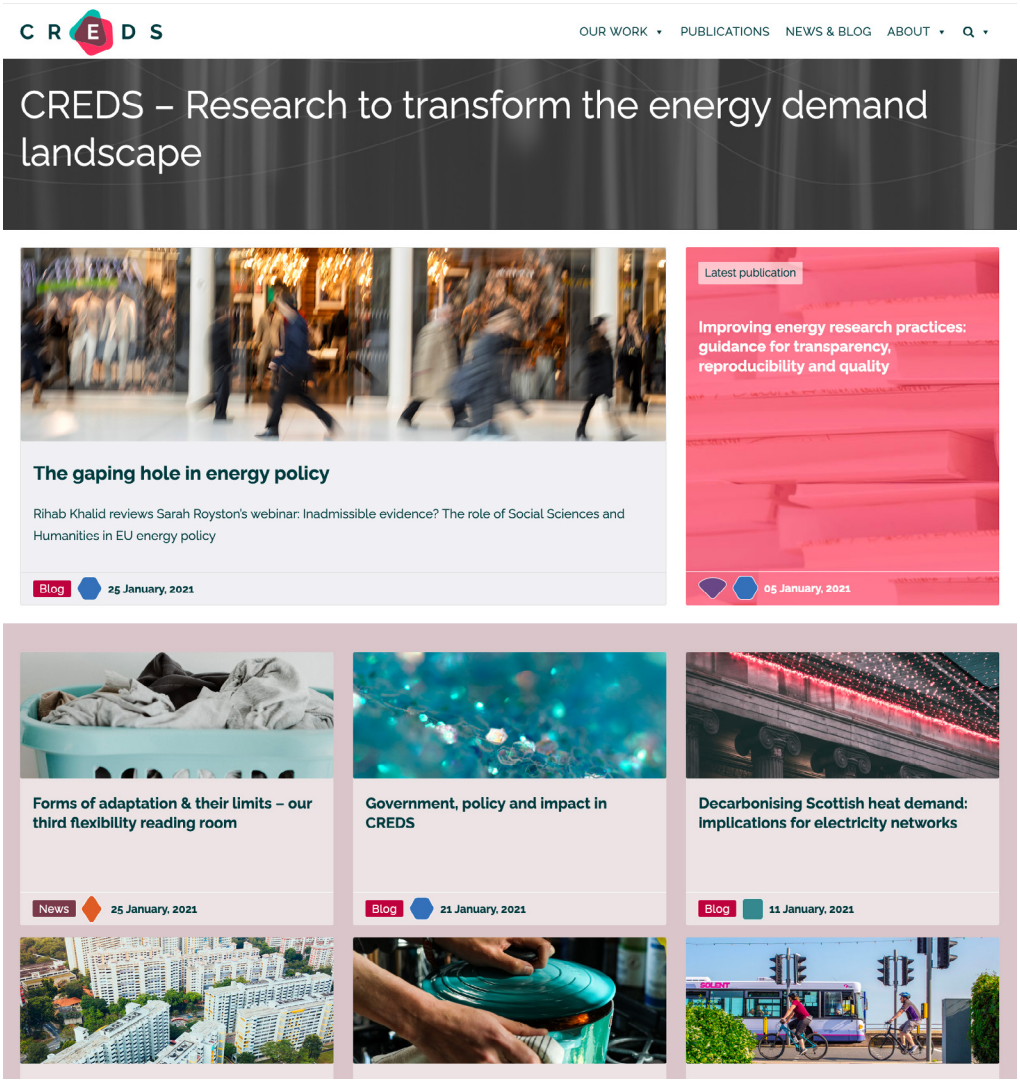

Figure 8: The CREDS website was launched in September 2018.

We have developed strong links with relevant UK Government departments, most notably with BEIS, DfT and Defra, but also with MHCLG, HM Treasury, the Government Office of Science and the Council on Science and Technology. We have very good links to the relevant policy officials in the Scottish and Welsh Governments, especially the former. We have very strong working relationships with Ofgem and the Committee on Climate Change. These links allow us to contribute directly to policymaking, including providing expert advice, facilitating cross-departmental discussions, championing energy demand and providing a rapid response to immediate needs. We set out some examples in the section on Impact below.

As part of our engagement work, we regularly respond to calls for evidence from Government and Parliamentary Select Committees. The latter raises our profile with key MPs.

Our engagement with local authorities is patchy, inevitably considering their number. Many members of the CREDS community have been involved in local energy activities over many years, so we have excellent engagement in Brighton, Leeds, Oxford, Edinburgh and London. We also taking a more systematic approach by working with the Local Government Association. (See Impact, below).

Through the EDRN activities discussed below, we have a central role in the energy demand research community. We have made strong links with stakeholders in the research area, particularly the centres with a whole systems approach, such as UKERC, CESI, the Supergen Hubs and CAST. The CREDS Director has supported the EPSRC calls on EUED Technologies and Heating and Cooling. CREDS has played a key role in supporting the EPSRC EUED Technologies call, as an initial part of our role as a hub for the energy demand research community.

