Innovate UK
Knowledge Transfer Network

LOW CARBON ENERGY FOR DEVELOPMENT NETWORK

Potential for Application of UK Energy-Related Technologies to Developing Countries

Dr Nick Rousseau, Dr Kerry Dickinson, Luke Owen, Dr Jonathan Cloke, Antony Davies and Fay Kenworthy

July 2019

UNCONVENTIONAL CONNECTIONS

Acknowledgements

This report was undertaken by the UK Low Carbon Energy for Development Network, Energy 4 Impact and the Knowledge Transfer Network, with the assistance of Unconventional Connections Ltd.

We gratefully acknowledge the contribution of those that we interviewed who generously shared their extensive knowledge and experience.

The report has been funded by the UK Government, however the views expressed do not necessarily reflect the UK government's official policies.

Final report of July 2019.

UNCONVENTIONAL
CONNECTIONS

Facilitating innovation-related policy and partnership-building projects.

Our expertise across innovation, policy development, international project management and extensive network of contacts will help ensure your project's success.

www.unconventionalconnections.co.uk

TABLE OF CONTENTS

EXECUTIVE SUMMARY

With the backdrop of global population increase, rapid demographic changes, expanding urbanisation in developing countries along with climate change, a massive global challenge is to provide clean, green, secure, affordable energy for everyone and to deploy this energy within holistic transitions to low carbon economies. This means simultaneously:

- reducing emissions
- re-thinking energy use regimes
- improving security of supply, and
- reducing cost of energy

The UK is already a major contributor of research and innovation into low carbon transitions within the countries of the developing world, particularly through the leadership of the Department for International Development (DfID). However, this work has not previously included a focus on where the UK's commercial sector has a particular contribution to make. This is now a focus for Government support and, as such, the work is increasingly being coordinated with the work of the Business, Energy and Innovation Department (BEIS) to maximise the deployment of the actors within the UK economy and knowledge base to support HMG aims in the developing world.

As a result, there is a strong focus on where there are significant opportunities for the UK to enhance its presence within these markets, to help deliver UK growth ambitions and also make a major contribution to meeting international development targets and climate commitments.

By harnessing the UK knowledge base and commercial capabilities there is a significant opportunity to:

- position the UK as a first mover in emerging markets
- create commercial opportunities for energy sector entrepreneurs
- catalyse wider economic value chains for the benefit of local communities in the Global South
- help meet international development targets and climate commitments

However, there are a number of challenges involved in looking to introduce UK technologies into a Global South context. The socio-political context presents a complex mix of political, financial and technical issues that vary from region to region and country to country, whilst environmental and climatic factors can create more extreme and challenging conditions under which a technology must operate.

Another challenge is to understand the social and cultural context in which energy use takes place, so avoiding the temptation to ascribe 'western centric' motivations, drivers and explanations whilst failing to understand local social dynamics, norms, behaviours, needs and structures.

For companies looking to operate in the Global South, understanding local markets and forging effective knowledge and business partnerships can also prove complex and time-consuming. Companies can also find that local consumer trust and confidence in new technologies and products takes time to build due to negative experience they may have had with undeveloped or poor quality infrastructures and weak market institutions.

Further to this, most energy technologies facilitate the distribution, storage or generation of energy which is then utilised within another system. All technologies operate within energy systems made up of a combination of technologies, resources and social systems/cultures. As such, any technology has to suit the particular circumstances of generation resources, storage and load-shedding capabilities and energy uses, as well as the social environment.

We focus the report onto a number of areas where there are particular opportunities for UK business and industry (Energy Systems, Bioenergy, Solar, Thermal Energy, Energy Storage and Appliances).

This means that, for the UK to achieve the most impact when seeking to step up its involvement within this sector, it needs to adopt an holistic approach to understanding the specific challenges involved within low carbon energy transitions, the interplay and mix of technologies and methods to resolve those challenges and the local social, political and economic contexts within which those technologies must be situated. The types of steps involved in developing such an approach might include:

- Drawing on academic knowledge and experience to identify particular markets and develop a deep understanding of need and context – this could relate to a particular scenario in a given country where there is a particular mix of energy resources in place.
- Road-mapping with in-country partners to plot different pathways to low carbon economic growth and solutions. This would help identify where wider contextual factors need to be addressed such as the development of suitable standards or in-country capacity.
- Running a competitive programme offering financial and other support for organisations to develop **service-based business opportunities** – the focus would be on finding/stimulating the creation of teams with the ability to build service delivery propositions that reflect an accurate understanding of a need. This should include mechanisms for providing access to academic partners, charities or other bodies active in the country (eg through offering innovation vouchers). Distributed Energy Service Company models would be one example of this kind of thing – ie focus on a service for which there is a demand, which will then drive the identification of a means of delivery. Finding suitable in-country partners and champions within the communities being targeted is critical.
- Encouraging/facilitating engagement with investors early on as investors can potentially get involved/contribute as and when they can add value, and also so that they are well exposed to the emerging opportunities and have some personal investment in where opportunities develop.
- As part of this approach, on-going support could be used to provide access to a range of tools/mechanisms for sourcing technologies and skills to fill gaps identified. Thus, Innovate UK/KTN, for example, could help set up projects as potential customers for SBRI challenges, open innovation platforms, etc. Funds could be provided to support

R&D, design work, piloting, for technology companies that have been selected as offering the best prospects. These open innovation platforms would be run to draw as widely as possible on UK technology expertise, not just energy tech. Where in-country skills are lacking, the project would be enabled to reach out to the UK Vocational Education sector to seek partners for skills training in-country.

However, there is also a need to consider the wider challenges and issues that were identified through this report, that will require a long-term, sustained and collaborative approach between UK partners.

To take this forward, a partnership of key organisations should be convened to build a multi-faceted programme that could take UK support beyond piecemeal funding of individual companies to cover the following broader cooperation themes:

- Leveraging UK expertise in fundamental research,
- Facilitating complementary partnerships between UK companies
- Facilitating international partnerships
- Leveraging UK expertise around systems thinking
- Aligning innovations with targeted, user-informed, business models
- Catalysing value chains and local entrepreneurship
- Capacity building around institutions and governance
- Helping UK Companies to operate in the Global South
- Better availability of research, information and intel
- More actively positioning the UK in emerging markets

Summary of each of the technology areas

Technology Area	Market observations	Opportunities and challenges	UK strengths	Interventions
Energy Systems	Developing countries tend to have inadequate or dysfunctional grids and so distributed, micro-grids and smart grids offer the best prospects. Solutions need to be tailored to a very diverse range of situations with different potential energy sources and uses.	Lack of good data and predictability over energy requirements demands innovative approaches to financing and payment. This will require business model innovation. There will be a need for tailoring of existing solutions to particular contexts.	The UK is at the forefront of smart grid thinking and energy system innovation, with a lot of Government funding going into these. Range of companies with potential including consultancies.	Take a systems approach to seeking and implementing solutions. Use an approach to develop an energy service analysis and need specification to draw in technology requirements. Need to create incentives for businesses to adapt systems approaches originally tailored to a Western context for the developing world. We propose a process model to drive innovation and inform Government funding support.
Bioenergy	The preponderance of agriculture in developing country economies results in opportunities to harness biomass for energy generation. This is an area that has a long history. There are a growing number of options and models but also competing uses for these agricultural bi-products.	Challenges include variability and seasonal nature of many sources of biomass, and the wider implications of different types of bioenergy generation in relation to GHG emission, air pollution, etc. Different energy extraction methods and technologies have very	The UK has worldleading research capability in this area but most of the funding has focused on the Western market so this capacity is not being exploited as well as it could be for developing countries. Bioenergy is a well-developed and varied sector in the UK, with a	We need to find a way to incentivize the UK research base to engage on the immediate practical challenges of bioenergy generation and less on cutting edge technologies that are some distance from real impact. Innovation Vouchers could be one way to do that.

