
MAPPING THE UK RESEARCH & INNOVATION LANDSCAPE: ENERGY & DEVELOPMENT

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A review undertaken by the UK Low Carbon Energy for Development Network, Energy 4 Impact and the Knowledge Transfer Network, with the assistance of IOD-PARC.

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EXECUTIVE SUMMARY

The UK is already a major player in terms of research and innovation into low carbon transitions within the countries of the developing world. However, there are significant opportunities for the UK to enhance its presence within these markets whilst also making a major contribution to meeting international development targets and climate commitments. At the core of the research analysed in the report is that it reflects disparate, research initiatives funded with different research/innovation targets in mind; much latent strength in UK research for low carbon energy for development therefore is implicit in linkage possibilities enhancing systemic effectiveness, particularly by cross-fertilizing innovations taking place in the private sector. Gaps and weaknesses are reflected as much in the lack of collaborative initiatives and 'siloization' as in the absence of actual research/funding.

The Low Carbon Energy for Development Network (LCEDN) is currently taking the initiative in one aspect of this through the provision of a programme of capacity building and partnership activities to support the development of DfID's Transforming Energy Access research initiative. What is required of UK energy for development research for the purposes of building a functional system, however, is that the discrete areas of research outlined in this report be re-assembled as coherent, overall research narratives addressing the apparent contradiction of increasing energy access whilst transitioning to the low-carbon economy.

Part of this work involves identifying the state and dynamics of UK research capacity in this sector, facilitating greater integration between research funders active in this area, evaluating gaps and key research needs and mapping potential future directions for research interventions and collaborations that build on, and develop, existing UK research capacity. It is expected that this will lead to a range of UK-led energy innovations developed, tested and scaled across developing countries by 2020. The much-needed harmonization of energy access and low carbon transition as a UK research theme however has ultimately to be created out of re-thinking research fields from a combination of existing research, plus demand known to be 'out there' but which has yet to enter the field of vision of research-funders.

This report presents the first part of this work with an overview of current UK research and innovation capacity in a widely defined 'Energy and International Development' research area. It identifies key institutions and research centres, thematic areas of excellence, research funding trends over the last decade, emerging research themes plus an overview of grant funding for innovation on the ground. A number of key areas/questions for potential further development of UK research and innovation capacity have been identified and are up for discussion and consultation. The work has been undertaken by LCEDN in partnership with the Knowledge Transfer Network, Energy 4 Impact and IOD PARC

The Current Research and Innovation Landscape

A detailed picture of UK capacity has been built up by drawing on consultations with and contributions from a wide range of UK academic experts, as well as the collation and analysis of a database of research projects, institutions and individuals focused around energy and international development issues and the relationships between them. The capacity review takes a relatively wide definition of energy research covering a range of themes relating to the provision of energy services within international development contexts. The main focus is on off-grid electricity supply, although it also covers questions of energy efficiency, biofuels and clean cooking.

The project database identifies 37 UK research institutions that have conducted research on energy in an international development context over the period of the study. These research institutions are well networked internationally with almost 100 overseas partner institutions recorded as taking part in these projects. The database reveals, unsurprisingly, that most UK-funded research on UK low carbon energy and development themes addresses the challenges articulated in the energy trilemma; namely, energy poverty, energy security and environmental challenges, including climate change.

About half of the projects in the research portfolio have had a strong technology focus, i.e. they focus on the development of a specific technology or technologies, but socio-cultural, policy and business perspectives are also well represented. Of the technology-focused projects, the database reveals a particularly strong emphasis on solar and bioenergy solutions.

As much as anything else, the research landscape poses a series of questions to funders and the research councils:

- 1) Are there areas of research/innovation it may not be worth the UK's while to pursue?
- 2) What should the UK do about key areas of research which receive too little focus/funding (cooling themes, for instance)?
- 3) How should UK research areas that are already funded but have much more potential than they are funded for be approached (Bioenergy, energy storage, off-grid modelling, energy efficiency), or those which need better-targeting on low-carbon transitions and development
- 4) Energy access and low carbon transition should not be a trade-off, they should be complimentary; climate change adaptation must also go hand-in-hand with low carbon livelihoods, so how can this be built into research funding?
- 5) How will the separate remits of the research councils address key transitional disciplines/ Research themes vital for harmonizing the social with the technical (anthropology; socio-technical transitions; governance and political economy; innovation studies; stakeholder and community engagement and capacity building; and policy analysis)?

These questions are particularly important because the current state of empirical research shows that the link between mere electricity access and poverty alleviation is not direct, linear or certain. Identifying key researchers/technologies and centres, therefore, is not enough – the key steps for UK research should be identifying a framework linking all of these actors by focusing on:

- 1) Building existing strengths
- 2) Identifying strong potential
- 3) Crossing the socio-technical divide that marrying energy access to low carbon entails

Key Themes Identified

There has been a considerable investment in **Solar PV** research in the UK over recent years including the launch of the EPSRC SUPERGEN SuperSolar Hub in May 2012. Much of the focus has been on the development of new materials meaning that much solar research funded in the UK has not been particularly relevant to the international development context, although that may change in the future as new technologies reach the marketplace. Some of the work that has been jointly funded by DFID and Innovate over recent years is addressing this area, including the development of new materials that might improve efficiency and drive down costs.

Most research with direct relevance has been more applied work looking at the deployment of existing solar technologies at household, community and larger grid-connected levels in the Global South (and the development of new business models, financial modalities and applications). This has not often been strongly connected to the broader UK solar energy research community. There are a number of established centres/ research groups in the UK who have worked on mini-grid based electrification. Their expertise covers a range of areas including technical expertise to design and develop mini-grids using a combination of generation technologies and field level action research has fed into social science driven research on user behaviour, business models, enabling environment and socio-technical innovation systems.

The main strengths of the research arise from the applied research approach taken by most of the groups that tends to be multi-disciplinary in nature. Alongside the emerging work on mini-grids, the UK also has an established track record on research into the development of and deployment of smaller-scale solar home systems at the household level and pico-solar devices such as solar lanterns. Spin out companies have emerged at several UK universities who have made successful entries into these markets on the basis of effective system

design, reliability improvements and in particular innovations in payment systems (and most recently) in appliance availability. Alongside more technical research in this area on system design and product reliability, there has also been some important social science work initiated in this area.

Other areas where there is some existing crossover between more technologically-focused research and international development contexts and significant potential for expansion include on payment systems and affordability. UK researchers have been involved in the development of novel new payment systems, data management and communication software and business models. This reflects both university research projects to develop the technology, assessment of its utilization and the development of spin-out companies which have emerged to take advantage of international market opportunities.

Looking to the future, the key emerging research areas which relate to solar PV have been identified as: appliance development and its availability and affordability; developments in (mini) grid architecture; data management; planning and governance; and in the development of hybrid systems. Of the solar research being done, effective and appropriate functioning of mini-/micro-grids is one of the most urgent for development purposes, in harmony with the development of financial/commercial models and payment systems – researching ways to hybridize projects effectively (solar/biogas, solar/wind etc.) at the community level would also represent a substantial advance.

Bioenergy is perhaps one of the most complicated areas of energy research since it encompasses so many different elements, technologies and scales. UK research investments in this area can be divided into a number of different research themes including: whole bioenergy systems and sustainability assessments; biomass production; bioenergy processing and conversion technology (i.e. gasification, biogas or anaerobic digestion, briquetting etc.); socio-economic impact assessment; environmental impact assessment; and clean cooking. Our analysis of the current energy and development research portfolio reveals a reasonable range of bioenergy-focused projects, yet research on bioenergy within development contexts remains a relatively minor component of the UK work. That said, there is a body of UK research being undertaken on the development of bioenergy solutions for meeting energy access objectives, as well as a series of innovations being developed by UK SMEs and university spin-off companies with clear Southern market potential.

Emerging themes in bioenergy have been identified and include, inter alia: further improve knowledge of biomass resources within specific countries and regions; further research into new conversion techniques, with particular relevance to those suited to specific regions of the Global South; further work calculating the environmental, economic and social performance of bioenergy systems, considering feedstock and other variations and supporting infrastructure needs; and strategic analysis of the potential to build biomass value chains to support policy and industrial development

Innovations in **energy storage** in the UK are focused on batteries and flow cells (electrical), phase change materials and inter-seasonal storage (heat/cold) and hydrogen (gas) where the hydrogen has been produced from non-fossil fuel feedstock. With the exception of some DfID-funded energy catalyst projects, few have focused strongly on applications within Global South contexts, although there is potential for their application in the future.

Alongside expertise within specific energy technologies, the UK academic community also has demonstrable **modelling expertise** in the area of off-grid energy access. The main strengths of these groups arise from the existence of a core set of modellers within a number of research groups. Current expertise covers: techno-economic analysis of energy systems; economic and econometric analysis of rural energy issues; decision analysis; and system-wide analysis. However, the visibility of UK academic research on rural energy modelling appears to be relatively limited.

There is considerable research expertise in **energy efficiency** within the UK context however, with the exception of work on building design and certification and consumer behaviour, certification and labelling schemes for energy products, very little of this expertise has been deployed in exploring questions of energy efficiency within the diverse settings of the Global South.

The current research portfolio tends to be of two kinds. The first is an engineering focus on the development of new technologies or new forms of deployment of existing technologies; whilst the second approach concerns

the methodologies required to take new technological developments 'to scale' via the development of new 'delivery models' designed to accelerate the deployment of energy technologies in pursuit of the achievement of the international access targets. What has been largely missing in this effort has been an adequate appreciation of the broader social context of these interventions. In the last five years a small, nascent literature has emerged that focuses more explicitly on the socio-cultural, political and innovation dimensions of energy access. Whilst some of the expertise behind this research lies overseas, there is also significant emerging capacity in these fields within the UK. The following branches of UK **social research** have made important contributions and have built up their experience and expertise: anthropology; socio-technical transitions (a strand of innovation-based research); governance and political economy; innovation studies and stakeholder and community engagement and capacity building; and policy analysis.

The analysis demonstrates how difficult it is to bring together various disjointed research ideas to encourage a more transdisciplinary research approach. Part of the problem is the 'silo-ized' situation in which UK research funding is focused, which does not encourage the multi-thematic needs of this sector. This is ironic, because the 'strengths' in UK research lie in linkage possibilities between disciplines and in enhancing research opportunities with input from innovations taking place in the private sector. The gaps/weaknesses in the research portfolio are reflected as much in the lack of collaborative initiatives as in the absence of actual research/funding.

UK Research Portfolio in a Global Context

UK research will only contribute to the challenges of securing universal energy access and accelerating low carbon transitions if it clearly responds directly to the demands and needs of communities and the variety of organizations working towards those aims. There needs to be a much stronger focus on the demand for research, real palpable demand that would have direct impact as well as commercial relevance. To meet that demand, however, we would argue that the currently limited understanding of 'solutions' needs to be broken open and the dominant focus on technology re-directed towards a strengthening of socio-technical understandings of social energy systems. Mapping the activities of entrepreneurs currently deploying potential solutions perhaps contributes to this intention, by exploring the UK research and innovation portfolio in the light of the articulated needs of communities and businesses in the global South. Therefore, an analysis has been carried out of a database of grant-funded enterprises/projects compiled by E4I along with a view of where the promising areas of research to support replication and scale-up appear to be according to the experiences of the communities and organizations that E4I work with.

A total of 488 projects are included in the database. The results of the analysis show that there is a clear geographical focus of the activities in a number of countries in Eastern and Southern Africa (notably Kenya, Tanzania, Uganda, Zambia, Rwanda and South Africa) plus India and China and, as would be expected from funding mostly targeted at enterprise-related innovation, almost all funding is available for testing and scaling up of technology and business models. As with the UK research and innovation landscape, solar PV dominates as a technology with bioenergy also receiving significant support: 41 % of the grants include a focus on solar PV whilst 32 % of grants include a focus on some form of bioenergy.

Solar PV systems for domestic energy supply is the largest funded area and most of the grant funding is directed towards pay-as-you-go (PAYG) models selling Solar Home Systems (SHS), followed by mini-grids. In the vast majority of cases the grant funding is used for testing business models and finance rather than focussed on the technology per se. Funding for bioenergy is split between solid biomass, biogas and clean cooking. Solid biomass focusses on the manufacture of briquettes, pellets, green charcoal and bio-char made from locally sourced agricultural, forestry and municipal waste. Support for biogas or gasification technologies is focussed on technical feasibility and demonstration whilst support for energy efficient biomass stoves has focussed on scaling up manufacturing capabilities, demonstrating the technology, some testing of business model ideas, or scaling up distribution.

New Directions

Based on the current status of commercialisation and a review of the current UK research portfolio, some suggestions can be made as to research themes that, from the available analysis and information, seem to be missing in the current research, innovation and commercialisation space in the UK. These include the following key themes

1. **Longer-term research horizons** - Research that more fully recognises the complexity of innovation and the rapidity of change in the low carbon energy sector and is able to adopt a timeline that is much broader, for example, than research that focuses on more short-term tangible impact and commercial interest.
2. **Longitudinal studies** - exploring the longer-term impact of existing energy sector interventions and their unintended consequences and subjects the untested assumptions being made about the benefits of access to modern energy services and their impact upon pre-existing patterns of poverty, marginalization and exclusion. Unpacking the reality of access impacts will require detailed longitudinal empirical studies of both existing interventions and the expanded roll-out of programmes as they accelerate over coming years in pursuit of international targets. Clearly, an important aspect of this is **the differentiated impacts** of low carbon energy interventions upon women and other marginalised social groups that highlight important intersections with questions of age, class, ethnicity and identity.
3. **Changing energy wants and needs** - Innovation and interventions that are more adequately based upon an informed understanding of change over time, rather than making assumptions which then produce a focus on 'technical' solutions against static assumptions of demand. This requires a change in how innovation is understood and how researchers engage with target communities. It is only when researchers interact over extended periods with the communities that they research that community understandings of energy, electricity and technology become apparent and innovation becomes more grounded.
4. **Scalar governance frameworks** – Understanding socio-technical decision-making in off-grid locations as embedded in changing socio-political and economic relationships that make changes to livelihoods and living standards possible. Energy access continues to be examined as a technology not a social mechanism, even at a time when the political decentralization which will determine impact is being rolled out globally. Given the reality of decentralization initiatives it makes sense to be thinking in a coherent way about the scale of generation and what areas the UK should be targeting. Scalar issues directly affect the kinds of skills and capacities that need to be developed if the current wave of energy sector interventions is to bring sustainable and equitable benefits.
5. **Energy access for the poorest** - Research that focuses on questions of energy justice and in particular focuses on providing energy access for the poorest sectors in ways which current interventions, e.g. support to SHS and mini-grids, generally tend to fail to reach.
6. **Productive uses** - More innovation and research are required that focus on the design and implementation of energy interventions which focus on productive uses specifically. This includes the business models, business support services and institutional environment required.
7. **Development of mini-grids** - Research into the technologies supporting mini-grids needs to continue and deepen with a particular focus on new forms of energy storage, novel payment systems, data management and energy efficient appliance development.
8. **Transforming Cooking** - A radical transformation in **clean cooking** research that moves beyond the current focus on improved cookstoves to initiate wider, more holistic thinking about the clean cooking challenge, that looks further into the future and is more innovative via, for example, exploring new developments in the distribution and marketing of LPG, detailed examination of the potential for transitions to electric cooking and transformations in the sustainability of biomass production/charcoal supply. More broadly to encourage wider, more holistic thinking about healthy households –the socio-energetic possibilities inherent in ventilation, cooling, natural lighting, clean lighting and enhancing the social environment of informal economy households.
9. **Urban energy poverty** – an under-researched issue needing a renewed focus on the energy challenges for energy access in urban areas. Living 'under the grid' does not guarantee access to energy as supplies can be unaffordable and unreliable. Research is needed to identify the specific needs of the urban poor, and to integrate them into energy and urban planning processes.

Next Steps

The report attempts to trace the contours of the diverse and highly complex portfolio of UK academic research and innovation activity around low carbon energy and international development themes. We acknowledge, however, that our knowledge of the sector and our assessment of need are partial.

This is the first report of an ongoing project within which we are exploring the nature of the current research portfolio. In the ensuing stages we intend to deepen our analysis to map the networks within which specific research teams are involved, assess the geographies of where that research is located and further deepen our analysis of the most appropriate directions for future interventions by the UK government within this research space.

MAPPING THE UK RESEARCH & INNOVATION LANDSCAPE: ENERGY & DEVELOPMENT

1. INTRODUCTION

The UK Low Carbon Energy for Development Network (LCEDN) brings together researchers, policy-makers and practitioners from across the United Kingdom to expand research capacity around low-carbon development in the countries of the Global South. The LCEDN is currently providing a programme of capacity building and partnership activities to support the development of DfID's Transforming Energy Access (TEA) research initiative. Part of this work involves identifying the state and dynamics of UK research capacity in low carbon energy and international development, facilitating greater integration between research funders active in this area, evaluating gaps and key research needs and mapping potential future directions for research interventions that build on and develop existing UK research capacity. This part of the work programme is being conducted in partnership with Energy 4 Impact (E4I) (whose key expertise lies in catalysing market opportunities for energy sector entrepreneurs and innovators in developing country markets) and the Knowledge Transfer Network (KTN) (who have unique expertise on the UK innovation landscape) and with the technical assistance of IOD-PARC in the management and presentation of research data.

As part of this work, this report presents an overview of current UK research and innovation capacity in a widely defined 'Energy and International Development' research area. It identifies key thematic areas of excellence, research funding trends over the last 10 years, emerging research themes and key areas for potential further development of research and innovation capacity. This report takes a relatively wide definition of energy research covering a range of themes relating to the provision of energy services within international development contexts. The main focus is on off-grid electricity supply, although we also cover questions of energy efficiency, biofuels and clean cooking. In general, we do not cover transport research or research into on-grid electricity supply, although we are actively pursuing collaborations within those areas (for example via a new programme of collaboration with DfID's Energy and Economic Growth (EEG) programme which explores on-grid energy supply) which may lead to these areas being covered in our ongoing review work in the energy and development field.

The ensuing sections of the report are organised as follows. Section Two outlines the methodology that we have employed, presents an overview of the current UK energy and development research and innovation portfolio and discusses developments in each of the key areas of study. Section Three then explores this portfolio in the light of the articulated needs of communities and businesses in the Global South. Section Four then outlines some of the key potential directions that the UK research endeavour in this area might take over the coming years. Finally, there is a short conclusion and reflection on next steps.

2. THE UK RESEARCH AND INNOVATION PORTFOLIO

2.1 INTRODUCTION

This section of the report presents an overview of the current state of research in the UK on Energy and Development themes. It outlines the current research portfolio, explores potential fruitful new directions and opportunities and identifies key gaps in UK capacity.

2.2 METHODOLOGY AND DATA ANALYSIS

This report draws on consultations with and contributions from a wide range of LCEDN members,¹ as well as preliminary analysis of a research database of individuals, institutions and projects which is being compiled by colleagues in IOD PARC alongside the LCEDN team. This database has been built from data on individuals draw from the LCEDN's existing membership database, information provided by LCEDN members and original research conducted by the project team. The database (which will feed into an improved 'expertise register' on the LCEDN website) remains a work in progress that provides a 'snapshot' of research capabilities in the UK. It will be expanded and updated regularly to provide an ongoing public resource for identifying useful research collaborations and tracking research capacity in this area.