We have developed good working relationships with other energy research communities, including other critical UKRI investments: UKERC, CESI, EnergyRev, IDRIC, and the Supergen Hubs.

In 2019, we identified that our progress on engagement with business has been weaker than with the research community and policymakers. We have good links at the level of some individual projects, but these do not map easily to whole theme or centre activities. We discussed this internally and with our Advisory Board. Our analysis is that whole systems research has less traction with most businesses than with the policy community and researchers. This is because most businesses have direct interests in particular sectors and products than in the whole system. There are exceptions with systemic interests, notably National Grid, and these tend to be the businesses with whom we work most easily. We also work closely with relevant trade bodies, professional institutions and others interested in promoting innovation, such as Catapults, as these boundary organisations offer established routes into businesses. Nevertheless, we believe that stronger business engagement should be a priority for us going forward. With the support of our Advisory Board, we have used the Flexible Fund to strengthen our capacity to engage with businesses through the recruitment of a Business Knowledge Exchange Manager. The initial focus is on developing and a strategy and priorities for business engagement, and this now needs to take into account the financial and engagement difficulties resulting from the pandemic.

6. CREDS Outputs and Impacts

6.1 Publications

CREDS is a research centre, and therefore our principal outputs are research publications. Peer-reviewed journal articles are the gold standard for academic research, and therefore important for our impact within the research community, as well as a key metric upon which CREDS researchers are judged. However, we recognise that targeted reports and briefings have higher impact with non-academic audiences than journal articles, and our communications strategy operates accordingly.

In the 30-month period from the start of CREDS to September 2020, CREDS staff authored over 180 publications, of which approximately 50% are peer-reviewed journal articles. We document full details in our annual Research Fish submission and an annex to each annual report. The rate of publication has risen over the opening period of CREDS. In the last 12 months, we have produced 91 publications, including 57 journal papers. We expect this to rise as research projects reach conclusions. Appendix 4 provides a full list of publications and outputs from CREDS form April 2018 to September 2019 and Appendix 5 provides a full list from October 2019 to September 2020. These are separate files.

We have benchmarked this against this against the collective efforts of the six EUED Centres. These were recognised as having a strong academic performance. Over a 5-year lifetime, and with a joint budget 30% larger than CREDS, they produced an average of 135 publications annually, of which 77 were journal publications. We therefore believe we have already demonstrated strong academic performance.

Of course, quality is a more important metric than quantity. It is more difficult at this stage to assess which papers will have a major impact. Some already have high citations, notably the multi-authored papers by colleagues from UCL on climate and health published in The Lancet. In most cases, citations take longer to accrue, and, even then, citation rate is an inadequate metric of quality or impact. However, it is clear that some publications are becoming influential, for example through citation by the IPCC, in either the Special Report on Global Warming at 1.5 degrees or the forthcoming Sixth Assessment Report.

6.2 Other outputs

Publications form only part of our outputs. We document a range of activities and outputs as part of the comprehensive CREDS report for UKRI's Research Fish database. A tabulation of the quantitative metrics for the year ending in September 2020 is below.

• Publications	91
• Collaborations and partnerships	23
• Further funding	22
• Engagement activities	178
• Influence on policy	100
• Influence on business	20
• Artistic images	10
• Data & other	12

This gives some sense of the scale of impact focus activity. Individual engagement activities with research, policy and business audiences are far more numerous than publications.

6.3 Website and media

The scale of CREDS knowledge exchange budgets is insufficient to allow comprehensive engagement with the mass-market audience of energy users. This was explicit in our proposal and is reflected in the priorities of the Communications Strategy. The CREDS website and work with the media are therefore our major routes to wider dissemination.

We established the website, using the CREDS branding, in month six of the centre. It was designed to provide an attractive and engaging window on CREDS activities, primarily for our external stakeholders, as information is shared internally by other means. The website has now been running for more than two years, and has extensive content and regular new material.

Web statistics tell us that use is high and feedback on content is very positive. In the last year, the site had 26,971 unique users. As expected, website hits are correlated with media reports mentioning CREDS. Notable examples are:

- the publication of our first cross-theme report: Shifting the focus: energy demand in a net zero carbon UK, which was featured in a number of BBC programmes and articles,
- BBC publicity for Top 10 tips for reducing carbon footprint, based on an international meta-review of consumption practices.

- the briefing on e-bikes, which was reported across a wide range of media.

Further information on all three of these examples can be found in the corresponding impact case study. In all cases, these have led to multiple downloads of more detailed analysis than can be covered by the media. There is more detail on our on-line and social media audiences in the CREDS annual reports for 2019 and 2020.

The website also provides an ongoing resource for our research stakeholders. It provides access to all CREDS publications and has played a key role in providing information on CREDS funding calls.

We also send out a quarterly newsletter to 448 external stakeholders and operate a Twitter account with more than 1000 followers.

6.4 Impact

We have impact with non-research audiences through routes other than peer-reviewed publications: both through targeted publications such as policy briefings and consultation responses, but also through direct contacts with decision-makers.