Technology Area	Market observations	Opportunities and challenges	UK strengths	Interventions
		different profiles. There can be a large capital investment requirement but this is only viable when feedstock supply is predictable. Ultimately, solutions will be dependent on the ability to combine this with other energy sources.	large variety of end-uses, technologies and fuel inputs, providing a significant economic and energy benefits. The UK landscape is dominated by Small/Medium Sized Enterprises and the research base is large but fragmented although the Bioenergy Superhub is seeking to address this.	
Solar	Off-grid solar energy generation at different scales and for different applications has huge potential given the climate and extensive sunlight in the developing world. It is a mature sector in many ways and a number of countries have targeted support and investment support at this to grow its contribution.	The cost of solar energy generation has reduced significantly but access to finance is still a major barrier. There are aspects of the environment of developing countries that adversely affects solar PV generation and this creates opportunities for technological innovation. There is scope for business model innovation.	The UK is not a major producer of solar panels and systems but has a large and growing number of highly innovative and specialist companies that are targeting the innovation challenges. A significant amount of Government funding has already gone into this area. The Solar energy Superhub is providing a valuable focus for innovation and can assist in testing new technologies before they	Interventions could focus on helping UK specialist companies to partner with existing solar producing companies in the developing world so that their particular solutions can be incorporated. Wider opportunities to support through standard setting, quality control and training.

Technology Area	Market observations	Opportunities and challenges	UK strengths	Interventions
			enter markets.	
Cooling and energy for and from this	This is a complex area but delivering cooling solutions could have wide-ranging benefits to the developing world including on health, nutrition and economic productivity, as well as reducing energy consumption and GHG emissions associated with inefficient technologies such as Air-conditioning. The issues vary considerably by context.	Opportunities to look holistically at all the factors that can support maintaining lower temperatures from design, behavioural change and technology	The UK has considerable relevant research expertise and commercial strength in relation to this area but deploying this to address the needs of the developing world would be relatively new and represent a shift. Much can be done, however, if we harness the diverse strengths we have, in combination.	There is a need to take a broad and long term view in relation to this area, backed up with substantial investment. The work should include road-mapping, scenario development. An Action Research approach to should be adopted to enable learning about what works best in different contexts.
Energy storage	Effective energy storage is centrally critical to meeting the challenges of energy delivery in the developing world because of the fluctuating and non-aligned supply and demand profiles and the distributed and off-grid circumstances meaning that balancing between sources and storage of excess energy are going to be needed	There are a wide range opportunities and challenges and there is a need to look beyond just battery storage to innovative approaches that fit the environment and resources including phase change materials.	The UK Government has focused substantial investment on energy storage but much of this is aimed at automotive and other Western country applications. The underlying expertise in both the research and commercial sectors could be harnessed to address the particular and different needs of developing worlds to good effect.	There is a need to support some business opportunity analysis to set out the case for commercial engagement in addressing the energy storage requirements of the developing world and shift the focus of attention in that direction. Research needs to focus on this area that could drive innovation and commercial interest.
Appliances	There is a substantial market for	There are particular	The UK is not a major	This is an area where there is

Technology Area	Market observations	Opportunities and challenges	UK strengths	Interventions
	appliances that are viable in developing world contexts with different demand profiles and where supply can be more erratic. This has been extensively studied with a wide range of appliance types being identified as potentially making a big difference to economic growth and health.	challenges associated with appliances as they need to be used directly by consumers and design considerations and user behavior are both particularly important. This creates a more fragmented market with appliances needing to be adapted for diverse cultural, language, educational level contexts. Particular sectors of interest include refrigeration and solar pumps.	producer of appliances but can bring substantial innovation, design and quality control strengths to the development of solutions.	considerable scope for the UK to play a part within multilateral programmes and play to its strengths. Partnerships with countries like China that are major appliance manufacturers could be very fruitful.

1 INTRODUCTION

The UK is already a major contributor of research and innovation into low carbon transitions within the countries of the developing world, particularly through the leadership of the Department for International Development (DfID). However, this work has not previously included a focus on where the UK's commercial sector has a particular contribution to make. This is now a focus for Government support and, as such, the work is increasingly being coordinated with the work of the Business, Energy and Innovation Department (BEIS) to maximise the deployment of the actors within the UK economy and knowledge base to support HMG aims in the developing world.

As a result, there is a strong focus on where there are significant opportunities for the UK to enhance its presence within these markets, to help deliver UK growth ambitions and also make a major contribution to meeting international development targets and climate commitments.

By harnessing UK knowledge base and commercial capabilities there is the opportunity to:

- position the UK as a strategically significant mover in emerging markets
- create commercial opportunities for energy sector entrepreneurs
- catalyse wider economic value chains for the benefit of local communities in the Global South
- help meet international development targets and climate commitments

The UK Low Carbon Energy for Development Network (LCEDN) brings together researchers, businesses, 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.

The Low Carbon Energy for Development Network report "Mapping the UK Research & Innovation Landscape: Energy & Development" (April 2008) identified UK research strengths and where future opportunities for development might lie.

This report builds on that work by considering UK commercial expertise in low carbon energy, where it might cross-fertilize with UK research expertise to establish areas of UK specialisms and how this might map onto both developing world needs but also market opportunities. This will ultimately support DFID in working with Innovate UK and BEIS to put together a programme that goes beyond the current series of Energy Catalyst and Newton programmes.

A picture of relevant UK capacity has been developed by consulting a range of UK experts (both academic and commercial) and businesses operating in this space, as well as reviewing various reports on energy access and international development. The review covered a range of themes relating to the provision of energy services within international development contexts.

This reports describes the findings and our conclusions on where the best synergies were identified between UK capabilities and developing country needs.

It starts by outlining the broad challenges and opportunities faced when introducing new technologies in a Global South context.

It then focuses-in on key technology areas where there are the most promising opportunities:

- Energy Systems
- Bioenergy
- Solar
- Thermal Energy
- Energy Storage
- Appliances

For each area, it outlines both developing country needs and market opportunities, how challenges play out around introducing the particular technology, UK capabilities in the area and finally, conclusions around what kinds of interventions could be most productive.

Although it is primarily about technologies, it attaches each one to the wider social, political and institutional contexts that ultimately dictate whether a technological solution is successfully adapted.

2 METHODOLOGY

The research consisted of a combination of desk-based research, a literature review and interviews and workshops with both technologists, academics, the business community and representatives from the UK Government.

The key elements involved:

- understanding the current landscape by identifying and surveying current support programmes and organisations (see Annexes 1 and 2). This included projects funded under the Catalyst programme in relation to the areas that secured the most funding, and the stage the technologies were at. We also reviewed the DFID evaluation reports from the TEA programme.
- working with the KTN and LCEDN members to build a picture of the diverse range of companies with technologies actively targeted at or relevant to developing countries. This identified companies that are fully aimed at developed country markets, solely focused on developed countries but with potential as yet untested, and a few in between that have had some success in developed markets and are starting to explore the potential opportunity in the developing world. Each of these tells a different story and the companies all had different support needs.
- developing a high-level framework to identify the range of factors that are likely to be important in assessing potential for a technology to be fit for purpose in a developing country setting.

Thirty-two interviews with business leaders, academics and policy makers were carried out to understand the specifics of developing world requirements, the adaptability of technology solutions and the challenges in exporting their technology internationally. (Annex 3 lists those who were interviewed.)

As the research was conducted over the summer, a number of potential interviewees were not available so there is scope to extend and deepen this research as part of the next steps.

3 CHALLENGES

THE POLICY CHALLENGE

With the backdrop of global population increase, rapid demographic changes, expanding urbanisation in developing countries along with climate change, a massive global challenge is to provide clean, green, secure, affordable energy for everyone as part of the transitions to low carbon economies. This means simultaneously:

- reducing emissions
- reordering current energy use regimes
- improving security of supply,
- while simultaneously reducing cost of energy

Current forecasts indicate 674 million people will still be without access in 2030, the SDG target year for universal energy access[1]. The average rate of electrification needs to accelerate to achieve the 2030 target, however progress on access to electricity is uneven across regions and countries. The challenge is especially pronounced in much of Sub-Saharan Africa, where progress on electrification is not keeping pace with population growth. Those gaining access will primarily be urban dwellers (but with the urban poor likely to continue to struggle[2]), while rural areas, where most of the energy impoverished reside, risk being left behind.

The ripples from these trends are profound. This is because slow progress on access to modern energy services (SDG 7) means slow progress on other SDGs. Access to energy is critical for poverty eradication (SDG 1), ending hunger (SDG 2), improving health and wellbeing for all (SDG 3), access to drinking water (SDG 6), and industrial development (SDG 8)[3]. Because energy is an enabler of social and economic activity, delay in universal access to modern energy services risks delaying progress towards all SDGs.

'Taking the Pulse – Understanding Energy Access Market Needs', a report produced by Sustainable Energy for All (SE4All), focuses on Sub-Saharan Africa and South Asia as having significant energy access gaps. The report finds that there are opportunities to close those gaps more quickly and at less cost.