The projects section of the database upon which most of the trends presented here are based, has been derived from information provided by Innovate, Research Councils UK (RCUK), the Royal Academy of Engineering (RAEng), the Royal Society and others, as well as detailed searches conducted via the RCUK's Gateway to Research (<http://gtr.rcuk.ac.uk/>) and UK Energy Research Center (UKERC)'s Energy Data Centre (<http://ukerc.rl.ac.uk/index.html>). The analysis of the research database has also been deepened by analysis of the wider Innovate portfolio by the KTN team and KTN's own case studies of select projects funded through a variety of forms of Innovate funding.

A spreadsheet template was developed to provide the database structure, and the following information recorded for each entry (for full details of the categories utilised please see Table 1):

- Name and general description for each project entry.
- The type of research being carried out
- The type of application of the research
- For technology-focused projects, the type of technologies
- The primary challenge that the research is intended to address
- The scale that the research focuses most strongly upon
- The locations where the research was conducted, as a first step towards geographical mapping.
- The name of the PI, their institution, other researchers involved and the names of partnering organisations
- The main weblink(s) where information was drawn from.

The project database identifies 37 UK research institutions that have conducted research on energy in an international development context over the period of the study. These research institutions are well networked internationally with almost 100 partner institutions overseas recorded as taking part in these projects. The analysis presented below focuses on the nature of the research undertaken within these projects which allows us to make some general reflections on the projects that have been funded, the themes that they have addressed and the key global challenges which they relate to.

¹ Those who contributed to this exercise included: Gabriel Anandarajah, Simon Batchelor, Subhes Bhattachyra, Ben Campbell, Ralph Gottschalg, Jon Leary, Yacob Mulugetta, Dave Ockwell, Mirjam Roeder, Patricia Thornley, Britta Turner, Jem Woods.

Table 1: Database Categories

Technology	Application	Type	Challenge	Scale	Location
Biofuels	Lighting and other Small Appliances	Technology	Energy Poverty/Access	Global	Free entry of countries/regions
Solid Biomass	Agriculture	Policy and Regulation	Energy Security	National	Not country specific
Biogas, AD and gasification	Large-scale Industrial/Commercial	Governance	Transport	Regional	
Wind	Small/Micro-business	Modelling	Gender equity	City	
Solar PV	Heating	Socio-cultural Practices	Biodiversity/Conservation	Neighbourhood /Community	
Solar Water Heating	Cooling	Knowledge Systems	Agriculture	Household	
CSP	Communications	Health and Well-being	Air Quality	Inter-Scalar	
Natural Gas	Transport	Business Models, Finance and Economics	Climate Change Mitigation		
Marine	Waste Management	Political Economy	Climate Change Adaptation		
Geothermal	Water Management, Pumping and Treatment	Education and Capacity Building	Refugees / Displaced People		
Hydro		Environmental Management	Economic Development		
Fuel Cells and Hydrogen		Communications	Sustainable Water and Waste Management		
Clean Cooking			Socio-Technical Transitions		
Energy Storage					
Energy Efficient Buildings					
Heat recovery					
Appliances					
Power Networks and Components					
Communications and Payment Systems					
Project Development Support					

The database reveals that most UK-funded research on low carbon energy and development themes has focused on energy access and energy poverty. Environmental challenges, such as climate mitigation, air pollution and conservation, are also strongly represented. (see Figure 1). Although it is not the focus of this report, several projects also addressed broader economic development objectives along with poverty alleviation aims.

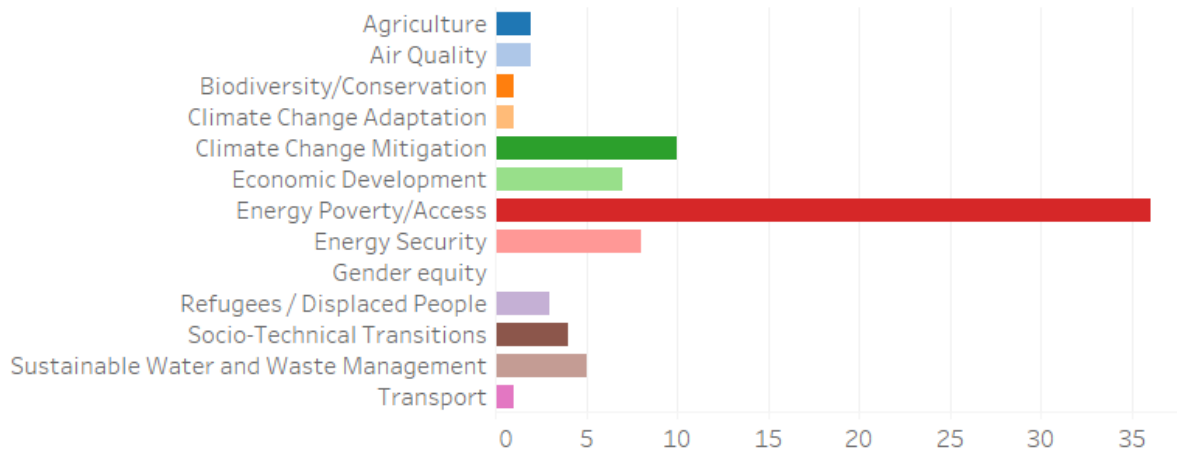


Figure 1: Projects by primary challenge

The research portfolio has a strong technology focus, i.e. projects tend to focus on the development of a specific technology or technologies, but socio-cultural, policy and business perspectives are also well represented (see Figure 2). Of the technology-focused projects, the database reveals a particularly strong emphasis on solar and bioenergy solutions (see Figure 3).

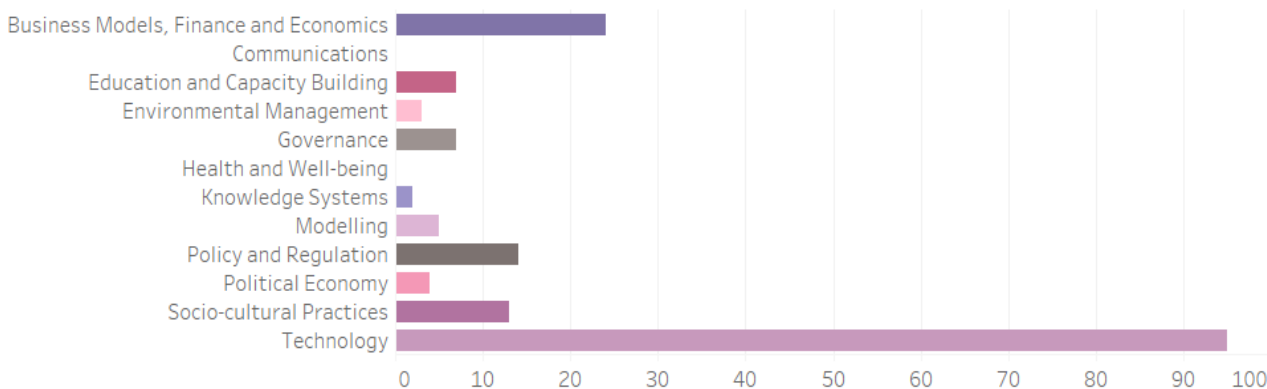


Figure 2: Projects by research type

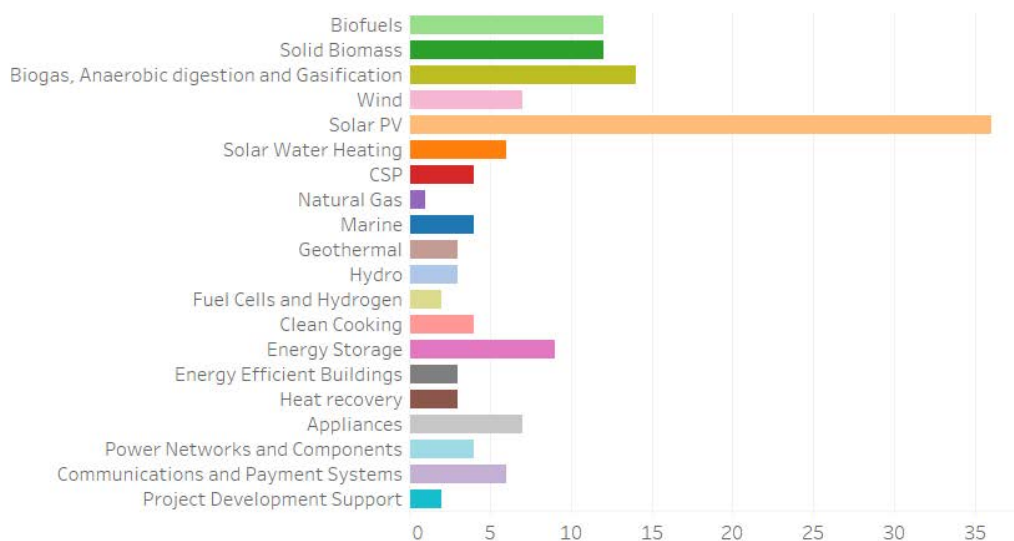


Figure 3: Projects by technology

Major funding sources for the projects that we have reviewed include Research Councils UK, DfID, BEIS (formerly DECC), Newton Fund, the Energy Catalyst programme of Innovate UK, and learned societies (Royal Academy of Engineering and British Academy). The largest interventions have included: an Engineering and Physical Sciences Research Council (EPSRC)-DfID collaboration which funded two large projects at Southampton and Dundee (which then moved to DeMontfort) respectively;² a DfID/EPSRC/DECC collaborative programme which is funding 13 projects between 2013 and 2018 and the last two rounds of Innovate UK's Energy Catalyst programme which have included collaborative funding from DfID. More recently this portfolio has begun to be expanded under the Research Council's GCRF initiative. These major funding schemes have also been complemented by a number of smaller funding sources, for example PhD Studentships funded by NGOs or the private sector (e.g. BBOX, SolarAid), public engagement funds and university-specific funds to encourage international collaborations.

2.3 KEY THEMATIC AREAS

The following section draws together analysis of the projects database with insights from a series of commissioned reflections on the current state of research within specific fields of energy research by experts within those specific fields. We present this analysis under a number of broad categories largely reflecting the technological/thematic orientation of the research. As suggested from the list of classifications outlined in Table 1, we recognise that there are a variety of different ways in which the discussion could have been organized but this seemed to be the most effective way of illustrating the general trends in UK research in this area for the report.

We begin with the two areas where most current research activity is focused – solar PV and bioenergy research. Whilst grid extension will undoubtedly play a role in meeting global energy access objectives, it is also clear that there will need to be a considerable expansion in off-grid energy provision. Some sources (e.g. IRENA, 2015) have suggested that as much as 60% of the investment needed to meet global energy access and carbon reduction targets will have to be directed towards off-grid energy programmes. Solar PV and bioenergy are the two technologies where the most significant research efforts are being expended towards supporting the growth of off-grid provision (see discussions in Section 3).

2.3.1 SOLAR PHOTOVOLTAICS (PV)³

A) RESEARCH OVERVIEW

² Southampton's Energy for Development project: <http://www.energyfordevelopment.net/current-projects/> and DeMontfort's OASYS project: <http://www.dmu.ac.uk/research/research-faculties-and-institutes/institute-of-energy-and-sustainable-development/research-projects/oasys/index.aspx>

³ This section of the report focuses on developments in Solar PV. We don't touch on work concerning solar thermal technology development or deployment/research on CSP (although we would point interested parties to the work being done at Imperial on this through a Royal Society project: http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_28-2-2017-10-12-36). Most work on CSP has focused on large grid-connected possibilities – however we are aware of a few initiatives now looking at the potential of CSP technology at much smaller scales, e.g. in Lesotho: <http://www.stginternational.org/project/pilot-health-clinic-lesotho/>.

There has been a considerable investment in Solar PV research in the UK over recent years which has seen its international status rise considerably; although, as UKERC's 2013⁴ landscape review of UK solar research suggests, the "research landscape..... is much stronger in areas such as materials science and weaker in manufacturing technology and process monitoring." This is reflected, for example, in the thematic make-up of the most important investment in UK solar research, the EPSRC SUPERGEN SuperSolar Hub which launched in May 2012 and brings together researchers from the Universities of Bath, Cambridge, Imperial College, Liverpool, Loughborough, Oxford, Sheffield and Southampton.

The focus on the development of new materials means that much of the solar research funded in the UK has not been particularly relevant to the international development context, although that may change in the future as new technologies reach the marketplace

Some of the work that has been jointly funded by DFID and Innovate over recent years is addressing this area – the development of new materials that might improve efficiency and drive down costs. The conversion efficiency of solar power into electricity using PV technology is currently limited owing to unwanted heat generation and high production cost. The latest developments in solar PV are associated with making PV panels more efficient and at a cost that poorer communities could afford either by changing the material of the PV panel or by introducing a hybrid technology to boost the performance of an existing panel. Examples of relevant Innovate funding include:

- **Reducing the levelised cost of energy for silicon solar cells through a low-cost efficiency-boosting tandem technology – Nava Technology Ltd.**⁵ Nava Technology has developed a nanostructured, hybrid tandem technology that is printed on top of a silicon solar cell and boosts the module efficiency by >3% (absolute value), producing more electricity from the same unit area.
- **Surface Treatment of Perovskite Solar Cell Inorganic Titania Meso-Porous Substrates – Dyesol UK Ltd.**⁶ Dyesol UK Ltd in collaboration with Sheffield University is investigating the potential of developing higher efficiency stable perovskite solar cells (PSC) by improving the meso-porous Titania cathode substrate structures through surface treatment processing. Building on existing perovskite PV material stack technologies; new process methods and the incorporation of improved electronic layers will be explored, developed and tested.
- **Development of Low Cost Alkaline Solar Cells - Solaris Photonics Ltd**⁷ - Solar Photonics Ltd is developing an innovative alkali thin film PV technology (APV). Current funding will allow Solar Photonics to design a high efficiency, low-cost, alkali PV cell, which uses thermal evaporation deposition, switching to an all sputtering manufacturing process in the long term. The proposed APV technology could become highly competitive with the cost of conventionally generated electricity at point of use.
- **Low Cost Copper Transparent Electrode Material (LOCUST) - Applied Materials Technology Ltd**⁸ - Transparent conductive electrode (TCE) is an essential component for solar cells, currently indium tin oxide (ITO) and silver form the TCE. However, they are expensive, scarce materials that tend to degrade in performance. Applied Materials Technology Ltd in collaboration with Cranfield University are developing low cost, sustainable Copper nanowire based TCE for solar cells

⁴ UKERC (2013) UKERC Research Atlas Landscape: Solar. Available at <http://www.ukerc.ac.uk/publications/ukerc-research-atlas-landscape-solar.html> (accessed 23/08/2017)

⁵ <http://gtr.rcuk.ac.uk/projects?ref=700647>

⁶ <http://gtr.rcuk.ac.uk/projects?ref=509338>

⁷ <http://gtr.rcuk.ac.uk/projects?ref=132720>

⁸ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FN50984X%2F1>

Overall, though, much of the work being conducted into new materials remains quite divorced from the solar solutions actually being marketed and adopted in off-grid communities across the Global South, although there are some initiatives that appear to have more direct relevance and are already targeting take-up in 'emerging' markets (one example is Big Solar's Power roll technology).⁹ Instead, most research with direct relevance to Global South contexts has been more applied work looking at the deployment of existing solar technologies at household, community and larger grid-connected levels in the Global South (and the development of new business models, financial modalities and applications) and this has not often been strongly connected to the broader UK solar energy research community which is an issue that certainly needs addressing going forward.

Beyond the specific research on mini-grid and household deployment discussed separately below, those areas where there is some existing crossover between more technologically-focused research and international development contexts and significant potential for expansion include:

1. STANDARDS AND CERTIFICATION.

There remain significant challenges in the development and utilization of national and international approaches to certification including data availability, independence and tensions between quality and usability. Some UK universities (e.g. Loughborough's work in India) have been heavily involved in work designed to address these issues within Southern contexts but there remains considerable work to be done in this area. At the same time, there are also important social considerations to be taken into account regarding usability, cost etc. For example, Edinburgh University have recently developed the Off Grid Solar Scorecard project (an online public database that ranks and rates the qualities of pico-solar lighting products based on their reparability) to explore its relevance to other parts of the solar industry.

2. NEW PRODUCTION PROCESSES.

As suggested above, whilst there is some research in the UK on PV manufacturing technology and process monitoring in the solar industry, this remains of lower quality and less extensive than research into materials. This is surprising in some senses since "the UK also has good strengths across the supply chain from materials supply through to system integration. A common characteristic is the degree of innovation and the number of small as well as large businesses."¹⁰ The nature of production processes and the prospects for Southern countries to play significant roles within future developments within the industry remains an important but under-researched question and there is significant potential for research in this area. Much has already been written about the tensions between the low carbon credentials of solar technologies and the exploitative and environmentally questionable production relations through which they (and their constituent components) are produced and marketed.¹¹ There is some important work to be done in assessing the implications of the development of new materials and new manufacturing techniques in the sector in the light of these debates about the nature of the global production networks through which solar technologies are developed.¹²

⁹ <http://www.powerroll.solar/application/>

¹⁰ UKERC (2013) UKERC Research Atlas Landscape: Solar. Available at <http://www.ukerc.ac.uk/publications/ukerc-research-atlas-landscape-solar.html> (accessed 23/08/2017)

¹¹ Dustin Mulvancy (2013) [Opening the Black Box of Solar Energy Technologies: Exploring Tensions Between Innovation and Environmental Justice](#), *Science as Culture* Vol. 22 , Iss. 2.

¹² Lucy Baker, Benjamin K. Sovacool, The political economy of technological capabilities and global production networks in South Africa's wind and solar photovoltaic (PV) industries, *Political Geography*, Volume 60, 2017, Pages 1-12, ISSN 0962-6298, <http://dx.doi.org/10.1016/j.polgeo.2017.03.003>.

3. PAYMENT SYSTEMS AND AFFORDABILITY.

Alongside the work on household and community solar initiatives which is explored below, UK researchers have also been involved in the development of novel new payment systems, data management and communication software and business models which have been utilised in developments at both scales. This reflects both university research projects to develop the technology, assessment of its utilization¹³ and the development of spin-out companies which have emerged to take advantage of international market opportunities, particularly in the pico-solar sector (the most well know examples being Azuri Technologies and BBOX) and collaborative projects. For example, Africa Power's current Innovate initiative with Southampton University.¹⁴ Their new generation solar home systems are integrated with a portable Pay-As-You-Go (PAYG) key-fob, an innovation that manages payment and data collection, using Bluetooth technology for transmission in remote, low/no connectivity areas. Most recently, a number of projects have emerged to track the potential of using blockchain payments alongside existing projects involving mobile payment systems.¹⁵

B) DIFFERENT SCALES OF SOLAR DEPLOYMENT:

1. MINI-GRIDS.

Internationally, it would appear that we stand on the brink of an explosion in the deployment of relatively small-scale community electricity systems (variously termed mini-grids, micro-grids and nano-grids) as part of the international commitments to the meeting of the SE4All targets. There are a number of established centres/ research groups in the UK who have worked on mini-grid based electrification in South Asia, Sub-Saharan Africa and/or Latin America for a number of years now. Their expertise covers a range of areas.