Direct contact is particularly effective with Government. The whole CREDS Executive met with the Deputy Director for Engineering and Research in BEIS to discuss the role that CREDS might play in the BEIS forward research programme. We have subsequently increased our capacity to work with BEIS by making a fixed term appointment of an energy efficiency policy specialist to develop and strengthen these links (see Case Study 05: Engaging with civil servants to improve impact). As a result, we have increasingly good engagement with BEIS analysis teams on energy efficiency and heat. In addition, the CREDS Director is an active member of the BEIS Buildings and Heat Strategic Advisory Group. We prioritise rapid response where this is needed and possible. We responded to direct requests, sometimes in confidence, for example on both the lessons from condensing boiler market transformation and the scope for increasing household energy efficiency retrofit. We have begun to bring together officials from BEIS and MGCLG to improve coordination on energy use in buildings.

We also have strong relationships with DfT. We were invited to meet the Minister of State to discuss a wide-ranging agenda. Subsequently we worked closely with officials developing DFT's road transport decarbonisation plan The Road to Zero. We have also had a significant impact by continuing the multi-stakeholder initiative of the Commission on Travel Demand begun by the EUED Centre DEMAND. The Commission produced a widely publicised report on Shared Mobility (see Case Study 08: Shared mobility: the case for fewer cars, more sharing); and it is notable that DfT provided evidence to this process.

We have developed links with HM Treasury's team working on net zero, with an initial input on misconceptions about behavioural change in reducing energy demand, and a subsequent briefing on vulnerability to fuel and transport poverty.

We have an ongoing relationship with policymakers working on resource efficiency in Defra, primarily though the work of the Materials and Products theme, to produce the methodology for consumption-based emissions that Government is now adopting.

We also seek to inform and influence critical non-departmental public bodies. We have excellent links with the Climate Change Committee (CCC). Four members of the CREDS team supported development of their net zero report and colleagues at Leeds were appointed to undertake a detailed report on industrial decarbonisation as an input to the CCC's Sixth Carbon budget report. We have had detailed discussions, in particular on the cross-theme report on low energy demand futures. We have similar detailed interaction with Ofgem, in particular through our Flexibility theme, which has provided advice on a range of issues, including evaluation of the Competition and Markets Authority price transparency remedy, the cost-pass through impact on customers and the reform on black start restoration.

CREDS responds to government and parliamentary calls for evidence and consultations where we judge we have critical expertise. Responses are coordinated by the Knowledge Exchange Manager for policy and approved by the CREDS Director. In each case, the best-informed CREDS researcher leads the response, and staff from different themes are usually included. To date we have submitted 18 such pieces of evidence. Our evidence to the Science and Technology Committee Inquiry on Technologies for meeting Clean Growth Emissions Reduction Targets was heavily cited in the final report.

We have good links to officials working on sustainable energy in the Scottish and Welsh governments. In Scotland, contact is made easier by the work of colleagues at the University of Edinburgh who are researching England/Scotland policy differences. We focused one Whole Centre Meeting on Scottish issues and used the opportunity to build links with other Scottish stakeholders.

CREDS staff receive frequent invitations to speak at conferences, meetings and other events. We encourage staff to assess the benefits carefully. For less experienced researchers, these often provide useful development, as well as dissemination opportunities. More senior researchers have far more invitations than they can undertake, and therefore careful prioritisation is required. Collectively we have sufficient profile for these invitations to provide important opportunities. CREDS researchers were invited to make two presentations to seminars on net zero organised by the Council on Science and Technology and attended by the Minister of State from BEIS.

In the last year, we have also made a major input to the growing number of deliberative decision-making events on energy and climate. Four CREDS researchers made separate invited presentations to the UK Climate Assembly, informing discussions on how we travel, reducing aviation emissions, reducing what we buy, and energy use in the home.

Working with local government is more difficult for a national organisation like CREDS, but we have made a significant impact with two initiatives:

- a building stock model that is helping the Greater London Authority plan the decarbonisation of the building stock in London, and has the potential to make a similar impact in other localities,
- a series of seven briefing notes on decarbonising transport for the Local Government Association to assist local councils who have declared a climate emergency.

Where appropriate we work with other organisations in partnership to increase our impact. For example, we briefed the Green Alliance on our Shifting the focus report to inform their report on Balancing the energy equation.

7. Flexible Funds

The funding provided to CREDS contained two uncommitted elements

- funding for two additional challenges (£2M), and
- a Flexible Fund of £2.7M

This section sets out how these have been used.

7.1 CREDS Challenges Call

The challenge on decarbonisation of heat was included in our initial research plan, with uncommitted resources for two additional challenges. We consulted with the research community and prioritised three topics for proposals: Equity and justice, Co-benefits, and Decarbonising difficult sectors. We then undertook a two-stage funding call. At the initial stage, there were 24 separate applications spread almost equally over the three areas. In February 2019, a panel of three Executive members, three members of the Advisory Board and two others reviewed the proposals and shortlisted seven applications. Full proposals were subject to expert peer review, with final decisions by a panel (with separate membership from the shortlisting panel) in July 2019.