The experience of countries that have already reached universal energy access, suggests that it takes strong leadership commitment, backed up by sustained public financing for grid-extension. The private sector increasingly plays a role in catalysing uptake of off-grid solar solutions, underlining the importance of a suitable enabling environment for new

[1] https://www.iea.org/newsroom/news/2017/october/universal-energy-access-by-2030-is-now-within-reach-thanks-to-growing-political-w.html

[2] https://www.worldbank.org/en/news/feature/2018/04/18/access-energy-sustainable-development-goal-7

[3] https://council.science/cms/2017/05/SDGs-Guide-to-Interactions.pdf

technologies, as well as strategic planning that clearly delineates the role for grid and off-grid approaches[4]

THE CHALLENGE OF INTRODUCING UK TECHNOLOGIES TO A GLOBAL SOUTH CONTEXT

In practice, historically, while the UK has invested considerable sums in research and innovation relating to "clean energy" technologies, the focus has primarily been on supporting the UK/Western nations' shift towards more sustainable energy use and may have limited relevance to countries where many of the conditions are very different. Hence, for example, a lot of research on bioenergy generation has focused on how the UK can shift to extracting energy from biomass where the biomass is often wood chips imported from Latin America and the context of extraction is within urban locations and contributing to the national grid.

As we will show, the focus on developing countries, especially in relation to poverty reduction, is on more local generation and micro-grid-based solutions as this can be made operational and more reliable more rapidly than relying on often weak national institutions. These institutions, even in relatively advanced African countries such as South Africa, struggle to respond to national scale energy demand in a reliable manner due to a range of factors including frequent industrial action. As a result, businesses have to invest in their own back-up generators.

Western energy-related technology is increasingly sophisticated and makes use of very advanced materials and processes that can be demanding of maintenance capability, spare parts and are optimized for more temperate climatic conditions (e.g. energy storage in electrochemical batteries and efficiency of silicon-based solar PV generation are both significantly affected by temperature).

There are a number of tensions when the twin drivers of economic growth in a developing country are sought to be combined with that of UK firms' achieving business expansion through access to these countries as markets. DFID is primarily focused on those towards the "bottom of the pyramid" where there is greatest need and poverty is most extreme but these inevitably have the least economic resources and are unable to commit to payment contracts. The challenge will include, therefore, making a technology available in a context where the service offered is affordable at the lowest level. We have heard it said that businesses transferring services from the West to India have to assume a 93% reduction in their price point in order to ensure the offer is affordable in that context.

From the point of view of BEIS and Innovate UK, the interesting and, arguably, more promising business opportunities, arise from larger scale energy generation and distribution – essentially linked to urban centres or the needs of large commercial operations or other organisations. Certainly, from the point of securing investment for the capital costs involved in installing new technologies, a model that involves less risk through having a more tangible market or relatively cash-rich customer, will seem less risky to investors. This

[4] https://www.irena.org/publications/2018/May/Tracking-SDG7-The-Energy-Progress-Report

also relates to the choice of target countries – the Newton Programme, for example, was explicitly focused on countries that were in the intersection between being deemed eligible for Overseas Development Assistance (ODA) by the Organisation for Economic Cooperation and Development (OECD) and yet had sufficient organizational capacity to be able to provide effective research and business partners to create the prospect of promising projects using the criteria used around research excellence and economic viability.

Another tension is in relation to the role of partners in the developing country. From the point of view of supporting economic growth in the country, the more the solution can involve the local population engaging in economic activity and enterprise the greater the flow of value that stays within the country. This can be seen in terms of a hierarchy of value that relate to different business activities:

1. hardware and its creation,
2. skills for users of the hardware so that they can benefit from it and be actively involved in its deployment and maintenance, and
3. innovation skills to enable the in-country population to generate their own solutions to their challenges which can lead to the greatest level of value retention.

From the point of view of the UK partner, we will argue that having in-country partners can be critical to success for market entry, however there can be many issues with the capacity of those partners and the need to develop a model of collaboration that is realistic and effective in the long run. This is a complex area for the UK firm to navigate with many issues that are in the intensely human domain of collaboration which can be far removed from their domain of technical expertise.

Ultimately, the role of energy access can be a key one in supporting economic transformation and this implies that a country/region will be changing over time as a result of better energy access. This is clearly positive from the perspective of DFID but also means that you need to find business models that are viable through a period of change. We understand that often it can take a number of years between a community having access to new energy resources and enterprise and economic activity growing as a result of that. Clearly while the absence of reliable energy can be a constraint on economic activity, having access to it does not immediately guarantee it will flourish as there will be a period of learning and adjustment to the new possibilities. This means that investments in micro grids that offer substantial increases in energy access for a community may not find that there is sufficient demand to cover their costs in the immediate period and further investment of support for economic activity and exploration will be needed to grow this.

It is important to recognize that business success could be achieved by selling a product/technology into a country at some scale without necessarily achieving the desired results in terms of economic growth or long term improvement in living conditions, despite the apparent connection that might exist between these. Thus, we have heard differing reports of the impact of the International Year of Light (2014) which included huge sales of solar powered lighting for domestic users across some African countries, and yet we understand that in some cases the experience of using these fell far short of the promise, for a variety of reasons. The legacy of this is that there is significant skepticism about the value of solar energy-powered devices that now needs to be taken into account and this will no doubt contribute to a greater challenge to introduce other energy technologies from the

West in convincing the end user to invest in these. Insofar as DFID/BEIS/Innovate UK have an interest in safe-guarding the reputation of the UK's technology offer to Africa, etc. it will be in their interests to operate some form of quality control to minimize the risk of a repetition of this.

More broadly, the dynamic of change is a common aspect that brings considerable risk to businesses and investors. Increasingly poverty is associated with conflict and crises of various kinds. Thus, the solution may need to be temporary or mobile such as that required by a refugee camp – and yet once these can be established they often become semi-permanent without the infrastructure having grown to support them. The more volatile and unpredictable nature of Government and regional administration in developing countries is another risk factor. These wider factors have a major impact and a key initiative led by Sustainable Energy for All is to publish "heatmaps" that give businesses and investors information about which countries have the best environment for investment in energy[5].

Finally, it is important to emphasise that ecological compatibility of technologies with local site conditions is fundamental to the success of development assistance. Development assistance organizations know that the specific sociocultural, political, economic and ecological conditions of a development site create the framework into which their efforts must be integrated. Each of these will affect the sustainability of the development project.

THE FINANCE CHALLENGE

The level of potential demand for clean energy across Africa and South Asia is huge and to meet this demand would require enormous levels of investment. The public or charitable sector cannot meet this need and real solutions will require substantial state, supranational institutional and donor investment to be combined with that of the private sector.

According to the International Renewable Energy Agency (IRENA) a key barrier to private investment in renewable energy projects is that, compared to non-renewable energy projects, the upfront costs are higher and, given a lack of track record in many economies, they are associated with a higher risk. Governments, therefore, need to create public policies which incentivise investment into renewable energy and which provide favourable returns on investment for the private sector. (Advancing renewable energy in Africa together with national climate plans, IRENA, 2016).

Access to finance has been identified as the most significant challenge to the penetration of solar energy technology in Africa. The effects of limited financing options are felt by all parties, from manufacturers to importers, distributors, dealers and end users (Lays et al, 2012).

Due to the size of capital investment even for village sized energy generation units or grid systems, the biggest barrier to sales is usually the customer ability to pay and creating a clear route to becoming profitable once the capital investment has been made is hard. As a result, securing funding and finance can be very challenging. Anecdotally we understand

---

[5] https://www.seforall.org/heatmaps/electrification/RISEbusiness

that most mini-grid installations across Africa have not covered their costs, let alone generated profit.

Demand for electricity from small industry and businesses, which is defined as the productive use of energy (PUE), is a key success factor for micro-grids. Because of the typically low energy usage of residential customers, without linkage to and support for these energy users, micro-grids are likely to struggle to reach the critical revenue needed for financial viability[6]. Productive users are also important to enhancing the economic and social development impacts of micro-grids and rural electrification programs more broadly.

As previously noted, for private investors, the barriers to investment include the high level of risk and long lead times of early-stage projects and the excessive complexity of bespoke deals[7]. Typically, investors need to develop a specialist understanding of particular developing country markets in all their complexity in order to accurately assess and mitigate the risks. There can be institutional investors that are willing to take a longer term, patient capital perspective, and accept modest returns but these will still need a good level of confidence that the risk exposure is acceptable – and this is where the changing nature of Government and policies can have a negative impact. It is unusual for an individual or corporate investor to combine a focus on both developed and developing country markets.