¹³ Rolffs, Paula, Ockwell, David and Byrne, Rob (2015) Beyond technology and finance: pay-as-you-go sustainable energy access and theories of social change. *Environment and Planning A*, 47 (12). pp. 2609-2627. ISSN 0308-518X.

¹⁴ <http://www.africapowerltd.com/innovation/new-approach/>

¹⁵ See a new Edinburgh University project working in partnership with the GSMA's Mobile for Development Utilities programme and ElectricChain, developers of the SolarCoin Blockchain, which will explore the potential for distributed ledger technologies to accelerate access to off grid solar energy in Sub-Saharan Africa by delinking current business models from existing mobile money payment infrastructures and third parties, creating new models for incentivising and rewarding the installation of off grid solar, and developing new peer-to-peer business models. See <http://gtr.rcuk.ac.uk/projects?ref=EP%2FP031854%2F1>

A number of groups (Southampton¹⁶, Loughborough,¹⁷ Strathclyde,¹⁸ DeMontfort¹⁹ and Imperial²⁰ amongst others) have developed technical expertise to design and develop mini-grids using a combination of generation technologies. There is experience of delivering such projects on a pilot scale in different countries/regions and a good number of overview reports, models (see separate section below) and recommendations have been published. Experience from field level action research has fed into social science driven research on user behaviour, business models, enabling environment and socio-technical innovation systems (the largest and most wide-ranging of these was led by De Montfort University under the EPSRC/DFID-funded OASYS project mentioned above).²¹ The main strengths of these groups arise from the applied research approach taken by most of the groups that tends to be multi-disciplinary in nature. As a consequence, all groups have developed collaboration within the UK and internationally to deliver their projects. Each project has involved local stakeholders and a good amount of knowledge is now available in the public domain.

Nevertheless, the mini-grid development and deployment research effort needs to move to the next stage of development where these solutions can be deployed at scale on the ground, supporting the efforts of the wide range of commercial and not-for-profit actors currently expanding activities in mini-grid development and providing support for pooling the lessons learnt from these experiences (particularly in relation to the forms of governance through which such projects are enacted).²² However, currently there appears to be limited UK research focus on scaling-up or replication efforts. Of course more generally, the experience with bulk deployment of mini-grids remains limited and hardly any successful medium-term examples exist. Despite some emerging relations between UK research teams UK /local start-up companies, the industry-research link in mini-grid research in general remains limited and greater efforts are required to bring the two together to create a thriving public-private partnership model for sustainable growth in the sector. This is one of the spaces where DfID have made some major recent investments, this includes support to the Green mini-grids Africa Regional Facility for Market Preparation, Evidence and Policy Development²³ and most recently the five year Transforming Energy Access research programme (which this report feeds into) that includes a focus on

¹⁶ Southampton's energy for development group are now working on six community projects spanning three countries with three different design models. <http://www.energyfordevelopment.net/current-projects/>

¹⁷ See both CREST's leadership of the £10 million Joint UK-India Virtual Clean Energy Centre (<https://www.epsrc.ac.uk/newsevents/news/virtualcleanenergycentre/>), as well as the SONG USES project led out of Geography (<http://lcedn.com/uses/song/>).

¹⁸ Strathclyde University have been working on a number of off-grid initiatives in Malawi. For example: <https://strath-e4d.com/sogerv-energy-in-malawi/>

¹⁹ See DMU's ESCOBOX project: <http://www.dmu.ac.uk/research/research-faculties-and-institutes/institute-of-energy-and-sustainable-development/research-projects/escobox.aspx>

²⁰ See Imperial's work in Rwanda and Nepal: <http://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Supporting-Rural-Electrification-in-Developing-Countries---Project-Overview.pdf>

²¹ OASYS was an EPSRC/ DfID funded collaborative research project focusing on the development of models for decentralized off-grid electricity generation in Developing countries that are techno-economically viable, institutionally feasible, socio-politically acceptable and environmentally sound. (EP/G063826/2). <http://www.dmu.ac.uk/research/research-faculties-and-institutes/institute-of-energy-and-sustainable-development/research-projects/oasys/index.aspx>

²² See Lorenz Gollwitzer's paper on governing community mini-grids: <http://steps-centre.org/wp-content/uploads/Rural-Electrification.pdf>

²³ See <https://devtracker.dfid.gov.uk/projects/GB-1-204784>

determining the main enabling mechanisms for delivering reliable decentralized modern energy services at scale and how business models and innovative financing can address those market gaps.

2. HOUSEHOLD SYSTEMS/DEVICES.

Alongside the emerging work on mini-grids, the UK also has an established track record on research into the development of and deployment of smaller-scale solar home systems at the household level and pico-solar devices such as solar lanterns. As suggested above, spin out companies have emerged at several UK universities (for example Azuri Technologies at Cambridge and BBOX at Imperial) who have made successful entries into these markets on the basis of effective system design, reliability improvements and in particular innovations in payment systems and most recently in appliance availability.

Alongside more technical research in this area on system design and product reliability, there has also been some important social science work initiated in this area. For example, Edinburgh University have recently initiated a project which ranks pico-solar products not just in terms of their efficiency and performance but also in terms of their ease of maintenance and repair. SPRU at the University of Sussex have conducted studies into both the range of factors involved in the emergence of the Solar Home System sector in Kenya and their replicability and the impacts and dynamics of PAYG systems.

C) KEY EMERGING RESEARCH AREAS

Within the context of the existing body of UK work on solar PV within international development contexts which has been described here, there are a number of important emerging areas of research being taken forward. These include:

1. APPLIANCE DEVELOPMENT

It is becoming increasingly apparent that many of the key questions around the potential living conditions and livelihood enhancement abilities of standalone solar systems or mini-grid developments relate to the availability and affordability of the appliances that can be run on such systems. Recent years have seen the emergence of televisions that can run on SHS and the development of appliances for milling, cooling (for example for milk) and other forms of processing. In 2015, for example, the UK's Department for International Development, working with Innovate UK, ran a competition for UK companies to develop an affordable solar powered irrigation pump. Two companies were awarded up to £300,000 each to develop their prototype and establish a delivery model with ongoing support by the summer of 2018:

- Azur Innovation Limited of Weymouth for the Solar Engine Irrigation System
- The Imagination Factory of London for the Solar Steam Vacuum Pump

One of the major challenges remains the development of appliances suitable for DC mini-grid systems which can operate at much greater levels of efficiency at lower cost but simply don't exist in the marketplace currently.

This is also linked to developments in new forms of demand. For example, across Africa to date there has been very little take-up of the utilization of off-grid electricity for cooking purposes. A current Innovate project involving Gamos Ltd and Loughborough and Surrey universities is looking at the potential market for PV-based cooking under different market conditions.²⁴

2. DEVELOPMENTS IN GRID ARCHITECTURE

²⁴ See the eCook blog at: <https://elstove.com/>

Whilst pilot research projects have explored a range of alternative grid infrastructures, there remains a need for considerably more research into community-appropriate technical elements of mini-grid design regarding system sizing, architecture, network management, monitoring, storage options, metering etc. There is a need to bring together knowledge in assessing the future options for system design (particularly in relation to DC systems), whilst bringing to bear real world knowledge of operating conditions and community needs. This will require explorations of the relative merits of different system architectures, PV generations, yields, reliability and efficiency, energy management systems, metering, monitoring and control challenges and storage options within the context of detailed discussions of the different demand profiles and their social implications within the diverse settings

3. DATA MANAGEMENT

Energy system providers in the UK, both thermal and electrical, have been encouraged to consider the needs of the consumer when developing integrated energy systems. This involves the use of 'big data' to optimize the performance and user experience whilst also helping to reduce the cost of energy. Less work has been done on data in Southern settings but there is some really interesting work now emerging. Research undertaken at DMU and other UK universities is exploring questions of data and its utilization in online system optimisation developments in terms of clean energy generation, storage and demand matching. The use of resource assessment for integration into remote sensing applications that can deliver system health monitoring. This also raises questions regarding access to data and wider questions surrounding data management and utilization and energy planning and governance which are explored below in later sections in more detail.

Steama Co Ltd, for example, is designing a low cost, robust, LPWAN (Low-power wide area network) wireless smart meter & mobile payment system designed explicitly for rural, off-grid sub Saharan Africa. Their system uses emerging mobile technology to connect thousands of energy consumers to mini grid electricity. Using cloud technology, advanced data analytics, PAYG mobile payments & a range of intelligent power & data algorithms, their system will allow the retail of affordable electricity even in the most challenging, remote locations.

4. PLANNING AND GOVERNANCE

The development of new ways of measuring and mapping the geographic location of solar resource and demand (so that the pros and cons of networking can be considered) and the exact timing and any temporal flexibility of resource/demand remain important challenges for mini-grid system developers and for those charged with the management of service development more generally. There is emerging recognition of the need for improved flexibility in system design and greater coordination of mini-grid and household system development within particular regions.

5. DEVELOPMENT OF HYBRID SYSTEMS

There is important research emerging that explores the potential interactions between solar and other energy technologies particularly in relation to livelihood enhancement potential. Hybrid systems have the potential to provide additional and more flexible energy services and contribute towards supply reliability through multiple sources of energy. The dominance of agriculture in many Southern economies provide opportunities to utilize agricultural and other organic waste arising in combination with solar technologies (see the following bioenergy section).

A) RESEARCH OVERVIEW

Bioenergy is perhaps one of the most complicated areas of energy research since it encompasses so many different elements, technologies and scales. Research in this area covers such diverse areas as natural, agricultural and forestry science and engineering, biomass processing, energy conversion technologies, environmental and socio-economic impact assessments and policy analysis. There are a wide range of different feedstocks (both dedicated bioenergy crops and agricultural and forestry residues and organic waste materials) which can be subjected to a diverse array of conversion processes in the production of different energy outputs (power, heat or fuels for motive power). Writing back in 2009 UKERC suggested that “UK R&D activities must be considered to be lagging behind international leaders in this field.”²⁵ Since then there have been considerable research investments and developments, particularly, although certainly not exclusively under the auspices of the EPSRC Bioenergy SUPERGEN hub based at the University of Manchester. Our analysis of the current energy and development research portfolio reveals a reasonable range of bioenergy-focused projects and yet, as one leading Bioenergy researcher argued in responding to our survey, “overall there is very little being done in international development compared to the rest of the bioenergy research scene.”

In other words, despite some significant investments, research on bioenergy within development contexts remains a relatively minor component of the work of most major centres of bioenergy research in the UK. At the same time, globally, whilst there has been some growth in the uptake of bioenergy deployments within African, Asian and Latin American contexts, bioenergy growth has tended to lag behind the substantial acceleration in solar installations over recent years. Support for bioenergy development also tends to be more controversial. Even though traditional biomass use for domestic cooking and heating is one of the main energy provision in the Global South, one of the complicating factors around the establishment of more coordinated approaches towards the development of modern bioenergy interventions across the Global South is that there remains a lack of consensus about the consequential impacts of, for example, the expansion of a more coordinated and potentially commercial biomass provision. This lack of consensus relates to controversies over such issues as:

- 1) the implications of competition for resources between dedicated biomass production and food production (particularly in relation to land and water).
- 2) the impacts of intensified biomass production on ecosystem service provision (e.g. water use and hydrological impacts; carbon stocks; biodiversity; soil degradation), as well as debates over the acceptability of GMOs etc.
- 3) the impacts of bioenergy combustion on carbon emissions and air quality,
- 4) the scale of bioenergy applications and potential beneficiaries along the full supply chain from biomass production to energy consumption

This lack of consensus has yielded multiple, highly visible, public debates and quite different policy frameworks; for example the EU (RED2) and Brazilian perspectives are diametrically opposed in their orientation. This means that the advocacy of bioenergy initiatives remains partial, frequently controversial and subject to change. There have been some very strong recent critiques of current bioenergy policies produced by UK researchers. For example, Duncan Brack’s recent (2017) paper for Chatham House²⁶ claimed that “current biomass policy frameworks are not fit for purpose and require substantial changes to ensure they contribute to mitigating climate change rather than exacerbating it.” This prompted a public response by

²⁵ UKERC (2009) UKERC Energy Research Landscape: Bioenergy. Available at: <http://www.ukerc.ac.uk/publications/ukerc-energy-research-landscape-bioenergy.html>

²⁶ Duncan Brack (2017) ‘Woody Biomass for Power and Heat Impacts on the Global Climate’, Chatham House, <https://reader.chathamhouse.org/woody-biomass-power-and-heat-impacts-global-climate#>

the International Energy Agency's Bioenergy Inter-task group,²⁷ including several noted UK researchers, rebutting those claims. The debate continues but it is worth noting that the very large commitments to LULUCF-based carbon sinks in many of post-Paris NDCs and the role of bioenergy (+ BECCS) in the IPCC 5th Assessment Report and associated modelling mean that bioenergy interventions are likely to have a major role in the future energy strategies across the globe.

Despite the controversies and difficulties, as suggested above there is already a body of UK research being undertaken on the development of bioenergy solutions for meeting energy access objectives, as well as a series of innovations being developed by UK SMEs and university spin-off companies with clear Southern market potential (as, for example, evidenced in the portfolio of DfID-funded Innovate Energy Catalyst projects). In addition, the Bioenergy SUPERGEN has perhaps been the most globally-oriented of all of the EPSRC's SUPERGEN investments and looks set to embrace further international elements within its next five-year programme of activity. At the same time, a major new DFID investment ('Bioenergy for Sustainable Energy Access in Africa' (BSEAA)) is currently in its first year of scoping activities for a £5 million programme of activity (see below).

B) MAJOR RESEARCH AREAS

Existing UK research investments in this area can be divided into a number of different research themes.

1. WHOLE BIOENERGY SYSTEMS AND SUSTAINABILITY ASSESSMENTS.

The UK has a very strong record in research outlining the nature of whole bioenergy systems, the sustainability implications of different bioenergy development options and the role of bioenergy within future energy strategy mapping. There has been some work done in this tradition which has been applied to Non-Western contexts, although most expertise is not focused there. There has been a strong tradition of this kind of work at Imperial, as well as projects based at Edinburgh (e.g. RE-Impact)²⁸ and Aberdeen amongst others.

2. BIOMASS PRODUCTION

Secondly, there is a focus on issues surrounding bioenergy cropping and in particular research into bioenergy feedstock provision and the plant science that promotes it, with particular expertise located amongst others at Rothamsted Research, Aberdeen and Aberystwyth (e.g. a project exploring plant-microbe interactions in sugarcane and Miscanthus for sustainable sugar and bioenergy crop production in Brazil).²⁹ Research is focusing on how to improve the livelihood potential of biofuels via addressing issues such as yields, the costs of inputs and other issues. One current Innovate project (Drygro)³⁰ is exploring producing biofuels (via sealed pod crops) on land that is currently too arid to support crops (with an initial focus on Kenya), reducing the amount of water required to produce biomass by 99% compared to conventional agriculture.

3. SOCIO-ECONOMIC IMPACT ASSESSMENT

²⁷ See <https://www.chathamhouse.org/sites/files/chathamhouse/publications/2017-04-05-IEABioenergy.pdf>

²⁸ <http://research.ncl.ac.uk/cluwrr/ProjectPages/Re-Impact.htm>

²⁹ <http://gtr.rcuk.ac.uk/projects?ref=BB%2FM029271%2F1>

³⁰ <http://gtr.rcuk.ac.uk/projects?ref=132714>

There is also considerable strength in the wider assessment of the social and economic impacts of different types of bioenergy systems, with, for example, research being conducted at Imperial, Oxford,³¹ UCL, Manchester^{32,33} and Greenwich³⁴ amongst others. A recent ESRC project based at Leeds University³⁵ also attempted to move beyond outlining the major concerns over the social impacts of biofuel production to suggest and initiate alternatives. Drawing on the pioneering work of the Hassan Biofuels Park in Southern India, they are encouraging the use of local plant species for energy production alongside, rather than instead, of food crops, improving access to appropriate energy inputs and making locally-focused decisions over conversion approaches which leads on nicely to a discussion of conversion technology and processing.

4. BIOENERGY PROCESSING AND CONVERSION TECHNOLOGY

There is also considerable UK expertise in the processing and conversion of a wide array of dedicated bioenergy feedstocks, residues and wastes to electricity, heat and energy carriers (liquid, gaseous and solid fuels,) via combustion, gasification, pyrolysis, anaerobic digestion (AD), fermentation and extraction etc. Amongst key existing research in this area are: Aston University's work in India via their Pyroformer technology,³⁶ Manchester's work on AD via rice straw³⁷ which has recently spawned an Innovate Energy Catalyst project, Straw Innovations,³⁸ UCL's AGRICEN³⁹ project's work exploring the use of agricultural residues with large agricultural enterprises via a number of different technologies in the sugar, coffee and other sectors. Exeter's hybrid BioCPV initiative⁴⁰ and a further hybrid project funded at Nottingham⁴¹ - both funded under the EPSRC's BURD⁴² initiative emphasize a particular focus on India for research in this area.

The latest developments in AD technologies are associated with reducing the amount of water required for the process, reducing the amount of preprocessing of the feedstock and enhancing the amount of biogas produced by adding CO₂ bubbles to the mix. In a current Innovate project Perlemax Ltd⁴³ are developing around the last of these. The micro-bubbles have beneficial effects on the methanogenesis phase of Anaerobic Digestion. Use of pure CO₂ micro-bubbles has produced over 100% increase in methane production over other AD techniques. The micro-bubbles also assist in mixing the reactor contents and can alleviate the need for mechanical methods reducing the need for maintenance with clear benefits for Southern contexts. Other current Innovate projects are focused on the processes through which the products of AD (and other waste to

³¹ <http://gtr.rcuk.ac.uk/projects?ref=NE%2FL001373%2F1>

³² <http://www.sciencedirect.com/science/article/pii/S0960148117305979>

³³ <http://www.supergen-bioenergy.net/research-projects/rice-straw-project/>

³⁴ <http://www.acpnonfood.com/Project-Overview.html>

³⁵ <https://www.geog.leeds.ac.uk/research/egc/projects/energygardensinnepal/>

³⁶ See <http://www.aston.ac.uk/eas/research/groups/ebri/projects/energy-harvest/>

³⁷ <http://www.supergen-bioenergy.net/research-projects/rice-straw-project/>

³⁸ <http://strawinnovations.com/>

³⁹ <http://www.ucl.ac.uk/steapp/research/projects/agricen>

⁴⁰ <http://biocpv.ex.ac.uk/index.html>

⁴¹ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FJ000361%2F1>

⁴² <https://www.epsrc.ac.uk/newsevents/news/ukindiacolaboration/>

⁴³ <http://gtr.rcuk.ac.uk/projects?ref=132708>

energy processes) can then best be processed. Oaktec⁴⁴ are developing a novel engine capable of running on unprocessed biogas (with, they argue, a step change in efficiency and emissions, reliability and manufacturability), for application alongside a variety of small-scale biogas facilities. Alongside this, there are several initiatives looking to enhance current gasification techniques. For example, Syngas are focused on improving the efficiency of gasification at lower temperatures (i.e. reducing the amount of energy needed), improving the purity of the gas and enabling the system to work with varied forms of feedstock without a reduction in gas produced. The technology has been designed at a small modular scale to be placed locally where the waste arises or where there is a need for fuel.