The successful proposals were:

- Fuel and transport poverty in the UK's energy transition'. PI: Mari Martiskainen (Sussex University, and involving Edinburgh, Manchester, Liverpool John Moores and Oxford Universities).
- Complete decarbonisation of the steel industry – how do we get there? PI: William Gale (Leeds University, and involving Sheffield University).

The new challenges began work in early 2020, with the two PIs joining the CREDS Executive.

7.2 Flexible Fund allocation

The role of the Flexible Fund is to allow for unforeseen external change and for research community development. The Fund is £2.7M (at 80% FEC) of which £200k was allocated in advance to the Clean Growth Strategy project, leaving £2.5M uncommitted.

The CREDS Advisory Board oversees the distribution of the Fund. It was agreed that the Flexible Fund should be allocated into six elements with different goals. These are summarised below, with an indication of funds left uncommitted in October 2020.

Flexible Fund element	Key Goal	Budget (£k)	Uncommitted (£k)
Researcher led projects	Capacity building	1,000	Zero
Strengthening core team	Enhanced impact	250	Zero
Impact acceleration awards	Enhanced impact	250	70
Integration projects	Research integration	250	205
Closing project	Research integration	500	500
Gap projects	Gap filling	250	250
Total		**2,500**	**1,025**

7.2.1 Researcher led projects

Early Career Researchers (ECRs) face difficulties in gaining experience of leading projects, due to insecure employment in many universities and UKRI's unhelpful distinction between investigators and researchers. Our call for ECR-led projects was designed to overcome this.

We launched the call in July 2019 and it was open for 20 weeks, closing in December 2019. Researchers who had not held a grant of more than £100k were eligible to apply. We supported potential bidders through a webinar, mentoring circles and training materials.

The call received a remarkably large number of applications, 75. In order to expedite decisions we used a one-stage decision-making process. All bids were peer-reviewed, thanks to excellent support from the CREDS colleagues and the wider research community. Based on peer review scores, we shortlisted 19 proposals for consideration by an independent panel consisting of CREDS Advisory Board members, which met in March 2020. We announced the results in June 2020, and all contracts have now been agreed.

There were eight successful projects.

- Using electric vehicles as distributed energy storage systems: a digital twin-based approach. Senthooran Balasubramaniam, University of Coventry

- Adding another layer? A future for clothing in heat demand reduction and decarbonisation: Janine Morley, University of Lancaster.
- CoCo hybrid project: George Bennett, University College London
- Decarbonisation of coastal shipping: Nishatabbas Rehmatulla, University College London
- Social entrepreneurship at the grid edge: Charlotte Johnson, University College London
- Old for new? Mapping skills and communication networks for traditional and off-site building energy retrofit: Faye Wade, University of Edinburgh
- DeViz (Defect visualisation via thermography): Julie Goodhew, University of Plymouth.
- Facilitating policy change for low carbon mobility: the role of multilevel governance. Louise Reardon, University of Birmingham

More details are in Appendix 3.

We have attached each project to an existing theme to help with integration into the consortium, support and reporting. Most projects have just begun or are about to begin.

Unsuccessful project proposers were offered one-to-one feedback from the Knowledge Exchange Manager for research. The vast majority accepted and their feedback has been helpful. The process has been evaluated and the evaluation report published.

Overall, the process was time-consuming for the CREDS core team, Executive, Advisory Board and external reviewers. However, we believe it was a good use of resources to help build capacity in the next generation of research leaders in the field.

7.2.2 Strengthening core team

We have allocated additional funding to recruit a Knowledge Exchange Manager for Business, based on recognition that we were not giving sufficient attention to business audiences. The post holder started in March 2020, so her work has been delayed due to COVID-19. She is developing a stakeholder map, in liaison with our main business-related themes – materials and products, and steel decarbonisation – and is developing a strategy for engagement with the business community.

7.2.3 Impact acceleration awards

We launched our internal programme for Impact Acceleration Awards (IAA) in November 2019. The aim is to provide small amounts of funding to enable researchers to take forward specific high-impact activities. We ask for a short project description and aim to make decisions very quickly. To date the programme has funded three proposals:

- to work with the Local Government Association and other partners to develop seven briefing notes on decarbonising transport,
- to develop a carbon calculator for transport related emissions for use by local authorities, and
- to intensify our policy engagement work, principally working with the buildings, heat and governance theme leaders, to build closer relationships with BEIS and MHCLG.

We view this as a very cost-effective use of funds, as it enables us to target existing research outcomes to specific users. We expect the programme to gain more applications as research outputs grow and new potential users are identified through stakeholder engagement.

7.2.4 Integration projects

Integration projects are larger projects, drawing on insights from across the CREDS consortium. The first, assessing the energy demand content of the Government's Clean Growth Strategy, was a commitment in the CREDS proposal and designed to stimulate cross- consortium working from the outset. Four subsequent projects, arising from new opportunities and insights are ongoing.

In all cases, the cost to the Flexible Fund does not represent the full cost, as CREDS investigators have committed time within existing budgets. In some cases, there are also partner contributions.

Five projects have been funded.