CHALLENGES FACED BY UK COMPANIES LOOKING TO WORK IN THE GLOBAL SOUTH

Our research and interviews with companies that have some experience of working on energy technology and solutions for developing countries have highlighted a range of challenges and issues that come up repeatedly.

In particular, regulations can be hard to understand and Government policies can be more fluid, it can seem chaotic and very different to Western or other more familiar developed country markets. This environment is often outside any previous experience they may have had, unless they have particularly focused on the developing world, and their normal intuition can be misleading. Not only that but each country can be very different. Even within a country there can be considerable variation - if regulation is poorly made/ poorly communicated in country there may be considerable variation in regional interpretation of the regulations.

Essentially there is considerable distance between the company's base and the intended market – the distance can be both geographical, cultural and of other forms.

This can require them to either spend a great deal of time building an understanding or else they need to find individuals or organisations within the chosen market(s) who can provide them with the insights and understanding they need. Many of the companies we spoke to that had achieved some success either established a base in the country or else they had chosen the country because of a partner organisation – not necessarily another business –

[6] https://storage.googleapis.com/e4a-website-assets/Productive-Use-of-Energy-in-African-Micro-grids.pdf

[7] https://www.odi.org/sites/odi.org.uk/files/resource-documents/12365.pdf

who had significantly reduced the time and effort involved in establishing a viable presence. Where this exists, the in-country partner could be another Western firm that has established a footprint and is achieving impact but would benefit from a partnership with another company back in the UK that has technology that would add value to their own core agenda – we have seen examples of this.

There is a tendency to focus on finding technologies or “innovation” that can make a big difference in a particular context (ie focusing on some new technology as the primary agent of change) but our explorations have highlighted that the reality tends to be more complex than that.

In practice, there can be a great many factors that affect the ability of people to access the energy they need for their domestic and economic activities – with barriers to this access coming from public policies, weak infrastructure, inadequate institutions, corruption, environmental and climatic factors that can create more extreme and challenging conditions in which any technology must operate. Another challenge is understanding the social and cultural context in which energy use takes place so ascribing 'western centric' motivations, drivers and explanations fail to take into account local social factors. Finally, and without stating the obvious, the of the most pervasive and challenging aspects of any developing country is the level of poverty and the limited economic resources at the individual, community, municipal and national level.

This means that any attempt to change the situation and improve access to energy that does not take account of these circumstances will only have limited take-up or impact. Pilots of the use of technology that succeed but benefit from unrealistic levels of support or resource will not act as a genuine test.

Further, there are few single pieces of energy technology that can exist in isolation from a wider technological infrastructure. Some facilitate the distribution or storage of energy, or generate energy to go into another system. Thus, any technology needs to operate within an energy system and these have to be constructed to suit the particular circumstances of generation resources, storage and load-shedding capabilities and energy uses.

With regards to support programmes, the main offers that have been run between DFID and Innovate UK have essentially been competitive programmes offering funding for collaborative R&D projects. These require the projects to be led by a business but to involve academic partners and a commercial partner in the target country in order to benefit from local knowledge and support economic growth within the country. These will have limited impact unless the other challenges are addressed.

SUMMARY OF CHALLENGES

The key challenges to achieving sustainable energy access are a complex mix of social, political, financial, technical and environmental issues which vary from region to region and country to country. However, there are some broad, overarching themes that affect both the South Asia and Sub-Saharan African regions.

Most of the challenges do not directly relate to the technologies available, yet many might be solvable through the application or other technologies or interventions (eg training) that could be supported by innovative technology. As such, each challenge should be assessed in terms of its potential as an opportunity for the UK plc. The following is a collated list of challenges.

- High Dependence on Traditional Fuels
- Relatively Limited Utilisation of Renewable Energy Potential
- Lack of Energy Infrastructure
- Insufficient Access to Funding & Finance
- Undeveloped Market Structures
- Skills shortages
- Lack of awareness
- Limited or no access to technical support services

These can be broken down into issues and challenges:

- *Policy Barriers*
- Low priority given to Renewable Energy (RE) & Energy Efficiency (EE) in national planning and weak implementation framework
- Weak environmental regulations
- Fossil fuel subsidies
- Absence of feed-in tariffs /other incentives
- Lack of incentives for private sector involvement and inconsistent policies
- *Economic Barriers*
- Small economies of scale, high initial capital costs, and long payback periods
- High perceived risks and uncertainties
- High installation costs at the end user level
- Lack of access to credit and insufficient government financial support;
- Limited knowledge on market potential
- *Technical Barriers*
- Lack of standardised technology
- Limited local manufacturing of specialised equipment
- Limited technical capacity to design, install, operate, manage and maintain renewable based modern energy services
- *Information Barriers*
- Lack of quality information about RE resources and technologies, EE, equipment suppliers, and potential financiers
- Inadequate training and capacity building
- Insufficient information available on RE and EE for policy making and mobilizing communities
- *Human Resource Barriers*
- Insufficient expertise in business management and marketing skills
- Limited in-country capacity for RE data collection, analysis, and project development
- Lack of expertise and services in system design, installation, operation and maintenance of RE and EE technologies

4 ENERGY SYSTEMS

Here we argue for taking a systems approach to developing programmes to deploy UK strengths to impact on developing country energy access needs. This also sets out the overall recommendations for the approach to setting up and running a programme. It is intended that this would provide an overarching method and framework for developing opportunities in other technology areas discussed in this report.

THE MARKET

There are very few single pieces of energy technology that can exist in isolation from a wider technological infrastructure. Some facilitate distribution of energy, or storage or generate energy to go into another system. Therefore, an energy systems approach presents an opportunity to align and connect local activities and investments, leapfrog the standard grid stage and move to a more integrated system.

In developing countries, remote micro-grids may offer a cost-effective, sustainable solution to providing electricity and provide heating/cooling. Estimates of the global remote micro-grid market suggest it will see substantial increases to as much as $112bn by 2026[8]. Additionally, rapidly increasing urbanisation and economic growth is driving demand ever higher in many developing economies. Given the $37 billion (in cash, not opportunity cost) that the International Finance Corporation (IFC) estimates is spent annually on meeting these basic household energy needs, there is certainly a market for better solutions.

With the central grid unlikely to reach the majority of the Sub Saharan African population in the medium- or even long-term, mini-grid distributed energy service companies (DESCOs) are seeing a potential market worth hundreds of millions of dollars that could also blossom into other revenue streams.

A smart grid approach can usefully provide a hook for considering a wider energy system and how to blend external expertise with local resources. It opens up opportunities around:

- Improving and developing policy and regulatory frameworks around energy in developing nations
- Considering the role and interplay of different technologies in a holistic way
- Thinking about how to align effectively with local resources, capabilities and institutions
- Introducing complementary expertise around diagnostics, data/informatics, user led design and behavioural science
- Creating wider economic value chains and considering business models that incorporate opportunities for local entrepreneurship
- Scenario planning and road-mapping for the future

[8] https://www.smart-energy.com/resources/reports-and-white-papers/microgrid-tech-market/

CHALLENGES & OPPORTUNITIES

Challenges	Opportunities
Utilities in developing countries are often capital-constrained, limiting their ability to invest into smart grid projects even if they are economically viable.	Early stage grid development allows developing countries to technology 'leapfrog' and directly install smart grid technologies when building up their network.
Upper cap on the utility tariffs which can be charged so as still to remain affordable for the users.	Potential for innovative energy services such as linking payments to the mobile communications network, installing local charging stations, or using mini/micro grids for rural electrification.
Lack of detailed data, for example of the systems operation and consumer demographic. This kind of data is not readily available in many developing countries.	Reduce technical and power theft losses in the power network. By recording electricity loads across the power lines smart grids can be used to track and reduce these losses.
Regulatory and institutional issues may limit innovation. For example: regional standards, harmonising of different power networks, ensuring data privacy.	
The market must be carefully segmented to identify where it makes most sense for mini-grids of different specifications to be installed	Innovation of a range of appropriate business models that leverage technology advances to cost effectively reach customers

EVIDENCE OF UK CAPABILITY/INVESTMENTS

The UK has been at the forefront of smart grid thinking and innovation. Due to early government support for smart grid technologies there is considerable UK expertise and experience in smart grids. The establishment of the Energy Systems Catapult was a result of Innovate UK's analysis that energy systems represents an area where the UK has significant world class capability and potential to win business globally. Figures from Europe's joint research centre show that in 2014, the UK was leading the way in Europe in terms of investment in research and development of smart grids and that in 2017 UK investment in smart grids was still the second highest after Germany's[29].