5. ENVIRONMENTAL IMPACT ASSESSMENT

Another area of significant expertise in the UK is the assessment of environmental and wider sustainability impacts related to bioenergy systems. Environmental impacts of bioenergy systems vary by biomass type, conversion technology and end use. The majority of biomass currently used in the Global South is used in inefficient ways using traditional techniques and technologies. These have often significant environmental and health impacts. While in the Global North a main justification for bioenergy deployments it's its potential for mitigating greenhouse gases. For the deployment of modern bioenergy systems, it is important to understand the lifecycle and wider sustainability implications and minimize their impacts. This applies as much for the climate change mitigation potential of bioenergy as well as wider environmental and sustainability implication, e.g., land use, biodiversity, deforestation, particle pollution. Research conducted by the Supergen Bioenergy Hub⁴⁵ has investigated environmental and lifecycle impacts of a wide range of bioenergy systems considering various feedstocks, conversion technologies, end uses and global regions

6. CLEAN COOKING

One further area of UK research capacity relating to biomass and bioenergy concerns the challenge to accelerate the transition to clean cooking. Despite significant international expenditure on promoting clean cookstoves and the take-up of cleaner fuels such as LPG (where Liverpool University have made a major contribution via their work with the LPG network), progress towards meeting the SE4All goal of transitioning to cleaner fuels remains slow at best. UK researchers have been involved in initiatives in these areas including the University of Edinburgh's PISCES project which looked at charcoal market regulation and clean stove promotion. Nottingham University have also been involved in a number of projects including the BARRIERS project which explored the non-technical barriers to stove adoption and the SCORE project which investigated combining more efficient stoves with the possibility of phone charging: an idea which has now been taken up commercially by several companies, although not without its critics. There are also, as reported in the previous sections, initiatives underway exploring the potential of rapid expansions in the use of electricity for cooking. Finally, there have also been some interesting recent studies by UK researchers highlighting the

⁴⁴ <https://www.oaktec.net/what-is-the-pulse-r-engine/innovate-uk-energy-catalyst-programme/>

⁴⁵ <http://www.sciencedirect.com/science/article/pii/S0961953415001166?via%3Dihub>
<http://www.sciencedirect.com/science/article/pii/S0961953415002081?via%3Dihub>
<http://www.sciencedirect.com/science/article/pii/S0961953415001798?via%3Dihub>
<http://www.sciencedirect.com/science/article/pii/S235248471630018X?via%3Dihub>
<https://energysustainsoc.springeropen.com/articles/10.1186/s13705-016-0070-3>
<http://www.sciencedirect.com/science/article/pii/S0306261916310480?via%3Dihub>
<http://www.sciencedirect.com/science/article/pii/S0959652617302391?via%3Dihub>

difficulties in measuring the health and carbon impacts of clean stove adoption, the most well known of these is the group at Liverpool but there has also been work of this nature undertaken at:

C) KEY EMERGING RESEARCH AREAS

There are a number of potential investments and new research directions in this area.

Recent work by the Bioenergy SUPERGEN suggested a need for further research in order to:

- Further improve knowledge of biomass resources within specific countries and regions
- Further research into new conversion techniques, with particular relevance to those suited to specific regions of the Global South;
- Validation of the performance of the most important feedstocks within specific regions with key conversion technologies
- Strategic analysis of the role of different conversion technologies within the context of hybrid systems in different national and local contexts
- Further work calculating the environmental, economic and social performance of bioenergy systems, considering feedstock and other variations and supporting infrastructure needs
- Evaluate existing and future energy demands relevant to bioenergy systems
- Quantify the impact of bioenergy developments on global GHG emissions
- Analyse relevant ash, digestate and biochar compositions and evaluate their impacts
- Quantify the water impacts of bioenergy systems
- Evaluate the social and economic implications of bioenergy systems to reduce poverty and empower local communities
- Understand the energy demands within its specific context of local communities and identify the role and type of context specific bioenergy systems
- Strategic analysis of the potential to build biomass value chains to support policy and industrial development

This last objective has been taken up within the new DFID Bioenergy research programme indicated above. Following an initial period of reviewing literature and stakeholder mapping, technology value chain prioritisation and case study analysis has narrowed down to a focus on a specific set of countries, technologies and value chains for the four year Phase II research to focus upon. It appears that this will focus on those technologies which are closest to market – with a focus on anaerobic digestion and gasification, with some side research into sub-1 MW steam turbines.”

A) ENERGY STORAGE

Part of the challenge of reducing carbon emissions and increasing the adoption of renewable energy globally is the question of how to deal with the intermittent nature of renewable sources such as wind and solar – the amount of electrical energy they produce varies heavily with time of day, season, and weather conditions. This is an issue for independent off-grid networks as much as it is for larger grid-integrated renewables. In order to smooth out these fluctuations, there is a need for a step-change in the efficiency of energy storage technologies and the need to significantly lower its cost.

Innovations in energy storage are focused on batteries and flow cells (electrical), phase change materials and inter-seasonal storage (heat/cold) and hydrogen (gas) where the hydrogen has been produced from non-fossil fuel feedstock.

Whilst battery cost forms a significant component of off-grid renewable energy networks and standalone system costs, prices have been moving downwards rapidly. For example, while Leach & Oduro (2015),⁴⁶ calculated that the ex-factory price of Lithium Ion Phosphate (LiPO4) batteries would be \$350 per kWh storage by 2020, Kittner et al. (2017)⁴⁷ argue that it should fall to \$200 per kWh by 2019. Battery development has been primarily driven by the electric vehicle market, although they are now also beginning to be used for utility scale electricity storage on grids with 250 MW of storage installed in grids globally in 2015.⁴⁸ Off-grid systems place different demands on batteries that can cause rapid degradation. Ongoing work on battery technology is focusing on how batteries can work most effectively with multiple energy sources (with clear links to work on smart grids and integration research), how to optimise battery life (one of the major unknowns is the degree to which anticipated battery lifetimes will be achieved in diverse climatic conditions), battery safety (particularly as regards lithium ion batteries) and how to make batteries more efficient (for example relating to levels of power discharge or new battery chemistries, such as the lithium air batteries being developed at Oxford). Major centres for research in these areas include Warwick, Oxford, Birmingham and Surrey, although few have focused strongly on applications within Global South contexts.

Some of the latest innovations in this area include: Power Migration Partners⁴⁹ novel low cost flow battery technology. This is a graphite-sulphur Single-Liquid (SLIQ) flow battery. Power Migration has formed a consortium with KERA-charity which is a south Asian charity based in Sri Lanka, to carry out a trial of the prototype of a multipurpose Emergency Energy Supply Unit (EESU) to support disaster relief efforts. When not used as an EESU, this system will be used as an energy storage system in a Solar PV powered computer-training lab to teach essential computer & English language skills to plantation workers. Moixa Ltd⁵⁰ has developed a sodium-ion battery for the storage of domestic solar energy. The stored energy, generated when there are high levels of sunlight can then be used later in the day when demand is at its highest. The attraction of sodium-ion batteries is that they promise to be significantly cheaper than lithium-ion batteries. There is also some interesting work going on surrounding the disposal of batteries when they reach the end of their useful life (a growing problem within the context of the growth of off-grid energy supply).

⁴⁶ Leach, M. & Oduro, R., 2015. Preliminary design and analysis of a proposed solar and battery electric cooking concept: costs and pricing,

⁴⁷ Kittner, N., Lill, F. & Kammen, D.M., 2017. Energy storage deployment and innovation for the clean energy transition. , Nature Energy. 2. nenergy2017125. 10.1038/nenergy.2017.125..

⁴⁸ Frankfurt School - UNEP Centre/BNEF. (2016). Global Trends in Renewable Energy Investment 2016.

⁴⁹ <http://www.powermigrationpartners.co.uk/index.php/en/>

⁵⁰ <http://www.moixa.com/about/>

We do not review work currently ongoing on developments in battery developments as part of wide ranging research on smart-grids and the more effective integration of renewables into national grid systems. There are, however, some developments which may have relevance for smaller off-grid networks. One example is the EMBOSSA project being conducted by the University of Bath⁵¹ in collaboration with Swanburton and the University of Botswana. EMBOSSA introduces a low-cost energy store (based on recycled car batteries and smartphones) sufficient to ensure constant lighting and mobile communications which enables network developers to charge differential rates at different times of the day to encourage consumers to charge their batteries during low cost periods (periods of low network demand).

There is also considerable research activity investigating some of the major alternatives to battery-based storage. The work being conducted under the auspices of the energy storage Supergen explores thermal, cryogenic and compressed air alternatives but again little work to date has focused directly on international development-focused applications. There are, though, a number of DfID-funded energy catalyst projects which are beginning to look at potential developments in this area. Examples include: SunampPV's⁵² phase change storage device designed to store excess electricity from a Solar PV array as heat which can be delivered as fast-flowing hot water on-demand. Helios is developing a combined heat & power energy storage system (TESS). The device will be smart-enabled, and will use off-peak electricity to store heat energy in a high-density medium. The device will use a Sterling motor to generate electricity at peak hours, and heat losses will be used for heating or hot water. The device will also have the ability to store energy from renewable energy sources such as solar PV.

B) GENERATION TECHNOLOGIES

The areas discussed above form the main focus of energy and development expertise in the UK, however the portfolio does include some work that has focused on other technologies.

There has been a long-standing UK involvement in research on hydro-electricity and some of this has explored key elements of large-scale dam developments across the Global South, both in terms of their construction and operation but also relating to their social, environmental and political consequences.⁵³ There has also been a tradition of work on smaller-scale community mini-hydro systems, for example the work being done at Bristol⁵⁴ over recent years.

Despite the growth in grid-connected wind energy across the Global South over recent years and the large investments in wind energy research in the UK, very little research on large scale wind's deployment or potential in the Global South has been done in the UK. This reflects both a focus on offshore energy research in the UK and also perhaps a lack of interest amongst the major wind-focused research groups. The latest round of EPSRC funding has, however, seen some wind projects funded, for example, Durham University's WindAfrica⁵⁵ project which is exploring the complexities of designing the foundations for wind turbines in unsaturated soils. There has been some work done on small-wind deployments over recent years, much of

⁵¹ <http://gow.epsrc.ac.uk/NGBOVViewGrant.aspx?GrantRef=EP/P030114/1>

⁵² <https://www.sunamp.com/products/sunamppv/>

⁵³ See SOAS's ESRC-funded work on Chinese dams in Africa: <https://www.soas.ac.uk/cedep/research/cgg/> and the IDS broader analysis of hydropolitics in Southern Africa - <http://gtr.rcuk.ac.uk/projects?ref=ES%2FN009908%2F1>

⁵⁴ <http://www.bristol.ac.uk/engineering/research/em/research/pico-hydropower/>

⁵⁵ <http://gow.epsrc.ac.uk/NGBOVViewGrant.aspx?GrantRef=EP/P029434/1>

which, for example at Strathclyde University,⁵⁶ has been associated with the Wind Empowerment association.⁵⁷

Another area where there are significant pockets of UK research expertise is in the area of geothermal generation. This is an area of significant interest since there are ten developing countries in the top fifteen geothermal producing countries - examples include the Philippines, Kenya, Indonesia, Mexico and several Central American states. Our focus here is on smaller-scale off-grid energy research but there has been some long-standing research on grid-connected geothermal conducted by teams at Glasgow⁵⁸ (their latest project explores a novel geothermally sourced-combined power and freshwater generation technology. Alongside this there is also interest in the idea of small-scale community-focused off-grid geothermal systems. Imperial,⁵⁹ for example, are working on this with colleagues in China via Newton Fund project funding.

Finally, large-scale wave energy developments are not of particular interest for our purposes here and there has been little research work done on the potential of small-scale wave energy within community energy systems in the Global South. Although new projects being developed by the University of Plymouth⁶⁰ and Tide Mills⁶¹ in collaboration with the University of Cape Town are beginning to explore this option for coastal communities.

⁵⁶ See, for example, <http://windempowerment.org/market-assesment-working-group/>

⁵⁷ <http://windempowerment.org/>

⁵⁸ <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P028829/1>

⁵⁹ <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R005761/1>

⁶⁰ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FP017088%2F1>

⁶¹ <http://gtr.rcuk.ac.uk/projects?ref=132492>

2.3.4 ENERGY MODELLING

Alongside expertise within specific energy technologies, the UK academic community also has demonstrable modelling expertise in the area of off-grid energy access. The main strengths of these groups arise from the existence of a core set of modellers within a number of research groups. For example, UCL and Surrey have a long-standing focus on their respective modelling activities. The research attracts Masters and doctoral students to work on projects in these areas, thereby creating further capacities to sustain such efforts. The involvement of international students brings the international focus and local knowledge.

The current expertise covers the following areas:

- 1) Techno-economic analysis of energy systems: Published research indicates that a number of groups have applied tools like HOMER to study the techno-economics of renewable energy-based rural energy systems. These involved simulations of specific cases and development of ideas to enhance modelling performance.
- 2) Economic and econometric analysis of rural energy issues: A number of groups are involved in using standard economic toolkits to analysing primary/ secondary data from fields to understand the economic aspects (willingness to pay, demand analysis, socio-economic impacts, etc.).
- 3) Decision analysis: A few groups have applied/ developed tools for decision support systems to investigate performance of projects/ programmes and analyse drivers affecting them. Multi-criteria decision analysis appears to be used in these cases.
- 4) Demand analysis: There is some expertise in analysing rural energy demand. The research in this area appears from time to time but there is no continuity. Some studies do not specifically focus on rural areas but are broader in their approach.
- 5) System-wide analysis: The Rural Energy Model at Sussex and the WholeSEM modelling approach at UCL capture the wider national or regional picture. They often consider an integrated analysis of all energy systems which introduces a concern to model the relationship between grid and off-grid provision and also connects into the complexities of subsidization.

However, there are also significant gaps in modelling expertise.

- a) UK researchers have not published regional/ global level modelling studies to analyse rural energy access issues (in contrast to studies by Columbia University, KTH in Sweden, UC Berkeley).
- b) The recent trend of GIS-enabled modelling does not appear to have caught UK researchers' imagination yet. Spatial modelling studies (at the country or regional levels) are important for planning purposes and for decision support.
- c) The modelling effort appears to be dominated by engineering, followed by some engagement of economists. There is limited involvement of other disciplines, particularly business and other social science disciplines (an issue which we return to below) which means that too little thought has been given to how modelling outputs will be utilised and by whom.
- d) Modelling activities involving wider development agenda appear to be missing.

As a result of the weaknesses in this area, the visibility of UK academic research on rural energy modelling appears to be relatively limited. There has been limited investment in developing and consolidating UKJ expertise in this area. Funding for improving local data availability and data quality, demand analysis and open access tools for analysis could be considered for improving the impact and applicability of the work done in this field.

2.3.5 ENERGY EFFICIENCY

Most research on energy and international development issues has tended to focus on the question of how best to bring affordable modern energy services to those that are currently excluded. Nevertheless, the SE4All targets also focus on making significant improvements in the efficiency of the systems which generate, distribute and utilise that energy. Clearly, there are huge potentials to increase energy efficiency in developing countries in residential as well as industrial sectors. There has long been a focus on improving the energy efficiency of cooking stoves (as discussed in the bioenergy section) and lighting (via the development of more energy efficient light bulbs and so on); both of which have been identified as relatively low hanging fruit. There is, however, significant potential for research on other elements of energy efficiency including, for example, building design and human comfort (particularly in relation to cooling and heating), the energy requirements of appliances (both for domestic use, e.g. televisions, laptops, fans etc. as discussed above and commercial, e.g. refrigeration etc.), industrial processing, the performance of electricity generation and distribution systems themselves and so on.

This is an area where there is considerable research expertise within the UK context (the RCUK Energy Programme (in collaboration with the Manufacturing the Future Programme) has committed over £30 million to the establishment of six End Use Energy Demand Centres, and a further £13 million has been committed by industrial partners; whilst further resources have given rise to the various projects encompassed under TEDDI-NET).⁶² Nevertheless, with the exception of work on building design and certification (e.g. collaborative projects with India at Loughborough⁶³ and with a variety of international partners under Warwick's ELITH project)⁶⁴ and consumer behaviour, certification and labelling schemes for energy products (e.g. like that undertaken by UCL's MECON⁶⁵ project) very little of this expertise has been deployed in exploring questions of energy efficiency within the diverse settings of the Global South. Although there has been some important research on the role of local authorities and local planning in relation to energy efficiency (and sustainable energy development)– an issue which was central to the work conducted under the SAMSET project which looked at the applicability of lessons learnt from Cape Town in that regard for urban governance in Uganda and Ghana.⁶⁶

There is certainly a need for further research investments in this area, particularly when connected to developments described elsewhere within this review. There is a need, for example, for research focused on understanding the market barriers to the take up of more efficient technologies and approaches and providing technical support (maintenance) in rural areas in addition to information and finance. Another issue is the quality of electricity supply (voltage fluctuation) which can damage household appliances and make more expensive efficient appliances uneconomic as their lifetime is shortened due to voltage fluctuation. So, further research is necessary to understand how the quality of electricity supply tends to affect the uptake of more efficient appliances. In those countries where the quality of the power supply is very low with high voltage fluctuation, we need to generate evidence on how this might affect the behaviour of consumers.

Finally, one of the most intractable problems relates the impacts of the spread of air conditioning in urban areas and its role in accentuating the so-called heat island effect. Cooling is also important in rural areas where the demand for fans is an important part of household energy demand. In both contexts there is a need for more complex and effective thinking on how to deal equitably with the demand for cooling. As we argued a few years ago in one of the LCEDN's rapid reviews for DECC, "cooling demand should be incorporated into an

⁶² <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L013681/1>

⁶³ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FP029450%2F1>

⁶⁴ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FL002604%2F1>

⁶⁵ <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L002485/1>

⁶⁶ <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L002620/1>

overall urban cooling strategy that mobilizes and empowers the urban population. As a consequence, technology (even renewable technology) is one component in overall albedo-reduction through 'cool community' mobilization strategies. The most important part of deploying these strategies in cities where the vast majority of the built environment is informal and unplanned is including and facilitating the participation of the disenfranchised section of informal urban inhabitants in increasing their own comfort, rather than (for instance) strengthening heat-mitigating codes and regulations.”

2.3.6 SOCIAL SCIENCE PERSPECTIVES

Clearly, there has been some excellent research conducted on energy and development themes conducted over recent years and the potential for significant further funding under such initiatives as the GCRF and DFID's Transforming Energy Access programme look set to further accelerate some of the current directions and also to provide opportunities for research to move in new directions. One feature of the current research portfolio that we have noted in conducting this review is that current research (and this is true of the wider international research picture as well as that relating to the UK specifically) tends to be of two kinds. The first is an engineering focus on the development of new technologies or new forms of deployment of existing technologies; whilst the second approach concerns the methodologies required to take new technological developments 'to scale' via the development of new 'delivery models' designed to accelerate the deployment of renewable energy technologies in pursuit of the achievement of the international access targets. Whilst substantial and important work has been done in these fields, what has largely been missing in this effort has been an adequate appreciation of the broader social context of these interventions.