- The Clean Growth Strategy project leading to the report Shifting the focus – energy demand in a net zero carbon UK.
- Low Energy Demand Scenarios for the UK.
- The effect of COVID-19 on energy use in homes, working with the Smart Energy Research Lab (SERL).
- The effect of COVID-19 on travel and socialising adaptability, co-funded by other partners.
- The contribution of energy demand to the Covid-19 economic recovery package.

More details on each are given in the description of cross-theme research activities in Section 2.2 above.

7.2.5 Closing project

Funding for a closing project was included to ensure that CREDS has sufficient funding to undertake a high-impact integrating project (or projects) in the final two years of the programme. We will not take firm decisions on content until after the mid-term review, to allow project design to take into account the findings of that review.

7.2.6 Gap projects

Funding was allowed for gap projects to ensure that we would have sufficient resource to commission new work when important gaps in research are identified. To date, none of the funding has been allocated.

Following a review of the Flexible Fund by the CREDS Executive and Advisory Board, we have decided that, subject to the mid-term review, we propose to merge the integration, closing and gap projects funds to enable a much larger final project. The rationale and outline proposals are discussed below under Future work.

8. Centre Direction and Management

8.1 Management philosophy

The thinking that underpins our approach to the centre management is that excellence in research is achieved very largely from recruiting the best researchers and providing them with the environment, support and resources to allow creativity to flourish. Diversity in disciplines, methods, interests and approaches is to be welcomed. On a day-to-day basis theme leaders, project leaders and researchers operate with a high degree of independence, but are also expected to be collaborative and collegiate. This approach is embedded in the five core values to which we aspire and which were adopted in our initial planning: integrity, inclusive, fair, dedicated, and knowledgeable. These are embedded in the core policies of the CREDS on Equality, diversity and inclusion, and Communications and engagement.

Our declared aims are:

- internationally leading research,
- impact through knowledge exchange, and
- championing the importance of energy demand.

This threefold ambition has implications for our operations. Whilst top-down, hierarchical and one-size-fits-all management approaches are unhelpful in a university research environment, our commitment to collaboration, knowledge exchange and external engagement mean we need more than excellent research. So we value professionalism in other areas, and we encourage and support excellent researchers to communicate with different audiences from those with which they may be most comfortable.

The CREDS Executive team is committed to this approach in managing the centre. In general, we feel we have good buy-in across the wider consortium. We have recruited a group of researchers, knowledge exchange professionals and administrators committed to our vision. In addition, our Advisory Board has been supportive of this vision.

This overall approach leads to a number of challenges. These include building a team ethic and effective collaboration across the centre of more than 20 universities, and developing agreed key messages, without losing diversity and challenge.

8.2 Centre management

The first nine months of CREDS included intensive development of the centre and cross-cutting activities. The initial focus was recruitment of the core team to manage the centre, accompanied by development of the key CREDS management structures. The Collaboration Agreement between the universities was agreed within the first 3 months. The Advisory Board met first in May 2018 and subsequently in November, providing valuable guidance on early plans. The Executive Committee met monthly in the first instance. We addressed all the issues raised by the funding panel, and reported on this to UKRI. As set out above in the section on Communications, we rapidly took professional advice to develop a coherent vision and brand identity for the centre.

The CREDS core team is largely based in Oxford, supporting the Director. Led by the Centre Manager it includes three Knowledge Exchange Managers, a Web and Communications Manager, a Designer, two Centre Administrators and a Data Manager, some of which are part-time. The CREDS Data Manager is based in UCL, where he also works as a researcher in the Buildings theme.

Following the recruitment of the core team, we put in place the critical processes for a large centre. These include the internal communications mechanisms, the Communications and Engagement plan, the Equality, Diversity and Inclusion (EDI) Plan, processes for responding collectively to external consultations, and a quarterly reporting system. For each theme, one member of the core team acts as a key contact to ensure effective collaboration in the design of knowledge exchange activities. In additional to Whole Centre Meetings, we have regular emails to the full consortium (Consortium Update), and a number of cross-institutional activities, for example on EDI and between early career researchers.

The governance and management systems of the centre continue to evolve. Additional universities have joined the consortium as a result of the Challenges Call and the Early Career Researcher Call, so that there are 24 universities in the consortium.

8.3 Project management, reporting and risk management

The space constraint on the original proposal document did not allow sufficient detail on individual projects against which they could be managed. We have therefore required project leaders to produce more detailed project plans, against which progress is monitored.

We also require a data management plan (DMP) for each project, which enables compliance with the requirement to make research data available. The Data Manager provides support to all themes to achieve a consistent approach. We have developed a CREDS Data Management guidance document and provided training for researchers at the 6th Whole Centre Meeting in June 2020 and at a joint webinar with the UK Data Service in July 2020.

We have developed a quarterly progress reporting system that we use across the consortium. This provides the management information to allow us to track progress and identify where remedial action may be required. It is designed to assess the progress of the work, identify forthcoming activities requiring support and allow discussion of cross-theme interactions. These discussions are held at one of the two CREDS Executive meetings each quarter. The categories reported are consistent with UKRI's annual Research Fish exercise.