Data from Innovate UK on the Energy Catalyst funding rounds also shows significant activity in this sector with 10% of projects being involved in grid technology including smart grids. Some of this funding was directly to projects working on initiatives intended for the developing world whilst others were for more UK orientated smart grid technology. A key

[9] https://ses.jrc.ec.europa.eu/smart-grids-observatory

question is the degree to which any elements of smart grid technologies developed for the UK can be successfully transferred to developing countries.

The Energy Systems Catapult is primarily focused on the developed market. However, it represents an excellent concentration of key companies directly working in the energy system components and integration sector which could be instrumental in equipping such companies with the very different skills and knowledge required to be effective in the developing world.

Some examples of UK firms we have come across are:

- Bright Green Hydrogen Ltd offers consultancy and demonstration of renewable energy, hydrogen energy storage and mini-grid technologies.
- Off Grid Energy Ltd provide efficient, low carbon, grid quality power solutions in places where connecting to the Grid is not possible, too expensive or too complicated. They have developed smart technology that delivers systems that can combine conventional power generation with renewable resources like solar PV and wind power to provide innovative, tailored solutions for independent energy needs.
- Pinnacle Power builds bespoke energy networks for new and existing developments (currently in the UK only). They design, develop and then operate heat and power generating plant to offer clients an all-encompassing Energy Services package that makes the best use of available resources, local conditions and environmental factors.
- Tangent Energy supply an energy control system for modern energy infrastructures; harvesting data from all parts of the system, prioritising sources and intelligently controlling loads. They also have an energy storage system that combines batteries with bi directional power inverters in a weather proof enclosure. The Energy Systems Catapult is currently supporting them to launch a project in Africa.
- RedT Energy mainly focuses on storage, but has worked on a mini-grid project in South Africa.

Some companies supported by the Innovate UK in this area include:

- Entrust Smart Home Microgrid
- Solafin2go
- Orxa Grid

In terms of the research base, the UK has world leading research groups such as:

- The Institute for Energy Systems (IES) at the University of Edinburgh.
- Multi Energy System research undertaken at Manchester University.
- The Centre for Advanced Materials for Integrated Energy Systems (CAM-IES) CAM-IES - a partnership between industry and the universities of Cambridge, Newcastle, Queen Mary and University College London, focused on the development of advanced materials for energy conversion and storage.

CONCLUSIONS/POSSIBLE INTERVENTIONS

Our research has demonstrated that there are a number of reasons why the more conventional hands-off approach to supporting technologies entering a market is unlikely to be successful in this case. There are a wide range of very particular and highly challenging aspects of developing country markets which creates the conditions where technology-based businesses are less likely to succeed. This has two broad implications:

- Technology businesses are likely to be wary of these markets unless they have strong "demand signals" and clear parameters against which to assess their technical capabilities.
- It is critical that the "mix" includes individuals and/or institutions with the necessary local knowledge and connections to bridge the gap.

However, given the size and potential of these markets, if these issues can be successfully addressed then the scope for having an impact and achieving business success is considerable.

We make the following recommendations, therefore, for the kinds of interventions needed.

A UK offer around energy systems could act as a mechanism for bringing together UK expertise – both academic and commercial - to offer more comprehensive solutions. This could include a range of elements:

- Help to define needs through engagement with end-users, civil society, government, policy makers and commercial and finance partners
- Support and expertise in facilitating and bringing together a coalition of partners to accelerate system level solutions that blend external expertise and technologies with local resources, capabilities and initiatives. This could involve combining UK expertise around:
    - Development of business models that incorporate opportunities for local entrepreneurs, ensure wider community benefit and create a value chain of opportunity – and that lead to the identification of technologies needed to make these viable
    - Energy technology and systems thinking – as described in the other sections
    - Data, informatics and diagnostics – to support energy system and supply management
    - User led design and behavioural science – to provide methodological support to interpreting what is known about culture and user motivations into support for designs
    - Strategy Development and roadmapping
    - Action Research/Living Lab approaches to develop and demonstrate what works and gradually bring to scale innovative and integrated solutions and to use as a basis for leveraging wider investment

This will require strong support for networking and brokering interactions between different communities to form virtual teams that can work together around a common challenge or focus. The UK has significant strength in building collaborative projects in this way and bodies such as the LCEDN and the KTN have existing networks and skills to build on.

Finally, a recurring theme in interviews and analysis is the difficulty for UK firms to navigate the complex and varied regulatory environments in different countries across the developing world. This is made even more difficult where regulations are unclear, contradictory or not clearly communicated. The UK Government could offer support in helping developing nations to identify and implement longer term structural, policy and system level reform to create a better enabling environment for smart systems. The UK has bodies operating in the commercial realm that would be well placed to engage in this and where there could be further flows of value back into the UK economy. This could include:

- Strengthening institutions and regulatory frameworks
- Support around standards and accreditation
- Capacity building amongst policy makers

OUTLINE PROCESS MODEL

We believe we have identified from our conversations a set of factors that are critical for success.

- A business model that fits the context should be the starting point:
  - Technology is of no value without this. **Technology is an enabler** and must support the business model and not undermine it (e.g. must not push price of kit up prohibitively or create dependency on maintenance skills or components that are not available).
  - Best to look for **service delivery business models** that are backed up by the necessary hardware, infrastructure, systems, etc.
  - The business model must be **well grounded and developed in depth.**
  - Different **technologies will generally be needed to work in combination** – not just one – and this means that they will generally need to come from multiple companies – UK companies can offer a mix of added value contributions to build successful systems collectively.
  - Ideally, a **business person familiar with the context would be in the lead** – someone who sees a business opportunity, already with the right connections and basis for a supply chain, etc. – not a technology expert.
- Local partners with the right connections and knowledge:
  - To implement a sustainable business, the core service provider will need multiple partners with different roles (In many cases someone has to be able to manage the whole value chain – otherwise there will be an aspect that is vulnerable – developing countries do not have a good business infrastructure to provide this.)
  - It is not enough to just find any partner in the country you are targeting, it must have the right contacts, credibility, knowledge, ambitions, fit with the UK partner so as to create strong win-win potential.
  - Much more support is needed to building strong and effective partnerships.
  - Need to set up projects with governance that secures involvement of existing in-country bodies in decision making – the key players in the community of interest will be critical in determining success and acceptance.

- Incidents of poor tech being sold to Africa damaging Western/UK reputation, and wasted effort to set up trials in country – best to test in the UK and have high quality standards before allowing in-country implementation.
- Secure investor interest early on – and engagement throughout, or else present them with a well-developed business plan showing expansion potential and pilot results

A general process should consist of the following sequence:

1. Focus on one particular market and **develop deep understanding** of context – could be a particular scenario in a given country where there is a particular mix of energy resources in place. Draw on academic knowledge and experience.

2. **Road-mapping** with in-country partners to plot a course to low carbon economic growth and solutions. This would help identify where wider contextual factors need to be addressed such as around standards or in-country capacity.

3. **Competition for business opportunity** proposals where the prize is both financial and other support to develop service-based business opportunities – the focus would be on finding/stimulating the creation of teams who have the ability to build service delivery propositions that reflect an accurate understanding of a need. This should include mechanisms for providing access to academic partners, charities or other bodies active in the country (eg through offering innovation vouchers). Distributed Energy Service Company models represent the kind of thing we have in mind.

4. Encourage/facilitate **engagement with investors** early on so that these can keep an awareness of progress and potentially get involved/contribute as they choose.

5. Part of the on-going support would be access to a **range of tools/mechanisms for sourcing technologies and skills to fill gaps identified**. Eg. SBRI challenges, open innovation platforms, etc. A budget would be set up to support R&D, design work, piloting, for technology companies which are selected as offering the best prospects. These open innovation platforms would be run to draw as widely as possible on the UK technology expertise so not just energy tech. Where in-country skills are lacking, the project would be enabled to reach out to the UK Vocational Education sector to seek partners for skills training in-country.

This draws on the Reverse Funnel Innovation model promoted by Jim Dawton at Impellor Ventures. [10]

This approach fits well with the **World Bank Climate Technology Programme** and they are looking for developed countries to partner with them in setting up new initiatives under this in Ghana, Kenya and South Africa.