This predominance of economics and engineering was recognised in a 2012 DFID commissioned systematic review of the literature on energy access⁶⁷ which demonstrated that the energy access literature at that time reflected very little on the vital socio-cultural aspects of the problem and even less on the political aspects. This "scholarly deficit"⁶⁸ is fundamentally problematic and is reflected in a tendency for policy to treat energy access as a problem characterised simply of two dimensions: technology hardware and finance. Why is this so problematic? Because, as recent research on the emerging phenomenon of PAYG solar demonstrates, even when one only considers the financial dimension of energy access, transformative solutions only occur when combined with a grounded understanding of the socio-cultural and political dimensions of energy access.⁶⁹

Far from being a two dimensional problem consisting simply of technology hardware and finance, energy access is at least five dimensional in nature – the other dimensions pertain to socio-cultural and political considerations and the need for a more in depth understanding of the nature of "innovation", understood as processes that lead to the uptake of new technologies in new contexts (in this case, the uptake of sustainable energy technologies by people currently lacking access to sustainable energy). In the five years since the DFID commissioned systematic literature review, a small, nascent literature has emerged that focuses more explicitly on the socio-cultural, political and innovation dimensions of energy access. Whilst some of the expertise behind this research lies overseas, there is also significant emerging capacity in these fields within the UK.

To develop and sustain this capacity, however, significant new social-science specific research funding is needed in this arena. Effective policy interventions (see next section) must start from an understanding of local needs and perspectives that in turn emphasise the need for multiple pathways and ways of linking technology and social objectives - first asking how we should frame the problem of energy access will in turn determine how we think about solutions. Social science aspects of energy and international development research have certainly been present within funded projects in this area but they have frequently been included as 'add-ons' or complementary elements rather than as central to the formulation of objectives and the framing of research questions (for example where social science techniques of user consultation are used

⁶⁷ <https://www.gov.uk/dfid-research-outputs/what-are-the-major-barriers-to-increased-use-of-modern-energy-services-among-the-world-s-poorest-people-and-are-interventions-to-overcome-these-effective-systematic-review>

⁶⁸ Ockwell, D and Byrne, R. (2017) *Sustainable Energy for All: Innovation, Technology and Pro-Poor Green Transformations*, London: Routledge.

⁶⁹ Rolffs, P., Ockwell, D. and Byrne, R. (2015) "Beyond technology and finance: pay-as-you-go sustainable energy access and theories of social change," *Environment and Planning A* 47 (12) pp. 2609-2627.

to mould pre-determined technology-led interventions rather than being deeply embedded within the design of technology and/or the specification of need).

In the context of these more general observations, a few more specific reflections on key issues in different branches of social research follow below:

A) ANTHROPOLOGY

Among social anthropologists approaches to development tend to be informed by historically and culturally situated analyses of regional societies. This mostly leads to research based on holistic understandings of how transformations in political, economic, infrastructure and resource exploitation take shape through meaningful articulations of change with distinctive patterns of inequality and interpretive communities. Particular institutional arrangements and hierarchies of expertise affect the flows, exchanges, and operations of deliberative spheres in relation to technological innovation, and policy implementation in the nationally framed relationships of rural-urban dynamics. This results in anthropologists often being used as the cultural translators for engineers, agronomists, and economists, leaving behind some remarkably rich accounts of why certain development projects have been successful (often for certain sections of society), and others simply not.

It also means that research about energy innovation can often be used to tell informed stories about how societies experience globalisation and appropriate technology for unintended socio-cultural purposes, rather than seek to engage with the story line of sustainable energy transitions more generally. Anthropologists working on energy tend to speak and visit amongst their community of scholarship working on regional histories of development more broadly, rather than among academics in the low carbon research field in itself.

That said, anthropologists have been very influential in contributing to interdisciplinary study. The project on this theme headed up by Dame Marilyn Strathern and her colleagues⁷⁰, has resulted in some of the most quoted passages on contemporary modes and practices of interdisciplinarity. Oxford's QEH hosts many anthropologically informed research activities relating to climate change and resource globalisation. Anthropology is currently undertaking something of an 'infrastructural turn', with very important contributions on roads and water projects in particular involving explicit collaborations in both fieldwork interactions and the theoretical framing of engineering social worlds. Manchester, Sussex, Durham and UCL are particularly strong in these directions. More generally 'resource materialities' are now popular anthropological themes.⁷¹

The IDS at Sussex and the STEPS centre have significant momentum of expertise on Africa's rural transformations and processes of corporate landgrab, some connecting to biofuels in particular. Aberdeen and Canterbury have very strong experience of working on indigenous environmental knowledge and conservation processes, with attention on the lived experience of the consequences of environmental policies circulating with both finance and new knowledge resources attached. Both these anthropological institutions have substantial experience of interdisciplinary team work with natural scientists. Finally, Edinburgh have initiated a number of fascinating projects over recent years looking at exploring attempts to find value in poor

⁷⁰ <http://www.researchcatalogue.esrc.ac.uk/grants/RES-151-25-0042-A/read> See also Strathern, Marilyn, Barry, Andrew, Born, Georgina and Weszkalnys, Gisa (2008) 'Logics of interdisciplinarity', *Economy and Society*, 37: 1, 20 — 49 : DOI: 10.1080/03085140701760841

⁷¹ A much-cited collection in this respect is Richardson and Weszkalnys, (2014). 'Introduction: Resource Materialities. *Anthropological Quarterly*, 87(1), 5-30.

people's energy data,⁷² the social and material relationships that constitute infrastructure⁷³ and qualitative approaches to energy infrastructures in refugee camps and settlements across sub Saharan Africa.⁷⁴

B) SOCIO-TECHNICAL TRANSITIONS

Another key area of socio-cultural research capacity is work that brings insights from the field of socio-technical transitions (a strand of innovation-based research) to bear in the context of energy access. Some of this research also usefully bridges socio-technical transitions thinking with an explicit focus on the political economy of energy access. This research is concentrated at the University of Sussex, in SPRU (Science Policy Research Unit), the Department of Geography, Department of International Relations, the Institute for Development Studies and the ESRC STEPS Centre, although there is also emerging research on these themes at other research centres.

C) GOVERNANCE AND POLITICAL ECONOMY

A third key area regards the politics and broader political economy of energy access, as well as studies of governance. With regards the latter, there has been significant research done on the governance of clean energy transitions and institutional analysis of energy systems at UEA⁷⁵ and Sussex. There has also been some recent work done on multi-level governance. For example, Loughborough's READ project⁷⁶ focused on the relationships between political decentralization and energy access; whilst the SAMSET⁷⁷ project at UCL has made a major contribution to understanding the role of city governance in promoting low carbon energy transitions. Beyond academia, colleagues at ODI and IIED are testing models and documenting experiences of governance across various countries (e.g. Vietnam, Tanzania, Morocco, South Africa). More recently, some good work has been done looking at the PV market (Sussex, Southampton, Imperial, UCL), but has so far been limited in depth and geography, focusing mainly on Eastern Africa. It's worth mentioning also that the institutions & governance work across the UK seems focused on grid-based and small off-grid systems; but little on mini grids

The area of how institutions limit the emergence of mini-grids as viable options and the type of governance conditions for their widespread uptake is neglected. Part of the challenge may be that UK research funders and the decision makers suffer from an ideological lock-in, and so institutional and governance work (as they see it) needs to focus on opening up markets and private sector driven interventions and insufficient attention to other non-market incentives. This approach does not quite fit neatly with mini-grids. Even the huge amount of public sector reform work across the 'consultancy community' in the UK takes a narrow view of private sector participation (at all costs) and little in the area of strengthening public administration – a prerequisite for healthy private sector participation. There is a need also to strengthen connections to the growing literature on the energy, water and food nexus, particularly as regards strengthening governance systems that can effectively deal with such complexities. There has been some recent funding devoted to research initiatives in this area but few have contained strong governance components

⁷² <http://dataforall.io/>

⁷³ <http://www.lifeoffthegrid.net/>

⁷⁴ <http://www.displacedenergy.com/>

⁷⁵ <http://gtr.rcuk.ac.uk/projects?ref=ES%2FF037260%2F1>

⁷⁶ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FL002469%2F1>

⁷⁷ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FL002620%2F1>

In the case of political economy, researchers (at Sussex, Durham,⁷⁸ IDS, Kings,⁷⁹ Open University and Greenwich amongst others) have made important contributions to studies of the international geopolitics of energy, although there is significant scope for extending this body of work to a more explicit focus on energy access, as opposed to the political economy of sustainable energy in developing countries more broadly (we are only aware of one piece of work that explicitly focuses on the political economy of energy access, led by David Ockwell and Peter Newell at Sussex.⁸⁰ This research is being conducted by researchers from across the range of social science disciplines including economists, geographers and political scientists.

D) INNOVATION STUDIES

A fourth key area regards more traditional innovation studies perspectives on energy access, including innovation systems thinking. Several of the Sussex based researchers engage here. There is also highly relevant work being undertaken on inclusive innovation, as well as active participation in the Africalics network on innovation studies in Africa, together with work on sustainable energy access via the STEPS Centre's Africa Sustainability Hub (based at the African Centre for Technology Studies), provide UK access to significant established networks and active capacity building initiatives between the UK and Sub-Saharan Africa.

Beyond Sussex there is also significant research expertise focussing on approaches that bridge the socio-cultural and political dimensions of energy access, at the Universities of Loughborough and Nottingham. This includes, in particular, new thinking that combines thinking from geography with insights from Science and Technology Studies, as well as work between Loughborough and Durham that bridges Geography with Social Anthropology. Nottingham University⁸¹ has also been pioneering work looking at the social barriers affecting the take up of improved cookstoves which has moved analysis beyond research focusing on the design of stoves or the business models being developed to promote them.

It must be emphasised, however, that from the perspective of an explicit focus on the issue of energy access, all of the above work is new and emerging. There is a significant need to invest in bolstering the UK's capacity in these areas, areas which have seen significantly less investment (vanishingly small in comparison in fact) than the economic and engineering dimensions of energy access research – despite the fact that any attempt to “transform” energy access urgently necessitates more sophisticated understandings of the socio-cultural, political and innovation dimensions of the problem.

E) REGIONAL STUDIES

Regional studies associations' memberships with sub-specialisms in development studies have particular skills and analytical competencies of value to the Transforming Energy Access agenda. They have long term understandings of processes of change, and socio-culturally nuanced analyses of post-colonial political capacities for accommodation and adaptation to policy paradigm changes in the context of globalisation. Engagement with this international community, well-partnered already in research relationships, and epistemologically inclined for the knowledge interface in North/South, and South to South can provide a necessary bridge for energy innovation projects.

⁷⁸ <http://gtr.rcuk.ac.uk/projects?ref=ES%2FJ01270X%2F1>

⁷⁹ <http://gtr.rcuk.ac.uk/projects?ref=ES%2FN014138%2F1>

⁸⁰ see <https://steps-centre.org/project/low-carbon-political-economy/>)

⁸¹ <http://gtr.rcuk.ac.uk/projects?ref=EP%2FL002639%2F1>

Being informed about cultures of development expectation and local ways of getting things done can provide significant added value in a project's feasibility, and capacity to be further facilitated toward success by practical savoir-faire, as well as leading to better engagement through conceptually robust approaches to the dynamics of political and economic change in the distinctive social forms of countries and regions.

Examples of Regional Studies Associations included British Association for South Asian Studies, and African Studies Association. Other country-specific communities of scholarly activity such as Britain Nepal Academic Council, and British Association of Pakistan Studies have profound resources of inter-disciplinary development knowledge (health sciences, education, anthropology, geography, political science, archaeology, linguistics etc.), and members who offer willing partners for project design through to appropriate impact evaluation.

F) COMMUNITY-BASED RESOURCE MANAGEMENT

Biomass still constitutes around 75% of poor people's energy resources in many southern countries - the single most important approach to the issue in development studies is broadly termed 'Community Based Resource Management'. Whether concerning coastal zones or forests and rangelands, there is a massive resource of detailed studies of projects and policies that have and have not worked, exploring interventions that have been attempted to alter rights and relationships to biomass energy sources.

There is a wealth of knowledge and conceptual sophistication in this end of the people-environment as compared to the rather thin socio-cultural and socio-technical base of studies focusing on the cook stove debate. There are vital approaches to energy technology innovation by, with and for the poor in this field that include fields of research also labeled Common Property Resource Management, or more critically Political Ecology. These studies importantly challenge the technical bias of some versions of common property resources management that assume a simple and universal technical rationality is at play in these systems.

The reality is often that the social dimension of relationships spanning multifunctional domains of relevance are more important than specifics of technical processes in instrumental terms - the informal institutions of resource governance often defy translation into purely technical logics. It is within these extremely important

G) STAKEHOLDER AND COMMUNITY ENGAGEMENT AND CAPACITY BUILDING.

One key area where the UK has significant capacity, but which hasn't yet been applied to thinking in the field of energy access in low and middle-income countries, is in sociology-based research on the importance of social practices around energy. Several researchers in the energy access field have explicitly noted the transformative potential of research that seeks to understand the social practices of poor and marginalised women and men in consuming and paying for energy, using such understandings as a pre-cursor to subsequent economic or engineering-based interventions. Indeed, Ockwell and Byrne's analysis of solar pay as you go models argues that exactly such a preliminary focus on the social practices of poor people in paying for and consuming energy services is the key explanatory factor in explaining pay as you go solar models' success (Rolffs et al., 2015).

The RCUK funded DEMAND (<http://www.demand.ac.uk>) energy research centre at Lancaster University, has pioneered new thinking on the significance of research on social practice for energy policy. To date, however, this has principally focussed (as with energy research globally) on developed or rapidly emerging country contexts. New thinking that brought this social practice focus to bear in low and middle-income contexts, focussed on the social practices of poor and marginalised women and men in paying for and consuming energy services could hold potentially transformative potential.

As with all of the areas noted above, however, realising this would require significant new research investment in (non-economics based) social science research on energy access in the UK. The UK has huge potential to contribute, but existing research funding platforms so far look like they will mitigate against any explicitly social science-based research on energy access. For example, GCRF funding so far has explicitly required natural/physical science collaborations with social science. In a field where so much previous investment has gone into engineering and economics, the UK has a significant opportunity to focus on

developing world-class social science research capacity on energy access – capacity which could lead to genuinely transformative energy access solutions in future.

Another key area of activity here has been in explorations of approaches towards community/stakeholder consultation and capacity building (for example via the SONG project at Loughborough⁸² and Nottingham)⁸³ This work has piloted new approaches towards community consultation, communication and partnership in the context of differences in language, educational levels and cultural meanings. This is linked to the development of different approaches towards mechanisms for enhancing the capacity of communities involved in the co-creation of energy projects to develop their ability to manage their own energy systems and take advantage of the livelihood opportunities created.

H) POLICY ANALYSIS.

There is plenty of policy analysis expertise in the UK energy community. Indeed, there is a lot of expertise developed through the UK Energy Research Centre (UKERC), and the Imperial College team in particular has built up a huge track-record in the analysis of policy efficiency, policy effectiveness and policy implementation. Some of these colleagues have been called up to do work for various international organisations such as IRENA. Unfortunately, this crop of policy analysts have not been given the opportunity to extend their work to the developing world (bar perhaps China and possibly India), and transfer their skills, experience and lessons to these parts of the world. So the UK academic community is relatively strong in providing policy analysis on UK and EU policy challenges but little in other parts. There is some policy experience and expertise in energy policy in emerging and developing economies in UK-based consultancies such as Economic Consulting Associates, OPM (Oxford), ATA-Energy, etc. However much of this policy expertise is concentrated in the large-scale (grid based) side of the energy questions. The small-scale and off-grid side is yet to be given sufficient policy attention, both in the practitioner and policy communities – although we are seeing some movement in this area with the emergence of new policy instruments and ‘disruptive’ business models in countries. One suggestion would be to try and bring together the policy communities from the grid and off-grid sides given that we likely to see countries making real policy choices as the incumbent technologies are challenged by new and more flexible options, therefore demanding an integrated approach to policy development and implementation.

⁸² <http://gtr.rcuk.ac.uk/projects?ref=EP%2FL002612%2F1>

⁸³ <https://www.leverhulme.ac.uk/awards-made/awards-focus/making-science-public-challenges-and-opportunities>

3. THE CURRENT UK RESEARCH PORTFOLIO IN A GLOBAL CONTEXT

3.1 INTRODUCTION

The community of low carbon energy for development research in the UK is in some ways a nascent, fragile thing and the heterogeneous assortment of fragmented research ideas we have presented in the previous sections of this report illustrate then difficulties of pulling together the insights from this research portfolio and encouraging connectivity and the emergence of stronger, more transdisciplinary research trajectories. Part of the problem in doing this is the 'siloized' situation in which research funnels in the UK hardly encourage cross-thematic blending of the kind needed for these kinds of far more relevant landscapes. This is ironic, because the 'strengths' in UK research lie in linkage possibilities in disciplines which are currently not working together and enhancing that kind of systemic complexity by cross-fertilizing it with the innovations taking place in the private sector, whereas the gaps/weaknesses are reflected as much in the lack of collaborative initiatives as in the absence of actual research/funding.

This type of research will, however, only contribute to the challenges of securing universal access to a minimum acceptable amount of electricity and clean cooking and accelerating low carbon transitions if it clearly responds directly to the demands and needs of communities and the variety of organizations (be they private, public or third sector) working towards those aims. There needs to be a much stronger focus on the demand for research, real palpable demand that would have direct impact as well as commercial relevance. To meet that demand, however, we would argue that the currently limited understanding of 'solutions' needs to be broken open and the dominant focus on technology re-directed towards a strengthening of socio-technical understandings of social energy systems. The value of this type of perspective lies as much in how to persuade project designers, research councils, funders and the private sector to think in this kind of transcalar, interdisciplinary way as it does in analyzing the correct payment and financial models, although it clearly has a contribution to make here as well. This is illustrated well by the case of the spread of mobile phones and mobile payment systems in Africa, for instance, where mobile designers and providers were as blindsided by popularity of the technology as anybody else, because of the entirely different use values accorded the technology across rural Africa from those in the Global North. Ironically the mobile has now become the symbol of the potential of technology amongst the very technical specialists who had/still have little idea why it would become so successful in the first place.

Realizing the goal of developing this kind of research community has been the *raison d'être* of the LCEDN but we recognise that this will be a lengthy process. This section of the report contributes to this intention by exploring the UK research and innovation portfolio in the light of the articulated needs of communities and businesses in the global South. Mapping the activities of entrepreneurs currently deploying potential solutions provides perhaps a useful perspective on where opportunities and challenges lie. This section includes an analysis of a database of grant-funded enterprises/projects which has been compiled by E4I and a view of where the promising areas of research to support replication and scale-up appear to be according to the experiences of the communities and organizations that E4I work with. This shows the main areas where people are trying to commercialise application of a technology and so demonstrates where there is a synergy between UK funded research and innovation and what is happening on the ground.

3.2 ANALYSIS OF CURRENT GRANT FUNDING FOR COMMERCIALISATION OF ENERGY TECHNOLOGIES

The database has been built from data from a number of international grant programmes that fund innovation and scale up in the energy access sector. The list is not exhaustive and focuses on Anglophone sources. It includes the Energy and Environment Partnership Africa (EEP), Africa Enterprise Challenge Fund (AECF), Renewable Energy and Energy Efficiency Programme (REEEP), Private Financing Advisory Network (PFAN), Scaling off-grid energy development challenge (SOGE), Powering Agriculture, Development Innovations Ventures Program (DIV), Transform, Global Innovation Fund, Innovations against Poverty, Mobile for Development (M4D) Utilities Innovation Fund, DEG Upscaling and the DOEN Foundation. Where a fund

focusses on more than one application or area, only the energy access projects have been included. Projects funded since 2010 are included. An overview of these grant bodies and their funders is provided in the annex along with a number of other initiatives which were not analysed further since they fund more commercial or well established activities.