We have a Risk Register that is reviewed annually by the CREDS Executive and shared with UKRI. In 2020, we have undertaken a very substantial review of risks for each theme to assess the impact of the Covid-19 pandemic. The Centre Manager developed an initial Covid-19 risk assessment summary report in April and shared this with the consortium, Advisory Board and UKRI. This identified risks as potential delays, actual delays, changes to research and major implications for impact. Key findings were that:

- work has been delayed due to lower productivity caused by stress, caring and home-teaching responsibilities, with some reduction in productivity.
- there is a possibility of staff, members of their families, contracting the disease with potentially serious impacts to their health or temporary absence.
- stakeholder engagement and dissemination activities are affected, as stakeholders face similar issues.

The report set out what could be done to mitigate these risks, whilst recognising that the situation was fluid, complex and uncertain. Several colleagues have been ill with the virus, although as far as we know none is suffering serious long–term effects. Despite this, most work has continued using online platforms and home-working. Many projects have either adjusted plans by moving activities online or revising the scope of the work. The professionalism and commitment of colleagues has reduced disruption considerably. We are currently review this risk assessment. When the overall picture is clearer, we will make decisions on our overall response strategy. Currently, we expect this will include application to UKRI for a no cost extension.

9. Future plans

9.1 The internal context for development of CREDS

At this stage in the life of the centre, we have no critical concerns. CREDS has been established, has built strong relationships and is undertaking high quality research. Internally, there is good cross-theme working and support for the vision of the centre. It is challenging to balance a strong focus on research excellence with wider engagement, but we have a team committed to doing that. In addition, we have put in place processes to guard against the risk of themes becoming siloed. The Covid-19 pandemic has produced some delays, but we remain broadly on track.

We have some exciting work underway. The integration projects described above will put us at the cutting edge of work on the implications of Covid-19 for energy demand and what is possible in terms of demand reduction. We also have other work almost complete on the role of energy demand historically in UK climate mitigation and on the relationship between energy demand changes and the energy transition. We can build on these.

We encourage an open and transparent culture, which involves being self-critical and reflexive. In this spirit, we have identified two areas of our work where we have concerns that our impact in some areas needs further development.

The first area for development is our international impact. We were optimistic for our international visitor programme, but it has not generated the high-profile research visits for which we had hoped, and has now been blighted by the effects of the pandemic on international travel. We are considering alternatives. These are likely to include an international webinar programme, as long-distance engagement in webinars has proved to be one unexpectedly positive outcome of the pandemic. We will also investigate the option of a small number of in-depth relationships with other research centres.

The second area for development is business engagement. We have good relationship with some individual businesses, but these are weaker than our engagements with the policy community and other researchers.

To some extent, this is not surprising. Engagement with most businesses has been more difficult during the pandemic. We do not aspire to provide an energy management service, which is the critical energy demand issue for the majority of businesses. Whole systems research itself is only of interest to a minority of businesses. So our challenge is to find ways to make it relevant, for example by elucidating the effect of system change for individual products and services. Our experience is that this is likely to be easier through important intermediaries such as trade associations and professional institutions, and therefore that will be a key area in which to build stronger relationships. We will also need to focus on our research strengths that are of most business interest, such as flexibility and resource efficiency. Through the appointment of a Knowledge Exchange Manager for business, we are now taking forward these plans.

9.2 The external context for development of CREDS

In developing plans for the closing two years of the CREDS programme, we have been conscious of major changes in the technical, economic, social and political context over the period since we wrote the bid in late 2017.

Brexit uncertainties have been a constant through these three years, and some remain despite the UK having left the EU single market. The two major implications for energy use are the loss of some targets for energy demand and the future uncertainties for vehicle and product standards. In the former case, Article 7 of the Energy Efficiency Directive no longer applies. In the latter case, current EU standards have been adopted into UK law, but subsequent changes may not be, and it remains unclear how the UK will monitor, test and enforce standards. Whilst these are significant policy issues, on which CREDS comments with some expertise, they do not provide a strong case to change our research programme.

At the same time, there has been an upswing in local and civil society engagement with climate change, and therefore issues of energy use. The UK and devolved parliaments/assemblies and large numbers of local authorities have declared climate emergencies. In many cases, there are new commitments to net zero on timescales ranging from challenging to infeasible. Moving in a few decades to zero carbon energy throughout industry, buildings and transport will be extraordinarily challenging. Our experience is that the scale of change required is not grasped by most citizens, nor even by many decision-makers.

CREDS staff have played a part in a number of local deliberative processes. As described under Impact, above, four CREDS staff played a significant part in the UK Climate Assembly. We interpret these invitations as a vote of confidence in our ability to inform civil society discussion on practical issues. We expect public attention to climate will probably remain high in the run up to COP-26 in Glasgow. We are realistic about the crowded media attention that will surround the COP and are planning our input to be focused and high level. We will use the research we are undertaking on low energy demand scenarios to draw attention to the key, and often neglected, role of demand reduction in meeting climate targets.

We will collaborate with other respected voices to do this if there are appropriate opportunities.