[10] http://honey.co.uk/wp-content/uploads/2016/06/June2016_Output_SO_V5-2.pdf

5 BIOENERGY

THE MARKET

Since agriculture is still the mainstay of Global South economies, the most obvious opportunities for sustainable development of the sector are based around deploying a circular economy approach to generate energy from biomass using approaches other than burning to release energy. Such approaches need to be set within the context of viable agricultural value chains through using agricultural waste products to generate energy (and income/potential products) for both the farming sector and local communities e.g. cassava residues commonly discarded by subsistence farmers still contain significant starch which can be extracted for fuel and other products.

Historically biomass fuels were broadly produced in the same region in which they are used, but that pattern has been changing, leading to the development of and consequent rapid expansion of biofuel markets worldwide[11]. A recent International Energy Agency (IEA) report on bioenergy estimates that modern bioenergy will lead the global growth of all renewables to 2023[12].

However, globally, whilst there has been some growth in the uptake of bioenergy within African, Asian and Latin American contexts, bioenergy growth in the global south has tended to lag behind the substantial acceleration in solar installations over recent years.

In terms of application, biofuels for transport have probably received the most amount of international attention and resources. India, for example, has taken explicit policy positions and in 2009 instituted a national biofuels policy, promoting the use of biofuels in transport, and aiming to replace 20% of petroleum-based fuel with biofuels by 2017. In December 2017, the Indian Ministry of Road Transport & Highways made it clear that India sees a switch away from fossil fuels as an economic and environmental necessity, promoting a push by India to become a "Methanol Economy"[13] and eventually reduce imports of petroleum to zero.

Biofuels can be, and often are, classified by generation[14], while there is no single strict technical definitions for this classification they are helpful in distinguishing between the

---

11 'Sustainable Biofuels in the Global South', accessed 13 August 2018, https://research.cbs.dk/files/46592272/stefano_ponte_sustainable_biofuels_postprint.pdf.

12 https://www.iea.org/newsroom/news/2018/october/modern-bioenergy-leads-the-growth-of-all-renewables-to-2023-according-to-latest-.html

13 'Methanol Economy for India: Energy Security, Make in India and Zero Carbon Foot Print', accessed 13 August 2018, http://pib.nic.in/newsite/PrintRelease.aspx?relid=174919.

14 Eva-Mari Aro, 'From First Generation Biofuels to Advanced Solar Biofuels', *Ambio* 45, no. Suppl 1 (January 2016): 24–31, https://doi.org/10.1007/s13280-015-0730-0.

feedstock and the conversion method used,[15] and there are more or less commonly accepted definitions:

- First generation: This category includes biofuels produced from well-established and understood processes, using a portion of the above ground biomass of a plant. Generally, these fuels are produced from edible parts of agricultural crops, on land suitable for agricultural production. Bioethanol is most commonly produced from sugar and starch and biodiesel from oil crops.
- Second generation: This includes biofuels produced from lignocellulosic biomass from non-food crops like grasses, trees or waste wood, as well as the inedible parts of food plants like straw and husks. The most common product in this category is bioethanol.
- Third generation: These are derived from biological processes like the industrialised production of algae[16,] or hydrogen production from biomass gasification. They still require biomass to be destroyed as part of the process to produce fuel, but do not compete with arable land, and use significantly fewer resources in generating feedstock. Most third generation biofuel systems are not yet rolled out at commercial scale or commercially viable at this point.
- Fourth generation: The fourth generation of biofuels will not require the destruction of biomass to be converted to fuel. At this point, the aim is directly converting available solar energy to synthetic chemical fuel using inexhaustible, cheap and widely available biological resources. Photobiological solar fuels and hydrogen production as well as liquid electrofuels are current research targets. Photochemical carbon dioxide reduction would also allow for the conversion of CO^2 into fuels[17]. Fourth generation biofuels are still at an early stage of development.

The past decade has seen a rise in the adoption and deployment of bioenergy technologies, especially the production and use of liquid biofuels, in the Global South[18]. This adoption has been used as a mechanism to increase energy self-sufficiency, reduce import costs, and strengthen domestic agricultural development[19].

15 'The Current Status of Biofuels in the European Union, Their Environmental Impacts and Future Prospects', accessed 13 August 2018, https://www.easac.eu/fileadmin/PDF_s/reports_statements/Easac_12_Biofuels_Complete.pdf.

16 Firoz Alam, Saleh Mobin, and Harun Chowdhury, 'Third Generation Biofuel from Algae', *Procedia Engineering*, The 6th BSME International Conference on Thermal Engineering, 105 (1 January 2015): 763–68, https://doi.org/10.1016/j.proeng.2015.05.068.

17 'Sunshine to Petrol - Solar Recycling of Carbon Dioxide into Hydrocarbon Fuels', accessed 14 August 2018, https://energy.sandia.gov/wp-content//gallery/uploads/S2P_SAND2009-5796P.pdf.

18 Kathleen Araújo et al., 'Global Biofuels at the Crossroads: An Overview of Technical, Policy, and Investment Complexities in the Sustainability of Biofuel Development' (Agriculture, 29 March 2017), http://www.mdpi.com/2077-0472/7/4/32/pdf.

19 Kathleen Araujo, *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation* (Oxford, New York: Oxford University Press, 2018).

OPPORTUNITIES/CHALLENGES

Harnessing biomass to generate energy can provide major benefits to countries in the global south, and advances leading to the development of commercial scale second and third generation biofuel production would have a major impact on global energy production.

However, while biofuels can provide major benefits to countries in the global south, and advances leading to the development of commercial scale second and third generation biofuel production would have a major impact on global energy production, there are a number of challenges involved.

There are a number of challenges involved in existing bioenergy strategies:

- the implications of competition for resources between dedicated biomass production and food production (particularly in relation to land and water). The land-use tension is significantly ameliorated by a focus on wastes, residues and co-products rather than primary products, such as the 'Rice straw to biogas project', or 'DryGro Energy Crops'. Caution is still needed not to valorise the residues to the extent that they drive primary production, but in most valuable contexts that is not a realistic concern.
- the impacts of intensified biomass production on ecosystem service provision (e.g. water use and hydrological impacts; carbon stocks; biodiversity; soil degradation).
- the impacts of bioenergy combustion on carbon emissions. Biofuels can in theory provide an avenue for reducing GHG relative to fossil fuels. However, emissions reductions depend heavily on how the biofuels are produced, as well as transport methods and what fuels they displace. The conversion of rainforests, peatlands, grasslands or other carbon sinks to produce first and second generation biofuels can result in a release of more CO^2 than the produced biofuels displace from fossil fuel use. In areas where high carbon stock on land exists e.g. Brazil, Southeast Asia, and the United States production of biofuels in this way can create a "biofuel carbon debt", releasing to 420 times more CO^2 than the annual reductions in GHG production from fossil fuel use displacement.[20] The best example is probably palm oil in Malaysia – see Thornley and Upham's work[21] on soy, palm etc. showing payback periods of around 1000 years. However, biofuels produced from waste, as with the rice straw project to biogas project show potential to minimise this issue, while complimentary carbon capture technologies can also mitigate GHG emissions from biofuel use.
- The impact of burning organic feedstocks on air quality. We understand that there is currently a mixed evidence base over the fuels and combustion conditions under which biofuels may be better or worse for air quality than fossil fuels in transport.

[20] Joseph Fargione et al., 'Land Clearing and the Biofuel Carbon Debt', *Science (New York, N.Y.)* 319, no. 5867 (29 February 2008): 1235–38, https://doi.org/10.1126/science.1152747.

[21]https://www.researchgate.net/publication/236146900_The_sustainability_of_forestry_biomass_supply_for_EU_bioenergy_A_post-normal_approach_to_environmental_risk_and_uncertainty?enrichId=rgreq-cbcadcd937d652c7e6931042af6a40d1-XXX&enrichSource=Y292ZXJQYWdlOzIzNjE0NjkwMDtBUzo2OTc5NDUxNTAyMDU5NTdAMTU0MzQxNDQ5OTQzMg%3D%3D&el=1_x_3&_esc=publicationCoverPdf

- The scale of bioenergy applications and potential beneficiaries along the full supply chain from biomass production to energy consumption

Even though traditional biomass use for domestic cooking and heating is one of the main energy provisions in the Global South, one of the complicating factors around the establishment of more systemic, large scale and potentially commercial biomass provision approaches is that there remains a lack of consensus about the consequential impacts, as noted above.