The analysis is, necessarily, limited by the amount of information available about each project or beneficiary. This varies considerably between different programmes and between different organisations. However, the following analysis provides a good overview of the main focus of current activity on the ground.

A total of 488 projects are included in the database, although some enterprises receive funding from more than one source, or for different stages of their business development. There is a clear geographical focus of the activities in a number of countries in Eastern and Southern Africa (notably Kenya, Tanzania, Uganda, Zambia, Rwanda and South Africa) plus India and China, as shown in 4. The data is partly skewed since countries are determined by the scope of the funding bodies (e.g. EEP Africa accounts for a significant number of projects and only targets Southern and Eastern Africa). However even where the geographic scope is much wider the funding is still focussed on the same few countries and regions.

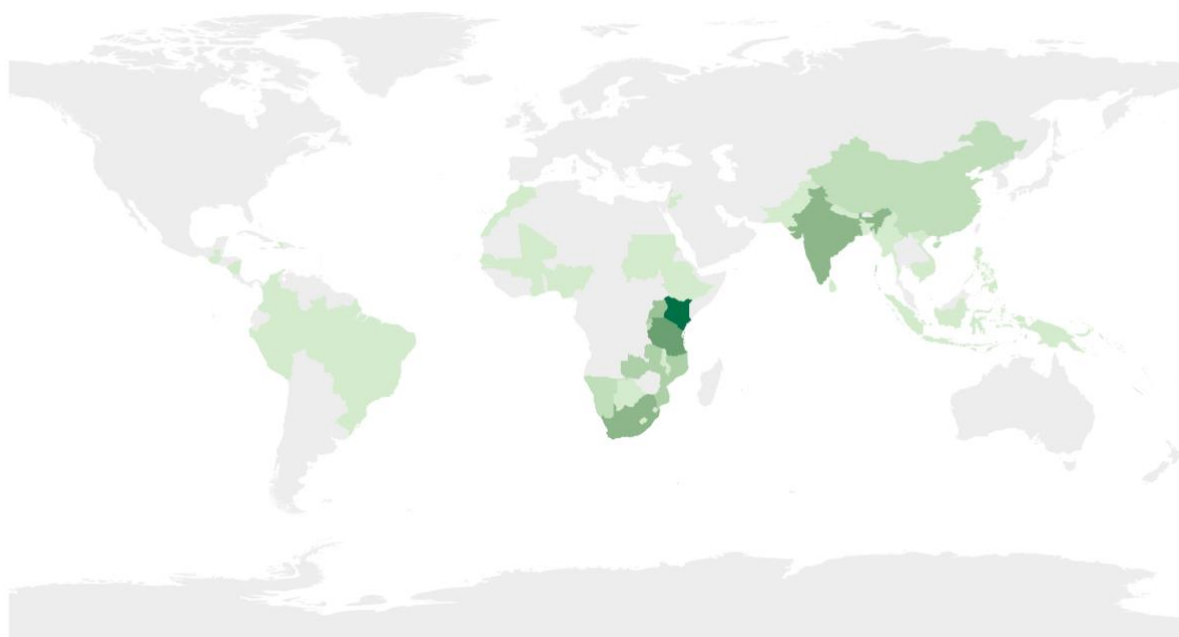


Figure 4: Geographical concentration of enterprise projects

As would be expected from funding mostly targeted at enterprise-related innovation, almost all the funding is available for testing and scaling up of technology and business models (93.4 % of projects). A few projects have focussed on education and capacity building, on policy regulation, knowledge systems and on modelling. Examples of these include funding: to upgrade and improve the capabilities of RETScreen; to develop regional observational wind atlases in Namibia; for *OneShore*, which stimulates small companies and co-operatives in Rwanda to switch to sustainable energy, and guides them through this process; for *Ecosmart* to work with microfinance institutions (MFIs) in promoting and financing renewable energy products; and in another project, funding to provide a plan and policies to support the wide-scale implementation and replication of renewable energy biogas (from tofu) in Indonesia.

Our analysis shows that solar PV dominates as a technology with bioenergy also receiving significant support: 41 % of the grants include a focus on solar PV whilst 32 % of grants include a focus on some form of bioenergy. These contrast with support for solar thermal (3.3 % of projects), energy storage (1.8 % of projects) or power networks and components (1 %). Part of the reason for this could be that solar thermal and some energy storage is more applicable to large scale grid connected projects rather than decentralised systems. (although there may be some under-estimation of storage focused projects since some solar projects will involve the development of innovative batteries). Further details of the key areas are provided in 5. Most projects are focussed at off-grid technologies and applications but about 12% of projects relate to grid-connected projects.

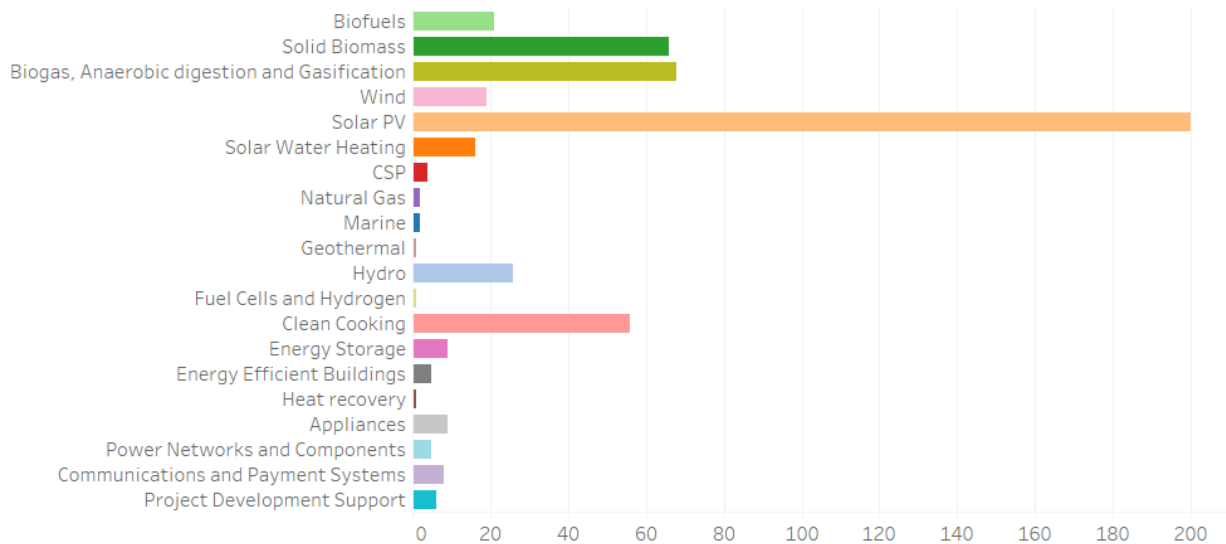


Figure 5: Enterprise projects by technology area

A few projects defy categorisation but are interesting nevertheless. For instance, support is being provided to Genziko to install and operate 1km of Roadway Power Generation System using its own patented vibrational energy harvesters embedded in the road surface.

As mentioned above there are a number of enterprises which have received funding more than once. Notable examples include: BBox Ltd with two sources of financing; Off-Grid Electric has received funding from at least three different sources to finance evidence finding, and scaling up; Orb Energy has received funding from four different sources; Husk Power has received at least three different sources of funding covering two geographies; d.light from four different sources but covering different geographies; Fenix International has received three sets of funding for its PAYG solar business and one for technology development for its biomass cookstove technology; Gham Power with two sources of finance; Global Supply Solutions with three funders; Simgas from three different sources covering a number of counties; and Simpa Networks receiving funding from four different sources.

3.3 SOLAR PV

3.3.1 HOUSEHOLD SYSTEMS

Solar PV systems for domestic energy supply is the largest funded area with most of the activity taking place in Kenya, Tanzania, Uganda, Rwanda, Zambia, South Africa. Most of the grant funding is directed towards pay-as-you-go (PAYG) models selling Solar Home Systems (SHS). In the vast majority of cases the grant funding is used for testing business models and finance rather than focussed on the technology. This money is targeted at early stage commercialisation so split between pilots, demonstrations and scale up. For example, grants have been used to test or demonstrate economic viability and scalability of business models (e.g. Orb Energy selling through banks and MFIs), for testing payment methods (e.g. PEG Africa is piloting three different payment tools to assess the greatest potential for scale) or testing sales and marketing material (e.g. Angaza). In some cases, money has been used to expand distribution networks into new areas (e.g. Greenlight Planet, Vitalite, d.light).

On the more technical side, examples of grant funded enterprises include: Product Health Ltd which is testing the value of remote monitoring and smart batteries for producers and distributors of SHS; NewLight Africa focusing on software development to facilitate agent-based sales networks; iD solar solutions looking to assemble solar solutions in Zambia; and Solar E-cycles which is finalising its design from three prototypes of

innovative transportation device, E-Cycles, which, with its storage batteries it is also a micro solar power station.

3.3.2 SOLAR PV MINI-GRIDS

Approximately 30 projects including solar PV mini-grids (some hybrids) have received grant funding. There is a mix of DC and AC models supported. As with the household systems almost all the funding is directed towards testing the business model and financial viability of one-off mini-grids in pilots and demonstration projects (e.g. Deveryg and Neseltec Ltd). There are a few exceptions looking at scaling up, for example Powerhive, or Mera Gao Power received funding to construct and operate 40 new village-level micro grid to provide realistic evidence on how a network of low cost micro grids may operate at scale.

3.4 BIOENERGY

3.4.1 SOLID BIOMASS

Funding for solid biomass focusses on the manufacture of briquettes, pellets, green charcoal and bio-char made from locally sourced agricultural, forestry and municipal waste. Only a few projects focus on invasive species for green charcoal or briquettes (e.g. Startle Ltd). Almost all the support is for pilots and demonstrations plus scaling up the capabilities. The customer base for the product is not always clear but is a mix for domestic use and industrial customers. There are also a few solid waste combustion projects for power generation.

3.4.2 BIOGAS AND GASIFICATION

Approximately 66 projects have received support for biogas, or gasification technologies. Support for biogas is mostly focussed on waste management and agri-processing with some targeted at gas supply for cooking/electricity for household, community or institutions, or electricity generation. The agri-processing includes using waste from coffee pulp and husks, fruit, soybean, tofu, chicken litter and cow manure. The biogas is used for local heat demand for agri-processing and in some notable cases for chilling, particularly for the dairy industry. At least four projects are focussing on this area: SimGas is developing a biogas-powered milk chiller whilst the University of Georgia is developing a biogas-powered evaporative cooling solution for the dairy industry in Uganda. Heifer International and Q Consultants are also testing this area. Funding received will test the viability of these solutions.

The majority of the support is focussed at feasibility and demonstration of biogas, particularly looking at the technology in different situations, but also testing business models. For example, Q Energy supplies prefabricated bio-gas systems for cooking and electricity production for domestic use and is testing a lease purchase business model and Takamoto Biogas is also testing a lease-to-own model.

A handful of projects are supporting gasification technology. The support is testing technologies as well as business models or assisting in the financing (e.g. Nexus C4D is setting up a revolving fund to provide affordable loans to rice mills to switch from diesel electricity generation to rice husk gasification). One project is focusing on agricultural waste (Chapter 6 Ltd) and one on gasifying pine needles (Avani Bio Energy). A few projects will distribute electricity (including B2D and Husk Power).

3.4.3 CLEAN COOKING / BIOMASS COOKSTOVES

About 79 projects have some focus on energy efficiency biomass stoves. The funding supports some (but limited) technology development but is more focussed on scaling up manufacturing capabilities (e.g. BURN, EcoSac), demonstrating the technology, some testing of business model ideas such as Potential Energy's

project assessing different marketing strategies, or scaling up distribution, e.g. Envirofit's rural marketing and distribution.

3.5 PRODUCTIVE USES OF ENERGY

For the purposes of this analysis productive uses of energy implies manufacturing, processing, including agriculture, water and waste management rather than small scale and micro business income generation (such as small commercial businesses). Approximately 12% of the projects supported involve agriculture whilst 3.5% support large scale industrial businesses. Almost all these projects use either solar energy or bioenergy.

A large proportion of the agricultural related projects relate to irrigation (e.g. Sunculture, Futurepump, ECO Consult, Earth Institute, Kickstart International and Claro Energy). One project is developing hybrid vehicles which allow power for community based agricultural mechanisation (Motivo Power) and another is installing solar mills in villages to process staple crops, such as rice, corn, and cassava (VIA). As above, support is either for technology development or to test business models (such as leasing of solar pumps). Support for large scale businesses is through power generation, waste management or energy efficiency. A number of projects use solar energy for water treatment

3.6 PROMISING POTENTIAL

Based on reviewing the grant funded projects (above) and linking to what is currently funded in UK innovation and research, areas with promising potential have been identified. Since the grant funds are focussed off-grid this is the area included here. From published data it is very difficult to understand how successful many of these projects have been. Therefore a number of conversations have been held with some of the grant bodies to gain their views on how they have evaluated their own effectiveness and how they select what to fund next.

Although much of the UK research and innovation is targeted at upstream technology development, research targeted closer to market and more relevant to the Global South, is aligned well with that funded through the grants analysed here. There is particular research capability around PV household products and PV (and hybrid) mini-grids. Specifically, we see promising potential as follows:

- Grant support for PV household systems is generally working and the enterprises are expanding and moving towards commercial financing. However further advances in the technology (lower costs batteries, cheaper more efficient panels) would help scale up and drive the market. Further research into impacts of policy on the markets could also help replication.
- Support for solar PV mini-grids is fairly aligned and is still focused on pilots with many of these models or demonstrations still commercially unproven. Further cost reductions in the technology would help the viability, as would greater demand stimulation. Results from previous social science research on user behaviour, enabling environments etc. could help if fed back to enterprises trying to commercialise these models beyond pilots. Research work in grid architecture, data management and hybrid systems all looks promising with potential impact.
- Increasing efficiencies and bringing down costs of components (e.g. batteries) or appliances has promising potential across the whole sector. There is already work being funded in UK innovation with widespread applications (e.g. smart wireless electricity meters, UPS systems)

In bioenergy there is some alignment between research and what is happening on the ground, relating to conversion technologies and clean cookstoves although, there seems to be a disconnect between the two communities, more so than in the more commercial solar markets. Some of the innovation support could be directly applied to the Global South now (e.g. R2B). The new DFID programme is currently scoping its potential activities and it looks like there will be a focus on AD and gasification for commercial scale deployments. In that area a review of projects and technologies needs to be undertaken so that we really understand what is viable at different scales and in what contexts (e.g. grid tied projects in Namibia and Kenya using invasive species as feedstock, or gases used for heat in agri-processing). It is not clear if domestic biogas has proved its viability in sub-Saharan Africa, nor small-scale gasification. We see promising potential in some

commercial biogas (for heat and power), and clear potential for developing technologies for specific (or mixed) feedstocks.

For solid biomass a review is needed of whether pellets and briquetting for domestic use is really viable at scale and to be compared with briquettes for commercial customers or for generation for the grid (or mini-grid). What are the wider implications for the use of invasive species which seems to be working in some areas? There are interesting enterprises working in both these spaces but it is unclear what the real future potential is.

4. OPPORTUNITIES: AREAS FOR FURTHER RESEARCH & INNOVATION

4.1 INTRODUCTION

Based on the current status of commercialisation and a review of the current UK research portfolio, this final section of the report examines the context in which energy access research needs to take place and some of the themes that, from the available analysis and information, seem to be missing in the current research, innovation and commercialisation space in the UK. Some specific suggestions, frequently related to individual research areas, have already been made in earlier sections. Here, we focus more on some of the wider themes and questions which might link those areas.

4.2 RESEARCH AND INNOVATION IN A DYNAMIC MARKET

Recent advances in solar PV and storage technologies, combined with falling prices and innovative business models, are changing the energy access sector in ways which could not have been imagined even a few years ago. As we look ahead to 2030 it is important to remind ourselves of how fast the pace of change is. This does not just apply to developing countries, in developed economies too we are seeing decentralised renewables, storage, smart networks and the internet of things starting to challenge centralised grid systems in profound ways. It is difficult, if not impossible, to imagine exactly what energy supply systems will look like in 2030. In Africa where legacy systems and sunk investments are at a much lower level than in industrialised countries, the potential for alternative generation and distribution technologies to emerge is huge. The energy access market is a dynamic space where disruptive innovation is challenging the incumbent technologies.

In 1999 McKinsey published an influential ‘Three Horizons of Growth’ model, based on studies of businesses with long term histories of growth. The model recommends a balance between the needs of today and those of the future. Innovation needs to take place to i) maintain and defend the core business; ii) to nurture emerging business with potential for the future; and iii) to explore longer range new opportunities that don’t exist today. All three horizons are needed. The same horizons are needed in research funding – research that looks at the long view, that questions established thinking, allows experimentation and which cannot be too tightly specified, in addition to research that is more prescribed for closer to market ideas and technologies. These horizons and funding are not necessarily aligned. It is likely that the long-term horizon research is much broader than, for example, DFID’s focus which needs to see short-term tangible impact and commercial interest e.g. TRL 7-9 technologies seen as the focus for the current four-year DFID bioenergy research. At the level of the market the same three broad horizons can also be identified. In energy access, advances in materials could, in the longer term, drive down costs and improve efficiency, whilst refining PAYG operating models in the short-term could open up the market to more people.

Within the overall market new service providers will enter and challenge incumbent firms for market share, and incumbents will respond. This will provoke competition between different interest groups. We are already seeing this happening. ‘Disruptive innovation’ theory recognises two areas of genuine disruption, both of which could be said to apply to off-grid solar energy products.

Firstly, disruptive innovations serve the needs of those ignored by the mainstream, for instance addressing the lower income part of a population whose needs are not served by the incumbents whose service offer is over-specified and expensive. The ‘disrupter’ enters the market with a lower cost, ‘good enough’ solution which, over time, improves in terms of quality until it starts to capture customers of the incumbent service providers. Since this happens over a period of time the incumbents often find it hard to recognise the disruptors. The way personal computers undermined IBM’s mainframe computer business is a classic example. In energy access ‘bottom up’ DC micro-grids and SHS are taking customers from the grid.

Secondly, disruptive technology creates a market for something you did not know you needed. In the energy access sector the ability to regularly charge a phone creates scope to move to a smart phone and with that the discovery of apps which can provide services such as pest and weather warnings for farmers.

UK research and innovation needs to be able to understand, adapt and support this changing landscape. Effort is needed to support all three horizons of growth, to support disruptive innovation and innovators, as well as to help market incumbents to adapt to change.