Public opinion and media attention clearly affect politics and therefore public policy. The cross-party commitment to strong action on climate change has held, which is welcome, although the subsequent focus on the pandemic has drawn attention elsewhere. The 2019 General Election campaign saw stronger commitments to improving energy efficiency from a wide range of political parties. The recent Ten point plan and Energy White Paper set ambitious goals for electrification of transport and heat, but otherwise pay insufficient attention to energy demand. Our analysis is therefore that the policy environment remains mixed. Our approach, as publicly-funded researchers, has always been to undertake independent research and engage with decision-makers constructively and, where required, critically. We see no reason to alter this positioning.

The Covid-19 pandemic has provided a major shock to society and the economy, and therefore to energy using practices. Energy use, especially in transport fell during periods of lockdown. As set out in the description of our research, we were quick to initiate research projects to look at these effects and their drivers. As the weeks of constraint have turned into months, we have begun to think more about the longer-term social, economic and political impacts of the pandemic. These include the acceleration of digitalisation and the potential impacts on energy use of the responses to the economic recession. We have identified important research to do a number of areas, including on:

- greater use of, and dependence on, information and communications technologies,
- shifts in working and commuting patterns,
- new patterns of retailing,
- the decline in, and re-purposing of, city and town centres,
- uncertainties about future leisure patterns, including long-distance travel,
- concerns about the safety of public transport,
- reinforced inequalities,
- the impacts of the economic recession; and
- the effects of different investment options within recovery packages.

These drivers will interact. Moreover, perhaps critically for energy use, they will also interact with the radical social and technological changes needed to decarbonise heat, transport and industry. This combination of pandemic's impacts and systemic decarbonisation points to the biggest uncertainties for energy demand in many decades. It does not invalidate our planned research, but it does point to the value of a Flexible Fund and the need to consider it use to address these issues.

9.3 Plans for the Flexible Fund

Having considered the options and consulted our Advisory Board, we believe that research on changes driven by the pandemic and system decarbonisation should be prioritised. To some extent, they can be addressed through applying what we are already researching. In other cases, new research is needed. The distinction between research integration and gap filling in our plans now seems less important than the overall objective. This is also urgent. It cannot sensibly await another UKRI research call for work to start in 2023. We therefore propose to use most of the remaining Flexible Fund to focus on these issues in the next two years.

The urgency and need for integration imply we will need a stronger top down approach than we have used in some other parts of the Flexible Fund. We will still want to ensure we encourage new ideas and participants, but delivery of impact by March 2023 will require a high level of coordination. Realistically, we can only achieve that through a work programme that is closely overseen by the CREDS Executive, so that is what we propose.

Having considered options, we envisage a process along the following lines:

- an open process within CREDS seeking outline descriptions of critical pieces of research, in January 2021,
- a (virtual) open meeting of CREDS researchers to develop these ideas into coherent work packages, in February 2021,
- detailed planning of the research programme, in March-May 2021; and
- feedback from the mid-term review and any necessary adjustment.

We believe that this approach provides an appropriate balance. It does not pre-empt the results of the mid-term review and will allow the panel to input into our plans. At the same time, it enables us to synthesise findings to date, build on existing knowledge and collaborations, and to start preparation for the project to begin in June 2021, allowing 21 months before the scheduled end of the centre's work in March 2023.

Appendices

Appendix 1: Membership of the CREDS Executive

Role	Name	Institution
Centre Director	Nick Eyre	University of Oxford
Centre Manager	Clare Downing	University of Oxford
Co-Director, Buildings Theme	Tadj Oreszczyn	University College, London
Co-Director, Transport and Mobility Theme	Jillian Anable	University of Leeds
Co-Director, Materials and Products Theme	John Barrett	University of Leeds
Co-Director, Flexibility Theme	Jacopo Torriti	University of Reading
Co-Director, Digital Society Theme	Tim Foxon and Steve Sorrell	University of Sussex
Co-Director, Policy and Governance Theme	Tina Fawcett	University of Oxford
Co-Director, Decarbonisation of Heat Challenge	Bob Lowe	University College, London
Co-Director, Fuel and Transport Poverty Challenge	Mari Martiskainen	University of Sussex
Co-Director, Decarbonisation of Steel Challenge	Bill Gale	University of Leeds

Appendix 2: Membership of the CREDS Advisory Board

Name	Affiliation	Time on Board (if not whole period)
Joanne Wade	Association for Decentralised Energy	
Dustin Benton	Green Alliance	until February 2020
Harriet Bulkeley	Durham University	
Siobhan Campbell	Department for Transport	
Hywel Davies, alternate Anastasia Mylona	Chartered Institute of Building Services Engineers	
Sylvie Douzou	Électricité de France	
Claire Dykta	National Grid	
Steve Fawkes	EnergyPro	
Maxine Frerk	Independent	
Adrian Gault	Formerly Committee on Climate Change	
Richard Hall	Citizens Advice	from March 2019
Sue Kearns	Scottish Government	
Victoria MacGregor	Citizens Advice	until November 2018
Mirabelle Muûls	Imperial College, London	
Libby Peake	Green Alliance	from May 2020
Clemens Rohde	Fraunhofer Institute for Systems and Innovation Research	
Jon Saltmarsh	Department for Business, Energy and Industrial Strategy	

The Board is chaired by Joanne Wade.