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 arguments in favour of bioenergy initiatives remain partial, frequently controversial and subject to change.

In addition, the successful financing of large scale biofuel projects requires significant capital. Constructing biofuel production plants producing 50 million gallons of usable fuel per year would require tens of millions of pounds in capital investment[22]. Smaller units suitable for village or community-scale use require significant capital investment.

Continued cost-efficiency is dependent on a regular, consistent and affordable feedstock. However, agricultural is often practised in rotation and there is a need to find ways in which integration of biofuel production into existing farming systems can deliver benefits e.g. increases in soil carbon and fertility, increases in biodiversity and phytoremediation of harmful heavy metals.

For a variety of reasons, therefore, bioenergy will only ever be part of the energy generation solution for a particular location/community and will need to be implemented in a wider system that integrates other energy sources and balances across these. This reinforces the need for a systems perspective, rather than simply looking at bioenergy generation as a solution in its own right.

EVIDENCE OF UK CAPABILITY/INVESTMENTS

RESEARCH

UK research investments in this area can be divided into several different themes including:

- whole bioenergy systems and sustainability assessments; biomass production;
- bioenergy processing and conversion technology (i.e. gasification, biogas or anaerobic digestion, briquetting etc.);
- environmental impact assessment

22 'Finance and Investment in the Biofuels Sector - Carbon Trust', accessed 14 August 2018, https://www.carbontrust.com/news/2013/10/finance-and-investment-in-the-biofuels-sector/.

- socio-economic impact assessment
- Wider social science including work on public perceptions, bioenergy policy and governance

The Supergen Bioenergy hub provides a key focus to bring together the UK's capability in bioenergy. Since 2012 it has operated under Prof. Patricia Thornley (now at Aston University) and has just been commissioned for a further 4 years to consider both thermochemical, biological and catalytic technologies. There is significant potential to leverage these in a Global South context, but there is a need to connect that scientific activity with economic, social and environmental challenges in a Global South context. At present delivery of benefits to beneficiaries in the global south is considered out of scope for the hub by UKRI, however where researchers have participated in additional projects e.g. R2B, Sweet energy etc. there has been significant progress.

The world leading expertise within the academic base in bioenergy system assessment could provide an invaluable underpinning support to testing new approaches/technologies and supporting a growing industry in this area by reducing the costs and risk of ineffective implementations. This aligns with the points we make about quality control in relation to appliances. For example, DFID have already invested in this area as a component of TEA [23] whilst the new MECS programme[24] will also be exploring new developments in areas such as smaller-scale biogas cooking, transportation networks and payment systems. The link between both these initiatives and the academic research community however has been limited to date, and there is considerable scope to grow linkages and find synergies.

Our analysis of the current energy and development research portfolio reveals a reasonable range of bioenergy-focused projects (with 32 % of Innovate UK grants including a focus on some form of bioenergy), 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. Understanding the underpinning science of feedstock conversion into energy provides translatable knowledge that can then be applied more efficiently to the myriad of global south feedstocks and so involvement and knowledge exchange around UK science is really valuable here.

There is pretty good local/in-country knowledge of feedstock resources in many cases, but it is just not collated/counted by those who report on these issues. If you look at FAO initiatives they have a biomass resource assessment tool[25] (lots of countries have achieved this), and some have even developed strategies, but then progress appears to halt – at the moment there are no incentives to support the right sort of plants that will deliver benefits and inadequate consideration of delivery of social benefits rather than profits.

[23] https://devtracker.dfid.gov.uk/projects/GB-1-201878/documents

[24] https://www.mecs.org.uk

[25] http://www.fao.org/energy/bioenergy/bioenergy-and-food-security/assessment/befs-ra/natural-resources/en/

Emerging themes in bioenergy have been identified and include, inter alia:

- further research into conversion techniques most relevant 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.

In terms of particular strengths, 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 on this which has been applied to Non-Western contexts, although most expertise is not focussed there.

One problem is that there is not sufficient UK funding or incentive for academics to engage in the more challenging issues in the developing South, as there are plenty of challenges and interesting opportunities to do cutting edge research closer to home.

Innovation in the UK is broad, but there is a noticeable trend, identifiable in the data[26] from the four rounds of the Energy Catalyst Funding from Innovate UK, as well as a broader view of UK university research on Biomass (including Durham University[27], Aston University[28] etc..) that novel fundamental research is focused on third and fourth generation biofuels, while innovative engineering solutions are more likely to be aimed at improving the efficiency of existing first and second generation approaches. The 'siloized' systemic incentives in the academic world do not encourage/reward those focusing on resolving transdisciplinary practical issues with older technologies, preferring to push towards "excellent" research looking at the lead edge models.

UK COMMERCIAL SECTOR

Bioenergy is a well-developed and varied sector in the UK, with a large variety of end-uses, technologies and fuel inputs[29], providing a significant economic and energy benefits. The UK landscape is dominated by SME's and the research base is large (over 70 institutes) but fragmented, although the Bioenergy Superhub is seeking to address this.

---

26 'Innovate UK Funded Projects since 2004', GOV.UK, accessed 13 August 2018, https://www.gov.uk/government/publications/innovate-uk-funded-projects.

27 'Durham Energy Institute : Biofuels - Durham University', accessed 13 August 2018, https://www.dur.ac.uk/dei/biofuelsresearch/.

28 'European Bioenergy Research Institute (EBRI)', accessed 13 August 2018, http://www.aston.ac.uk/eas/research/groups/ebri/.

29 'Biomass Sector Review for the Carbon Trust', accessed 13 August 2018, https://www.carbontrust.com/media/77236/ctc512_biomass_sector_review_for_the_carbon_trust.pdf.

Given the size and diversity of the sector, there is a wealth of broad and deep expertise around the fuels themselves and related technologies, across both industry and academia.

Bioenergy is well integrated into the economy, with biodiesel and bioethanol[30] making up part of the UK's transport fuel mix, and bioenergy being the single largest component of renewable electricity generation[31] and present to some degree in all parts of the UK's energy spectrum[32].

There are some notable successes that are showing real promise in particular markets and that could become the basis for much wider interventions. Thus, another type of opportunity with a UK company taking the lead is in deliberately seeking to grow Crassulacean Acid Metabolism (CAM) plants in areas without natural vegetation due to aridity. Tropical power is aiming to grow at least ten and possibly twenty tonnes of dried biomass per hectare each year. This is much more than is possible elsewhere. They have then built large size AD turbines so that they can produce large amounts of electricity at night when there is no solar energy being generated. They are currently trialling these in Kenya and they are also refining their AD system and trialling options that will derive even more energy from the same feedstock. There are 2.5 bn hectares around the world that are semi-arid and could be locations for growing CAM crops to generate energy.[33]

CONCLUSIONS/INTERVENTIONS

Capitalising on UK research strengths and commercial expertise, there is a need to catalyse market opportunities for bioenergy entrepreneurs and innovators to meet developing country needs.

Consideration should be given to:

- How we can re-frame the existing strengths in UK bioenergy research and deployment in a developing world context - in particular, through considering the support and incentives that might encourage collaboration between bioenergy researchers and their counterparts on development studies, and also through identifying opportunities for interdisciplinary work and practical application of research through Global South projects.

---

30 'Renewable Transport Fuel Obligation Statistics: Period 10 2017/18, Report 1', accessed 13 August 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656292/rtfo-year-10-report-1.pdf.

31 'UK Energy Statistics, 2017 & Q4 2017', accessed 13 August 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695626/Press_Notice_March_2018.pdf.

32 'DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2018', accessed 13 August 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/731235/DUKES_2018.pdf.

33 The Switch: How solar, storage and new tech means cheap power for all, Chris Goodall, 2016

- How we can facilitate and enable commercialisation opportunities in the Global South from UK research investments in bioenergy.
- How can we build on and scale-up successful experimentation in smaller-scale biogas projects and professionalise their delivery – e.g. through the developments in PAYG applications being considered by BBOX and biogas developers in Rwanda.

In terms of market opportunities where the UK might develop a specific offering, bioenergy systems looks promising for further investigation. The potential impacts of bioenergies on wider ecosystems, carbon emissions and also on local communities and socio-economic dynamics, is complex and remains a significant inhibitor for commercial-scale deployment.

Given UK strengths around the nature of whole bioenergy systems, the sustainability of different options and the role of bioenergy within wider energy system strategies, there is a potential offering in helping developing nations to build capability around sustainable deployment of bioenergy. This would also act as a fulcrum for then introducing specific UK expertise and capability across a range of biofuel technology applications.