At the same time, work in this area also has to recognise the complexity of innovation and the ways in which different forms of support for innovation enable different types of enterprises to realize very different impacts and implications for those who benefit from that innovation (end consumers and the innovators themselves). Setting decentralized energy initiatives in their proper context as a component in an incubating services circle can lead to all kinds of benefits over and above mere energy provision; education of children, training for youth and adults, energy and non-energy-related business/livelihoods opportunities and ultimately setting the scene for the ICT provision which is research-proven to enhance job/employment prospects

4.3 LONGITUDINAL STUDIES AND DIFFERENTIAL IMPACT

Research, however, cannot not just be about supporting the emergence of disruptive technologies and supporting private sector actors in taking their business models to scale. The research community needs to be far more focused on questions of impact. Given the current massive ramping up of investments into the energy sector across the Global South in support of international energy access targets there is an urgent need for more research which is centred, not merely on the design of delivery programmes, the enhancement of innovative technologies and the meeting of targets, but rather on the medium to longer-term assessment of the wider impacts of those interventions and their unintended consequences (e.g. the environmental implications of battery disposal from PV programmes),

There are, in addition, a tremendous amount of untested assumptions being made about the benefits of access to modern energy services (be it access to modern cooking fuels or access to lighting, communication technologies, entertainment, cooling, motive power or machinery) and their impact upon pre-existing patterns of poverty, marginalization and exclusion. Unpacking the reality of access impacts will require detailed longitudinal empirical studies of both existing interventions (in terms of electricity this needs to reflect grid expansion, off-grid household and community systems and the unexplored theme of 'under-grid', areas which have been grid connected but where access is limited and supply is still inadequate) and the expanded roll-out of programmes as they accelerate over coming years in pursuit of international targets. Clearly, an important aspect of this is the differentiated impacts of low carbon energy interventions upon women and other marginalised social groups that highlight important intersections with questions of age, class, ethnicity and identity. Effective understandings of such issues will require not only detailed empirical studies of the impacts of individual interventions but also engagement with the complex political economy of energy issues at multiple scales of analysis.

4.4 USER DEMAND

There appears to be little real analysis of 'demand' from users, rather assumptions on what users would like and a focus on 'technical' solutions against this assumed demand. What do people really want? What do they aspire to, what are their priorities and what do they value? There is a role for a better understanding of this demand. Practical Action's Poor Peoples Energy Outlook (PPEO) series provide valuable information in this space, the CHOICE project carried out some surveys and workshops on demands after carrying out some energy literacy training and Acumen is also doing some work in this area. As people get access to energy their needs and aspirations change. How much spontaneous productive demand can be expected on access to energy?

There is a need then for more fundamental research that can help explore the dynamics of 'user demand,' that is for sociology based research on the nature of social practices of women and men in consuming and paying for energy within the social, political and cultural contexts within which they live, using such understandings as a pre-cursor to subsequent economic or engineering based interventions. There is a really important role here for social scientists to build up the data and knowledge on practices, needs, and how and why they change. This type of research requires extended (and hence costly) interactions with local communities. It is only when researchers interact over extended periods with the communities that they research that

community understandings of energy, electricity and technology become apparent. Poor communities exist in a constantly-changing environment of experimentation with their own environment, surroundings and technologies and understandings available to them, which are frequently in direct contradiction to what researchers and practitioners think is the ground reality of energy provision and access projects, which tends to be far more rigid and static

4.5 ENERGY PLANNING AND GOVERNANCE

In addition to looking at specific technologies, issues or applications, there is a need for much greater macro thinking to determine the research direction, based on real needs. Much of the current research appears to take specific situations or contexts, yet there is also a role for a wider view (for example in responding to the challenges associated with the relationships between grid/off-grid electricity provision and in meeting the challenges of clean cooking). More effective and targeted modelling of relative costs of different technologies and likely cost trajectories is needed (albeit within the context of the kind of detailed demand focused social research suggested above) to identify front runners and indicate cost reductions needed to make others competitive. This needs to go beyond LCOE analyses and start from a proper demand analysis in the way Practical Action's most recent PPEO report attempts⁸⁴. This is likely to result in much greater attention being directed to affordable and appropriate off-grid solutions for much of the unconnected population. What is clear, however, is that modelling is only useful if it is utilised by planners and other stakeholders, there is therefore a need for modelling activity to be more strongly integrated into work being done on partnership strengthening, capacity building of energy sector professionals and multi-level governance.

There is a strong need for more detailed attention to be paid to understanding the governance frameworks within which socio-technical decision-making in off-grid locations is embedded and the effects they can have on the social and economic relationships that make changes to livelihoods and living standards possible. Governance factors are absolutely crucial to grasping *how* new forms of energy access will affect the lives of the poor across the Global South. In particular this necessitates reflecting carefully upon what 'inclusive' energy access might look like in distinct contexts and how this relates to questions of how energy interventions are governed at a variety of different scales (with a stress, for example, on questions of community engagement within private sector interventions; how to get different branches of government to work together effectively; the quality of local/regional energy governance and escaping from unhelpful grid/off-grid dualisms). Ensuring that these issues are identified and brought into visibility for those working within the energy sector will be absolutely crucial when considering the kinds of skills and capacities that need to be developed if the current wave of energy sector interventions are to bring sustainable and equitable benefits.

4.6 REACHING THE POOREST

Providing energy access to the poorest is acknowledged to be difficult; where potential customers may lack the ability to pay, lack knowledge and capacity which can lead to low margins and difficulty in attracting investors. Support to SHS and mini-grids receives much of the 'off-grid' funding, yet often these models have a limited focus on reaching these people. Providing energy access to the poorest is acknowledged to be difficult; where potential customers may lack the ability to pay, lack knowledge and capacity which can lead to low margins and difficulty in attracting investors. Support to SHS and mini-grids receives much of the 'off-grid' funding, yet often these models have a limited focus on reaching these people. Some exceptions, such as *SunTransfer Kenya*, state that they are trying to target this bottom of the pyramid (BoP) market through small user-defined payment instalments. However their systems are more expensive than M-Kopa's which is also criticized for not really reaching the poorest. Further evidence and work on synergies or potential collaboration between reaching the poor and mini-grids/selling SHSs could help direct research funding. How realistic is it to expect they can afford SHS and appliances? How much can be done by bringing costs down and

⁸⁴ <https://policy.practicalaction.org/policy-themes/energy/poor-peoples-energy-outlook>

improving payment terms? What incentives do SHS businesses need to engage this market segment which is not commercially very attractive? How might indirect subsidies be used which don't become market distorting, particularly in the context of subsidization of grid electricity? This also ties in with a need to further expand work on energy justice within international development contexts.⁸⁵

There are already a number of examples of innovative business models which do reach some of the poorest, e.g. Battery charging, kiosk models and renting lights, but these have not received much funding attention (only two projects in the database specifically focus on kiosks and charging hubs.) However, E4I is working with a number of organisations which are successfully reaching the poor. Solar Kiosk, ARED and Solaris OffGrid (formerly Eternum Energy) use the kiosk and charging model. Solaris OffGrid has a number of solar-based phone charging kiosks and they are adding more business-in-box models to it (e.g. solar powered hair saloon etc.). ARED is running solar powered phone charging and is adding data to it by setting up a local Wi-Fi with 1 TB of data on a hard-drive. Thus, effectively having a "local internet" by having the content on the hard-drive.

A number of other grant beneficiaries are trying to target this market with smaller products, such as solar lamps with mobile charging (e.g. *Elephant Energy*, *Nuru Energy*) and upgradeable systems (e.g. *d.light*). *Poa Power* promotes a PAYG with no upfront payment, and *Azuri* also claims to target the poorest, albeit with a larger and more expensive product than market entry ones such as lamps. Other examples include NLA and GiveWatts, which are not in the database, but are last mile distributors selling SHS and solar lanterns targeted at the poor. Their models rely on manual collection (e.g., \$3/week x 20 weeks = \$60 SHS) which avoids the additional \$60 equipment required in PAYG transactions. In this regard, there are several questions that need to be asked within the sector: .

- Do the poorest of the poor need to be burdened with paying for relatively expensive PAYG equipment?
- To what extent have energy enterprises (across business models) been able to move beyond pilots to scaling up solutions that work?
- How are these enterprises structured and are there clear standards on what constitutes a 'social enterprise' (income of communities being served, affordability of the solution, sustainability of cashflows and revenue, internal organizational practices and so on)?
- Is there adequate learning to discuss realistic expectations around investing in social enterprises, rather than simply viewing 'the size of the market' to determine returns?

Responding to these questions would be important in determining future areas of impact investment and research and in ensuring adequate support for enterprises and practitioners seeking to reach the 'last mile'.

4.7 ENERGY FOR PRODUCTIVE USES

Beyond the issues explored above, one of the major factors affecting the limited impacts on the lives of the poorest sectors, is that there is little evidence that the existing, mainly solar programmes of off-grid electricity provision, have created significant opportunities for livelihood generation and other elements of wider welfare improvement and community development. Clearly then, whilst low carbon energy interventions are in many ways ideally placed to facilitate a sustainable and just transition to economic development and reduce inequalities in income and life opportunities, this will not occur automatically. More research is needed on design and implementation of energy interventions which focus on productive uses specifically. This includes the business models, business support services and institutional environment required.

⁸⁵ See this year's LCEDN annual conference agenda for recent attempts to develop this agenda: <http://lcedn.com/blog/full-conference-programme-lcedn-6th-conference-11-12-sept-durham/>

Energy access alone does not automatically result in income growth, development or poverty reduction. In fact, there is limited evidence demonstrating how much spontaneous productive demand can be expected on access to energy. Firms connect for (relatively small demand) light and radio/mobile charging but not necessarily for larger productive power demands. Changes in income and economic growth are largely dependent on the market linkages for goods and services, access to efficient appliances and the availability of finance and the technical and operating capacity of those involved. A GIZ report concluded that “overall, it seems that the full potential of the economic impact of electricity can only be exploited if certain necessary preconditions are fulfilled, such as a certain endowment with capital e.g. for investment in electric appliances and access to markets and transport infrastructure.”⁸⁶

Current research and commercialisation has mainly focused on the domestic sector rather than on economic activity. Since agriculture is still the mainstay of Global South economies we would argue that should probably be a greater focus on trying to solve energy challenges in the context of viable agricultural value chains. In the agricultural sector, innovation which combines energy system supply with the agronomy advice, and which links farmers with buyers is starting to happen, but is limited in scale. Cross-disciplinary collaboration which can start to integrate small-holder farmers with export markets, including connecting with the global cold chain, hold out possibilities of improved incomes. Cost-reductions in the technology, and smarter systems, could help drive growth in this area. Research could also focus on improved efficiency of appliances and reducing costs all along productive value chains – pumping, milling, grinding, refrigeration and cooling etc. In particular, there seems to be a real gap in the market for affordable milk refrigeration and for cold storage (although there is now some emerging work in these areas, e.g. via the RE4Food USES project.⁸⁷ This would include standalone products such as solar irrigation and solar cooling as well as end use appliances (mill, pumps) and energy conversion technology (boilers, gasification, biogas for various feedstocks etc.) Although some work is happening in this area there are also still questions about different crops and their needs and how existing products can be rolled out to larger markets (e.g. solar pumping, solar refrigeration). Enhancing the availability of energy for productive uses can also catalyse broader energy access in rural areas. For example, via the opportunities for agro-industries to use renewable energy for their own operations, as well as providing energy services to surrounding communities. Further research on how other industries can contribute to energy access may unlock technical capabilities and finance required to achieve universal energy access.

In the non-farm income market there needs to be systemic change to see productive activity flourish with energy access. Although individual projects/support can have benefit it will always be limited by wider market factors, for example, the local availability of certain efficient motors makes it harder to power smaller non-farm livelihoods using decentralized renewable energy solutions. Some research is needed on what role, and to what extent, services such as local manufacturing, business development support, trade development, financial and ICT services play in facilitating productive uses of energy and contributing to economic development. The other wider barriers to productive use uptake (e.g. behavioural, local/national policies, corruption, cultural, transport, telecoms, etc.) also need to be explored. This could identify opportunities of how to improve support to result in better outcomes.

4.8 SCALING UP OF MINI AND MICRO-GRIDS

⁸⁶ Productive Use of Energy – PRODUSE, Measuring Impacts of Electrification on Small and Micro-Enterprises in Sub-Saharan Africa, Edited by Lucius Mayer-Tasch, Mohua Mukherjee and Kilian Reiche, GIZ, 2013

⁸⁷ <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/L002531/1>

As the analysis above shows, although there is growing experience of research which has supported the development of mini and micro-grids, there are few examples of medium or long-term success, nor of real commercially sustainable mini-grids. Clearly, research into the technologies supporting the development of mini-grids needs to continue and deepen with a particular focus on new forms of energy storage, novel payment systems, data management and energy efficient appliance development. At the same time, however, there are two urgent additional needs. The first is for sustained work on the forms of governance through which mini-grids are developed and managed and also how they intersect with household level systems and with the extending national grid. The importance of community ownership and involvement cannot be under-emphasized.⁸⁸ The second relates to the need for more sustained interactions between researchers and the companies and other organizations developing mini-grid systems. Many companies are finding it difficult to scale up, though some large energy companies are starting to invest in this area. There is therefore a need for further innovation to create effective approaches for widespread uptake of mini-grid systems, and ensure sustainable grids. As part of this there is a need to look to the future and to understand the role of changing technology and business models and the finance, regulatory and policy frameworks and capacity needs for these changes.

4.9 TRANSFORMING CLEAN COOKING

Despite considerable investment by the development community over the last 40 years, 3 billion people continue to cook with biomass which causes respiratory disease, environmental degradation and reduces productivity. Current expenditure has focused on the development of more efficient and less polluting stoves as well as the uptake of cleaner fuels such as biogas and LPG. Progress with improved stoves has been mixed, with recent critical research reflecting on the social factors determining demand, the barriers to uptake and analysis of evidence over the real impacts of the use of cleaner stoves on the health of individuals and the reductions in carbon emissions achieved. More attention also needs to be paid to the tensions between the local manufacture of cookstoves in-country and the importation of higher quality stoves from overseas (particularly China).

The time has come, we would argue, for wider, more radical, more holistic thinking about the clean cooking challenge, that looks further into the future and is more innovative, envisioning cleaner cooking as part of a wider focus on healthy households. For example, should the whole sector be aiming to move away from biomass all together and focus only on cleaner modern fuels. This would involve exploring new developments in the distribution and marketing of LPG (for example in the development of pay as you go systems) and a detailed examination of whether electricity (either via solar PV or national grid) could be a viable option in the context of solar system price reductions, improvements in battery technology and the increasing cost of more polluting alternatives (collaborative work between Loughborough, Surrey and Gamos described above is exploring this option).⁸⁹

Alternatively, given the likely continued presence of biomass cooking in many markets for many years to come, should we be looking at more sustainable forms of biomass production/charcoal supply, as well as the development of cleaner cookstoves? Could larger agro-forestry businesses produce charcoal more sustainably at a price which competes with inefficient small-scale production and what would the economic consequences for poor people be if it were possible to knock out the informal charcoal sector?

4.10 ENERGY ACCESS IN URBAN AREAS

⁸⁸ We will shortly be publishing an LCEDN briefing paper on this topic. The lead author is Lorenz Gollwitzer whose recent PhD focused on this issue, see this briefing paper for an overview: <http://steps-centre.org/wp-content/uploads/Rural-Electrification.pdf>

⁸⁹ <http://gtr.rcuk.ac.uk/projects?ref=132724>

Although, most people without access to energy live in rural areas, there are significant challenges for energy access in urban areas which have been under-researched over recent years. Living 'under the grid' does not guarantee access to energy as supplies can be unaffordable and unreliable. Energy access is a major challenge for the 880 million people who live in slums worldwide ⁹⁰ (UN-Habitat, 2016). Lack of security of tenure and official recognition form additional barriers to accessing energy. Research is needed to identify the specific needs of the urban poor, and to integrate them into energy and urban planning processes.

Research on smart cities and the built environment sector can also help to address this challenge, as can further expansion on research into sustainable urban governance. UK research capacity in these areas is strong but does not yet have a strong international development focus. There is clear potential for cross-fertilization of perspectives within this sector with initiatives such as the UK Collaboratorium for Research on Infrastructure and Cities (UK CRIC), a set of academic-led centres working with government and industry is focused on improving the UK's infrastructure systems to address challenges of affordability and sustainability, having clear potential for replication.

⁹⁰ UN-Habitat (2016). World Cities Report. UN-Habitat, Nairobi.

5. CONCLUSION: STRENGTHENING RESEARCH IMPACT

Over the preceding pages we have tried to trace the contours of the diverse and highly complex portfolio of UK academic research and innovation activity around low carbon energy and international development themes. We then explored this portfolio in the light of the articulated needs of communities and businesses in the Global South with reference to the main areas where people are trying to commercialise application of a technology and so demonstrates where there is a synergy between UK funded research and innovation and what is happening on the ground.

We acknowledge that our knowledge of the sector and our assessment of need are partial.

Many of us authoring this report have been involved within some of the key directions that the UK research community have taken in the energy and development arena over the past few years since the formation of the LCEDN. We celebrate the growth of the sector (and the emergence of UK funding initiatives such as USES, TEA and the GCRF), the greater sense of community and the first stirrings of more transdiscipline-oriented research, as well as much greater interaction with key stakeholders both within the UK and internationally. This is the first report of an ongoing project within which we are exploring the nature of the current research portfolio. In the ensuing stages we intend to deepen our analysis to map the networks which specific research teams are involved in, assess the geographies of where that research is located and further deepen our analysis of the most appropriate directions for future interventions by the UK government within this research sphere.