Advisory Board members attend in a personal capacity not as institutional representatives.

The Advisory Board is also attended by UKRI Portfolio Managers, currently Edward Jones (EPSRC) and Helen Rogers (ESRC), as observers.

Appendix 3: Descriptions of the Early Career Researcher Projects

Projects attached to the Buildings theme

How can compact combi hybrids contribute to decarbonising and reducing heat demand? PI: George Bennett, University College London

The project started in August 2020 and is currently finalising a Non-Disclosure Agreement and Data Sharing Agreement with Worcester Bosch who are providing the key dataset of diagnostic data from 50k+ boilers in the UK. The project will investigate whether the Compact Combination (CoCo) Hybrid technology that combines a gas boiler and an air source heat pump (ASHP) in one wall-mounted, compact appliance offers a potentially attractive transition technology that can bridge the gap between the current technology of gas boilers and a future dominated by high efficiency, low carbon heating.

DeViz (Defect visualisation via thermography) PI: Julie Goodhew, University of Plymouth

This project uses thermal imaging as a behaviour change tool for informing, empowering and engaging site supervisors to help them achieve zero defects in their buildings and so encourage a learning loop and zero-defect culture. In parallel, it is developing a methodology to enable autonomous checking by construction supervisors using thermal imaging cameras, monitoring their own work, identifying build defects as the build/retrofit happens and rectifying them much earlier in the construction process.

Projects attached to the Transport and Mobility theme

Facilitating policy change for low carbon mobility: the role of multilevel governance. PI: Louise Reardon, University of Birmingham

This project uses interpretive network and problem analysis to identify the role multi-level governance plays in influencing local-level policy responses towards low carbon mobility. We will compare the multi-level governance of two city regions: Birmingham and Cambridge, using original data from policy documents, participatory mapping workshops and semi-structured interviews. The project will provide recommendations for ways current UK governance arrangements can be supported to enable more effective local policy responses towards low carbon mobility.

Decarbonisation of coastal shipping in UK. PI: Nishatabbas Rehmatulla, University College London

This project will identify the most suitable geographic locations to establish green and blue hydrogen and ammonia as zero carbon marine fuels in order to facilitate the best possible early adoption and subsequent scale-up. The project is developing a set of key indicators and criteria that can be used to ascertain the suitability and success of a marine transition to alternative fuels that reduce emissions and develop long term sustainable energy demand.

Project attached to the Flexibility theme

Using electric vehicles as distributed energy storage systems: a digital twin-based approach. PI: Senthooran Balasubramaniam, University of Coventry

This project is investigating how digitisation would optimise the vehicle-to-grid (V2G) process in conjunction with distribution grid constraints, the availability of local renewable energy resources and customers' preferences. We are developing a durable and reliable V2G-based demand response system by implementing a digital twin-based energy management scheme which accurately calculates the mobile storage capacity in real-time, and uses it to achieve a balance between local generation and local demand.

Project attached to the Digital Society theme

Social entrepreneurship at the grid edge. PI: Charlotte Johnson, University College London

This project is investigating how community groups are responding to opportunities for community-led, renewable electricity generation that are appearing at the grid edge. Demand side response and collective self-consumption can match local demand-to-supply, opening up opportunities for more distributed renewable electricity generation. We are drawing on place-based entrepreneurship theory and critical infrastructure studies and comparing two countries (the Netherlands and the UK). We will then work with diverse community groups in Newham to co-design collective self-consumption projects that contribute to Newham's climate strategy and generate local value, such as social cohesion, poverty reduction, wellbeing and GHG emissions reductions.

Projects attached to the Policy and Governance theme

Old for new? Mapping skills and communication networks for local traditional and off-site modular building energy retrofit'. PI: Faye Wade, University of Edinburgh

This research will map the skills and communication networks of supply chain actors in local traditional on-site retrofit of homes and compare it to newer, off-site, modular ways of working. Most people retrofit their homes incrementally using local tradespeople, but this traditional, on-site strategy is unlikely to meet climate targets. An alternative way of working is to manufacture a new building with more efficient insulation and appliances in one unit, off-site. This project will examine who is involved, what skills they will need and whether it will deliver energy retrofit at the speed and scale needed to meet climate targets.

Adding another layer? A future for clothing in heat demand reduction and decarbonisation. PI: Janine Morley, University of Lancaster

This project aims to inspire greater research and policy interest in clothing and a greater recognition of its potential significance in the transition to low carbon heating. Reducing demand for heating in homes, and elsewhere, clothing could make an important contribution but tends to be overlooked. We will investigate what we currently know about how different styles of clothing affect the demand for space heating, imagine future scenarios to help clarify knowledge gaps and assess the role the fashion and clothing industry could play in this area.

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, low carbon energy system. CREDS has a team of over 140 people based at 24 UK universities and organisations.

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