ANNEX ONE: SUMMARY OF INTERNATIONAL GRANT FUNDING FOR INNOVATION AND SCALING UP

Name	Challenge/aim re. innovation	Funders	Firms supported (sample)	Area
Included in E4I database				
Energy and Environment Partnership (EEP)	A challenge fund investing in poverty reduction and job creation. Projects should demonstrate high innovation in delivering energy services , facilitating technology transfer, encouraging cooperation and local stakeholders' participation in projects.	Finland, DFID, Austrian Development Agency (ADA)	225 projects in includes Vitalite, Orb Energy, Sunculture, Huskpower systems	S&EA
Africa Enterprise Challenge Fund (AECF)	Funds innovation in commercial businesses in the agribusiness, renewable energy and adaptation to climate change technology sectors (REACT).	DFID, Netherlands, SIDA, IFAD, Danida, CCAP, Canada, Aus	More than 250 projects (not all energy) including Includes: Azuri, BBox, Huskpower, M-kopa, offgrid electric, Toughstuff,	SSA
Renewable Energy and Energy Efficiency Programme (REEEP)	Funds are used to “ test and demonstrate the viability of early stage ventures’ innovations ” in the market.	Varies per project	Current portfolio of 9 agro-food projects including Redavia, Futurepump, Sunflower, Station energy	Intl
Private Financing Advisory Network (PFAN)	PFAN works to facilitate financing for clean energy businesses. Most projects are brownfield and greenfield development but there is support for scaling up and technology demonstration projects, which focus on innovation	Aus, Canada, SIDA, USAID, Norway, The Energy and Climate Partnership of the Americas (ECPA),	4 energy access innovation projects including Fenix, and 100 scale-up projects.	Intl
Scaling off-grid energy development	Seeks to accelerate growth in the off-grid energy market. Funds early stage companies, supports	USAID, Power Africa, DFID and the	Greenlight planet (Nig, Ug) d.light (K)	SSA

challenge (SOGE)	innovative technology solutions and business models , and supports critical elements of the off-grid ecosystem.	Shell Foundation.	Fenix (Zam) Orb Energy (K) Vitalite (Zam) PEG Africa (Gha) Shinbone Labs (Benin) Village Energy (Ug)	
Powering Agriculture	Powering Agriculture provides technical, business acceleration, financing and policy support to its innovators and other stakeholders.	USAID, SIDA, BMZ, Duke Energy, and OPIC	24 projects incl: Eco Consult (Jor), Kickstart Intl (K), SimGas Tanzan, CAMCO (Be, Tz), Uni of Toronoto (Bang), Motivo Eng (In), UGARF (Ug), Husk Power (Tz), African Bamboo (Eth), Ariya, Sunflower	
Development Innovations Ventures Program (DIV)	DIV is USAID's open innovation fund . It focuses on three elements of an innovation: rigorous evidence of impact, cost-effectiveness, and pathway to scale through private or public sectors.	USAID	34 energy projects incl: off-grid electric, Orb energy, Angaza, Powerhive, Burn technologies, Simpa, Azuri, Mera Gao	Intl
Transform	Funds for social enterprises (includes energy). Not clear how much is on innovation.	Unilever, DFID	7 orgs supported to date including 4 energy orgs: Ubuntu Power, Mercy Corps, ENventure, My Sunshine	SSA/SA
Global Innovation Fund	Funding innovation in any sector anywhere!	DFID, USAID, SIDA, Omidyar Network, Australia	4 energy projects (Sparkmeter, POA energy, Simpa and Paygo Energy).	Intl
Innovations against Poverty (previously Practitioner Hub for Inclusive Business)	Supports innovations and business models in ICT, energy, WASH and Ag in Cambodia, Ethiopia, Zambia and Uganda.	SIDA,	9 energy projects in first round incl: Sharedvalue Africa, Sunfunder, Waste 2 Energy, Nuru energy, d-light Phase 2 - 13 energy projects shortlisted. None selected yet.	

Mobile for Development (M4D) Utilities Innovation Fund	Aims to test and scale the use of mobile to improve or increase access to energy, water and sanitation services. Seed grants for trials as well as funding for studies.	GSMA, DFID	About 13 energy companies supported incl Easypaisa, Mobisol, PEGGhana, Fenix, off-grid electric.	Intl
DEG Upscaling	Aims to scale up innovative business models. SMEs eligible for the support are early-stage ventures. They provide a repayable grant of up to \$500k	kfW	PV2 (Ph), PEG (Gh), Difficult to find investments made on website	Africa, Asia
DOEN Foundation	DOEN supports innovators and brings them into contact with each other. Annually, supports more than 200 initiatives by means of subsidies, participations, loans and guarantees. DOEN supports initiatives in the field of Culture and Cohesion and Green and Inclusive Economy.	Dutch charity lotteries	SunTransfer (Eth)	Netherlnds, S/SE Asia, E. Africa
Not included in database				
Results Based Funding (RBF) for low carbon energy access	Participants must show that they will be able to be financially sustainable in the long run after the intervention and therefore the products/market must be commercially viable. Support for some scaling up, not necessarily innovation per se.	DFID, Germany, Sweden, Norway, Switzerland, Netherlands	14 projects...	SSA and SA
Energy Access Ventures Fund (EAV)	EAV invests in a growing number of dynamic and innovative companies. They help founders raise further funding and develop a long-range exit plan. Managed by CDC	DFID/CDC, OFID, Schneider, Proparco, FFEM, EIB, Schnieder	d.light, offgrid electric, PEG Africa, Inspirafarms, sunculture, Paygo Energy,	

Global LEAP	Promoting Energy Access by Supporting Innovation and Competition in the Off-Grid Market. Includes a number of initiatives including capacity building, TA and 'Driving and Demonstrating Innovation and Scale.' The examples of innovation and scale are provided in the Global LEAP awards: see below	US Dept of Energy		Intl
GLEAP TV and fan awards	Review and highlight best off-grid products. Not really supporting innovation.			Intl
Global Leap refrigerator awards	As above but also includes support for late stage development, prototypes and field trials as well as a review of and incorporation of customer preferences (eg. space, design, price).	US, DFID		Intl
Global LEAP+ RBF	Couples the Global LEAP Awards with RBF incentives for early-mover off-grid solar and appliance companies. Not innovation in itself.	US, DFID		Intl
ESMAP	ESMAP states that it "works at the frontier of innovation and new business models to accelerate access" however a review of the work shows that it is not so targeted at innovation. More TA, in-depth reviews, standards, tools, not supporting technology/companies.	Multi		Intl
EnDev (non RBF)	Supports energy access by establishing economically sustainable energy solutions and distribution schemes, mainly for rural communities. Not	Germany, Netherlands (Sweden, Norway, Switzerland)		

	necessarily innovation or scale-up...			
James Dyson Awards	Innovation from student design engineers. Covers many areas including sustainability and some projects would be applicable to Global South.		Handful would be relevant. Could maybe look at...	UK
Infraco Africa	Provide funding to early stage projects. Their additionality could be to pioneer a new technology or innovative approach. Can fund development activities. Most activities more standard project development. Part of PIDG	DFID, Netherlands, Switzerland, ADA	9 projects including energy incl. Redavia,	
CKDN Innovation Fund	More on climate change adaptation/mitigation and not obviously focussed on energy.	DFID, Netherlands	Interesting project called "Fostering low-carbon technology innovation and transfer: an in-depth study" https://cdkn.org/project/fostering-low-carbon-technology-innovation-and-transfer-an-in-depth-study/?loclang=en_gb	
Ashden Awards	Supports sustainable energy innovators. Limited financial support provided plus business advisory.	Various	Winners included PEG Africa, Sunculture, off-grid electric...	
LGT Ventures	Philanthropic venture capital supporting innovative social orgs. Will not invest in projects. They invest in companies which are: <ul style="list-style-type: none"> o An effective solution to a social and/or environmental problem o A proven model that can be scaled or replicated o Management team with strong track record Investment ranges from EUR250k -EUR1m		3 energy orgs so far: Husk power systems, Green Oil (In), One Renewable Energy Enterprise (ORRE)	Asia, Af, LA

ElectriFI	Electrifi supports both public and private organizations promoting sustainable energy solutions. Support to new projects and pilots, the feasibility enhancement of projects in development, and the scaling up of existing projects. No grants. Not clear that it is funding innovation...	EC, Power Africa,	2 signed projects (Sigora, Haiti and Nextgen, Tz). 7 projects to be signed, all solar in India (Mera Gao), Kenya, India, Nigeria, Cambodia and Fiji.	Global
ENGIE Rassembleurs d'Energies	Projects contributing to energy access. Not so much on innovation.	private	In Africa 7 orgs– Fenix, FReeme, PEG, Fondation energie pour le monde, BBox, Simgas, AUSAR In Asia5 orgs – Rural Spark, Green Village Ventures, Simpa Networks, Friendship, Mera Gao,	France, Africa, Asia, LA
Nexus Pioneer Facility	\$ 80k - 350k, Grants, WC at growth stage, Clean Cooking Loan Fund, Partnership with Kiva, Interest rates 6-12%. Funds biogas and stove programmes as well as some organisations Not really innovation		Biogas (Vt), Hestian, GERES,	Africa, asia
Montpelier Foundation	Montpelier Foundation supports and empowers disadvantaged people across the world through social impact investments and grant programmes. The Foundation supports organisations offering sustainable and scalable solutions in sectors such as education, agriculture and energy.			

Also looked at:

- World Bank, SREP and CIF (more project grants, TA and finance)
- EDF Innovation (some smart grid stuff, customer interfaces – Europe focussed but may have some relevance)

- Ausaid, New Zealand Aid (both more Pacific, SE Asia focus, no real mention of innovation. Ausaid funds AECF and ECF in SE Asia),
- Canada (PFAN but couldn't find anything else, challenge fund on health),
- France,
- Germany (loads on energy but so innovative focused, set up 14 green innovation centres on agri-food),
- Sweden (included above),
- Norway (project support and innovation in health),
- Netherlands,
- Switzerland (project support, includes scaling up charcoal production in Tanz, biomass gasification in India),
- Clinton Foundation (Design and test innovative market solutions in the commercial and residential building sectors with the goal of developing and scaling these models, not sure if just in US).,
- Gates,
- Austria (support for ECREEE, CCREEE and solar thermal demo and training in Southern Africa),
- ADB (more project grants, financing and TA),
- AfDB (SEFA, Power Africa, Africa 50, all more project development; The New Deal on Energy Task Force exploring innovative pioneering business models to scale access to pay-as-you-go (PAYG) payment models for solar),
- IsDB (Science and Tech Centres of excellence and prizes, difficult to find anything useful, maybe Ben knows?),
- IRENA (studies, support),
- Aga Kahn, Ford foundations
- Taiwan, China, ...
- Reviewed a whole group of 'challenge funds' but most focussed on other sectors/geographies.

Did not look at:

- BEIS (incl REPP) or EU, nor DFID's Bio-energy Programme and Scaling up Clean Cooking Solutions, since I think they should be included in LCEDN's reviews.
- Impact investors such as Acumen, Shell, Imprint, Vulcan, Actis...; nor investment such as Berkley, PIDG (other than Infracore above).
- Others that have invested before, eg. Fundacion Netri, Mulago foundation, Omidyar Network, the worldwewant,

ANNEX 2: TAKING THE DATA FORWARD

INTRODUCTION

From an analytical/operational perspective, mapping knowledge across such a wide ranging, multifaceted and perpetually active space is an ongoing challenge. The current landscape for knowledge in Low Carbon Energy relies on the ability to draw together disparate streams from many non-aggregated, differently structured data sets, which exist in differing levels of completeness and accuracy. Whilst a valuable source of information, they have limited analytical capability and offer little to decision makers in the way of overview/insight into potential challenges/opportunities. The LCEDN approach aims to develop a database which not only acts as a record of the information, but actively engages with the sector to source information and process it within a consistent frame. This offers greater capability to visualise and interrogate the data to expose interesting patterns, which can be communicated to stakeholders in a coherent way with clear alignment to evidence.

STRUCTURE

The key challenge for the LCEDN database – as well as associated databases - is to be robust enough to capture the crucial details which make each project/research area unique, but at the same time organising information effectively to ensure it offers cohesion and structure. This will ultimately provide LCEDN and its audience with the

required consistency and depth to enable meaningful analytical capability and improved accessibility to the information bank within.

A predetermined open-ended attribution structure was followed to ensure that:

- The data is dynamic. A common problem with data sets is that they are designed without end use in mind - this can leave them flat and uninteresting in terms of data dynamics. It is important to embed appropriate measures to allow for information to be exposed from a range of different entry points, to expose particular relationships between elements in the data and maximise the scope for future application.
- Projects are accurately recorded, but not over engineered. Not all fields are applicable to different projects, so only relevant fields need to be addressed when entering information. This is highly accommodating for the anticipated range and potential complexity in the data across Low Carbon Energy.
- Appropriate detail is captured. The classification system is detailed and was developed through a test phase approach using real data, allowing it to be refined in response to content. This ensures the classification system is highly fit for purpose, and can more ably capture the level of granularity which is useful to the project aims.
- It remains agile to a range of potential applications. The database offers simplicity in design, a flexible base to build from, and holds a format which talks to a range of different software options with minimal processing effort. This is advantageous as it will cut down on the likelihood of needing to re-structure the information to process or visualise the data in a particular way. By using Excel as the central software, it has been very accessible to a wider range of people during the initial phase, allowing different user groups to contribute, verify or extract information.

SCOPE

The database is designed to be relatively agile (adjustable) in terms of its continuing development. Built for longevity, the database is set up to be a permanent work in progress, acknowledging that the exercise of data capture and verification will be ongoing. Much like a jigsaw puzzle, as more information is added to the database the overall picture will gradually become clearer and the analytical capability across the material will improve. This is likely to be supported by a process of presenting the database information (in a visually interesting way) to stakeholders within and beyond the LCEDN to clarify details and ensure the fullness in the dataset. This gives the database the best chance of being a living entity, rather than a record sheet.

The optimum scenario for the future use of this database is for it to be integrated into an online platform on the LCEDN website, using an interactive interface to visualise the data in a way which is unique to the audience requirements (See fig.1).

This dashboard view allows a quick route to key information, and to draw out key trends as live extracts from the database. The view would be fully customisable through the use of filters and the audience would be able to cycle through the different fields within the database to discover which patterns are most relevant to their work.

Adopting this method of presentation opens possibilities for overlaying different layers at the same time, which allows a greater exposure of the dynamics within and across data layers. (See fig.2)

Fig.1: (geographical concentration of projects; clockwise from top left- biomass, solar, clean cooking, wind)

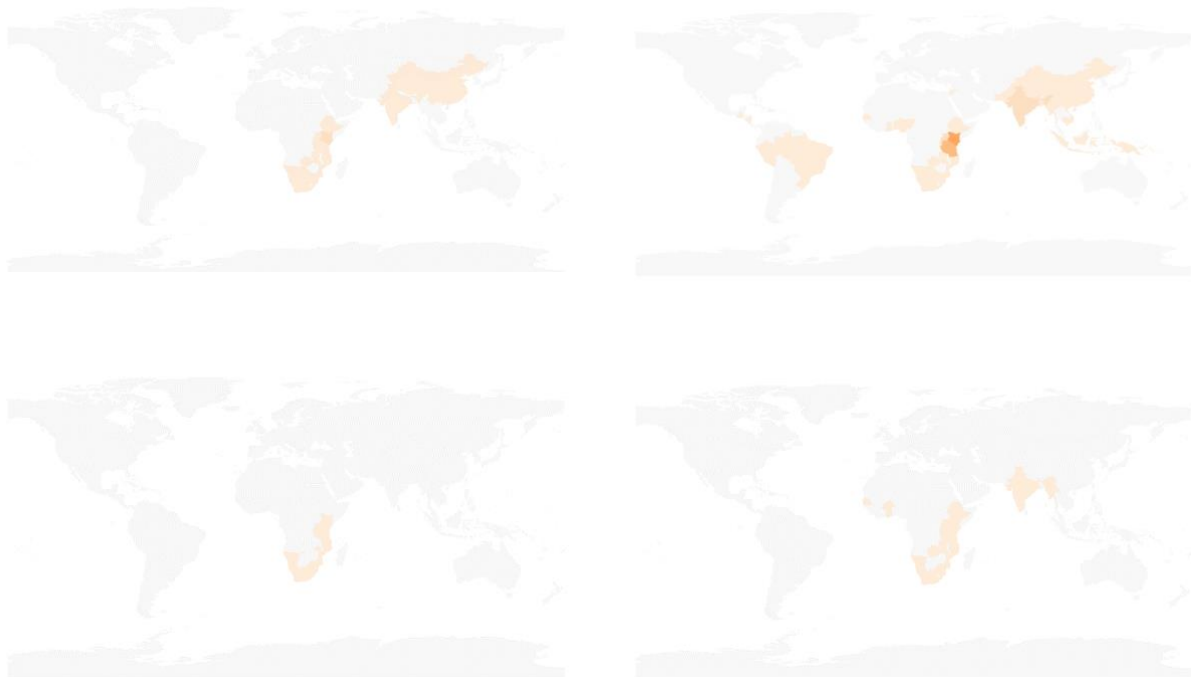


Fig.2a)

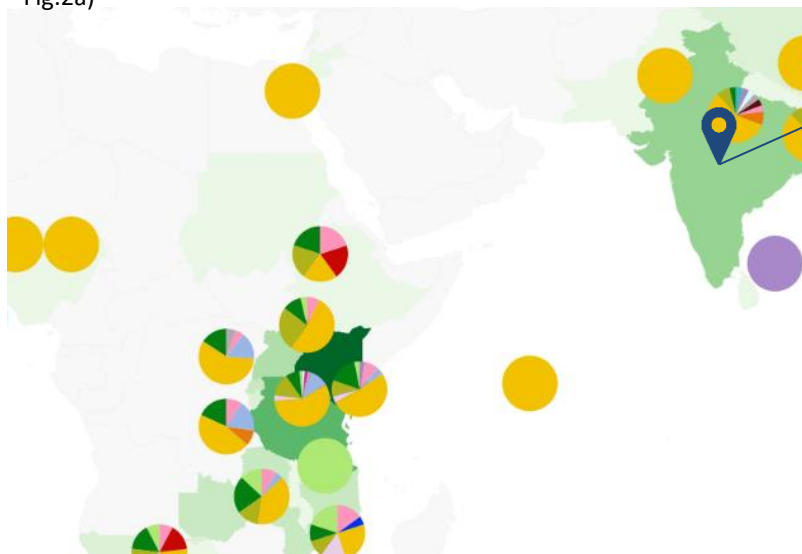


Fig.2b)

+ Add project

Location: [India]

Technology: [Solar PV]

Power generation scale: Household

Application: Agriculture

Research type: Technology

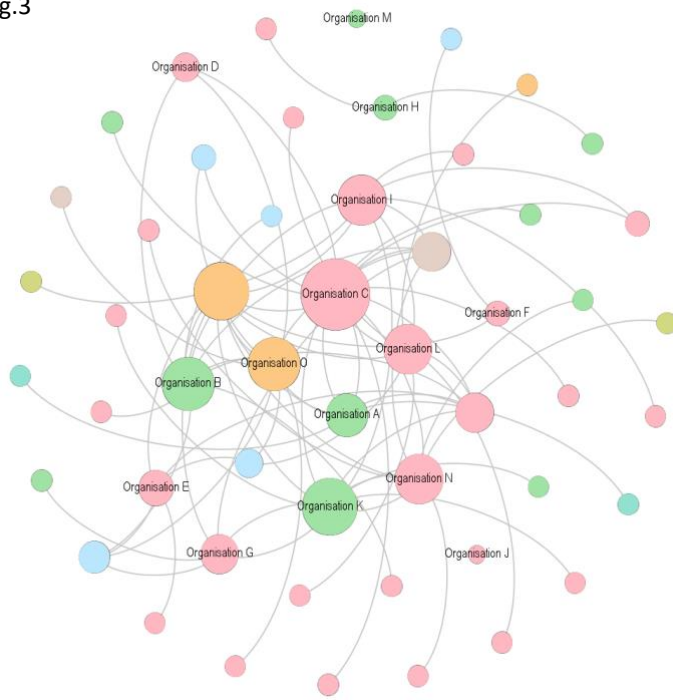
Primary challenge: Energy Security

Scale: Neighbourhood/Community

This interface could act as a participatory method of data collection/verification which allows participants to add database entries to the interface directly. This would be the most effective way of harnessing knowledge from those closest to the projects, ensuring accuracy and fullness in the data.

Drawing on the consistency in fields across different tabs in the data, a range of data visualisation options could be applied to display unique views on relationships, networks, key hubs and key themes. One such technique would be network mapping visualisations, which could be adopted for Individuals, Institutions, Organisations, Technology areas etc. Fig3. Shows an example of network mapping.

Fig.3



The Low Carbon Energy for Development Network (LCEDN) brings together researchers, policy-makers, practitioners and the private sector from across the United Kingdom (and indeed the rest of the world) to expand research capacity around low-carbon energy development in the Global South. The LCEDN was launched in January 2012 centred around hubs at the Durham Energy Institute and Loughborough University.