CASE STUDY: STRAW INNOVATIONS

Straw Innovations Ltd was started in December 2016 with the purpose of making better use of Asia's leftover rice straw. The company is developing an integrated process that will use this vast resource to produce more food, fuel and green construction materials.

Each year 300m tonnes of rice straw is burned as waste in Asia, with the associated negative environmental impacts. In India, the effect on air quality has been so marked that on certain days all the schools in Delhi were forced to close, and even NASA images showed thousands of fire spots in Punjab and the resultant smoke. So, the problem being addressed is not just one of affordable clean energy, but also reducing air pollution. At the same time, over 600 million people lack energy access in Asia.

The technology seeks to develop a village scale commercially attractive and optimum process to convert rice straw into biogas. Two 500 cubic metre 'dry' digestors from QUBE Renewables Ltd in Somerset have been supplied and installed on site at Los Banos in the Philippines. CO^2 and mushroom crops are also outputs from the process which provide options for commercial exploitation. (CO^2 can be converted to building materials with the addition to cement substitutes). The straw and manure left over after AD makes excellent fertilizer, which can then be recycled to the rice fields and potentially raises rice yields by 10%-15% compared to artificial fertilizers

A village scale pilot plant has been set up in the Philippines with project partners. The project started in March 2017 and will run to February 2020. The pilot plant will seek to successfully demonstrate the technology and supply chain so a full scale commercial plant can be set up thereafter.

6 SOLAR

THE MARKET

Off-grid solar solutions ranging from solar home systems to solar mini-grids are emerging as an important driver of rural energy access, complementing grid electrification in some countries. To get electricity to millions by fixing all the transmission lines for the grid would be very expensive and slow. Solar is quicker and more reliable. In countries with relatively weak Government machinery solar allows the devolution of decision making and fund raising to local institutions, businesses and householders (Goodall, 2016).

Solar PV technology can be employed in a wide range of domestic, agricultural and industrial uses and may form both off-grid and grid-connected energy generation capacity.

Three main categories can be described:

- Off grid non-domestic solar PV: In small industrial, agricultural and medical settings in remote locations these systems may provide power for a wide range of crucial services such as telecommunication, water pumping, vaccine refrigeration and cooling and refrigeration, particularly of agricultural produce. Large parts of the developing world remain 'off-grid' and not connected to any electricity supply network. Off grid solar PV systems provide electricity to households and villages for cooking, lighting, cooling, phone charging and other low power loads. These are often the most appropriate technology to meet the energy demands of off-grid communities.
- Grid connected distributed PV: Where users both domestic and industrial have connection to a main grid they may still use solar PV energy to provide energy for their own use and also sometimes to sell excess back to the main grid. This has the benefit of reducing load on the grid, reduced carbon emissions and in developing worlds situations where power outages can be common, better resilience for the user. Solar PV panels are often incorporated into the built environment and there are increasingly flexible applications allowing panels to be incorporated into a wide variety of structures.
- Grid connected centralised PV: Large scale solar PV panels to generate bulk electrical power that is fed straight into the electrical grid. This requires large scale investment and installation along with significant existing infrastructure to distribute the resulting power. Ultimately this deployment could provide large amounts of energy, but in areas with poor infrastructure it would have no way to distribute to off grid communities.

Solar PV is a fairly mature technology relative to other low carbon technologies and over the last twenty years the cost of solar PV panels has dropped by 90% and it is estimated that there is the potential for the costs to drop a further 50% between 2015-2050[34], all of which will contribute to making solar an ever more-promising, cost-effective energy source in Africa and the developing world.

---

[34] 'Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.Pdf', accessed 13 August 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593465/Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.pdf.

The high levels of solar irradiance available in Africa make it a prime market for solar systems and it is estimated that Africa's capacity to generate electricity through solar is around 11 terawatts[35], however this total is not close to being realised at present and current assessments are that the region accounts for only 9% of the global installed capacity of photovoltaics (PV).[36]

To illustrate the level of interest in solar in the developing world Governments:

- In 2016, Prime Minister Modi has set a target for India of 100 gigawatts of solar capacity by 2022 – a ten-fold increase on the country's 10 gigawatts 2016 capacity.
- Many African countries, notably Nigeria, Zimbabwe, Burundi, have begun to push solar generation driven in part by the existing electricity supply proving unreliable.

OPPORTUNITIES/CHALLENGES

Solar PV is fairly mature relative to other low carbon technologies and over the last twenty years the cost of solar PV panels has dropped by 90% - it is estimated the costs could drop a further 50% between 2015-2050[37], all of which will contribute to making solar an ever more cost-effective energy source in Africa and the developing world.

Access to finance has been identified as the most significant challenge to the penetration of solar energy technology in Africa. The effects of limited financing options are felt by all parties, from manufacturers to importers, distributors, dealers and end users (Lays et al, 2012). On the demand side, low levels of consumer awareness of solar power have prevented the expansion of solar markets (Tearfund, 2018).

However, a significant subset of companies are commercialising pico-PV and solar home systems by utilising business models that allow end users to reduce initial upfront costs by committing to "pay as you go" ongoing payments[38]. There are two basic models:

35 Tarryn Swemmer et al., 'Brighter Africa The Growth Potential of the Sub-Saharan Electricity Sector' (McKinsey & Company, February 2015), https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/east%20africa%20the%20next%20hub%20for%20apparel%20sourcing/brighter_africa_the_growth_potential_of_the_sub%20saharan_electricity_sector.ashx.

36 Izael Pereira Da Silva, 'Lessons from Kenya about What's Holding Back Solar Technology in Africa', The Conversation, accessed 11 August 2018, http://theconversation.com/lessons-from-kenya-about-whats-holding-back-solar-technology-in-africa-64185.

37 'Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.Pdf', accessed 13 August 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593465/Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.pdf.

38 'Fee-For-Service or Pay-As-You-Go Concepts for Photovoltaic Systems - Energypedia.Info', accessed 11 August 2018, https://energypedia.info/wiki/Fee-For-Service_or_Pay-As-You-Go_Concepts_for_Photovoltaic_Systems.

- one where companies are not selling the system itself, only the power generated. This involves one-time installation and then ongoing weekly costs.
- a rent-to-buy model that again involves a one-time installation cost and ongoing weekly costs, but which does ultimately lead to the customer owning the system after a set number of payments.

These have led to the rapid spread of the model and suggests that business models, anchored around user needs, could be one way of accelerating adoption.

Finally, it is well understood that local environmental conditions (for example, humidity, high temperatures, dust) and local technical capacity (to install, operate and maintain) can affect the performance and durability of solar systems. So, there is a need to identify technical solutions to overcome these environmental challenges, designing systems that are user-friendly and also building the skills and knowledge to deploy systems effectively.

EVIDENCE OF UK CAPABILITY/INVESTMENTS

There are various companies around the world developing ways to reduce the cost of solar energy generation by creating cheaper to manufacture panels but most of these are not in the UK.

However, with its expertise in fundamental research, engineering and materials science, the UK does have some specialisms around value added aspects of solar technology either through reducing cost, improving efficiency or overcoming specific challenges and/or limitations in specific environments. For example, for solar PV, UK companies have developed novel materials to create a dust resistant covering.

According to the Low Carbon Innovation Coordination Group's report in March 2016[39] the UK has some core strengths in solar technology sub-sectors particularly around incorporating PV into the built environment and in advanced materials technologies for components (such as for glass substrates, materials for functional layers, novel PV chemistries, thermal storage and high temperature engineering).

Whilst the UK has comparatively lower levels of solar irradiance, Solar PV has been bolstered through support from government in the form of feed-in tariffs and innovation funding. The data from the Energy Catalyst shows that a significant proportion of funding went to companies developing solar PV projects[40].

There are a number of distinct delivery scenarios:

- In small industrial, agricultural and medical settings in remote locations these systems may provide power for a wide range of crucial services such as telecommunication,

[39]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593465/Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.pdf

[40] 'Innovate UK Funded Projects since 2004', GOV.UK, accessed 10 August 2018, https://www.gov.uk/government/publications/innovate-uk-funded-projects.

water pumping, vaccine refrigeration and cooling and refrigeration, particularly of agricultural produce.

- Where users both domestic and industrial have connection to a main grid they may still use solar PV energy to provide energy for their own use and also sometimes to sell excess back to the main grid. This has the benefit of reducing load on the grid, reduced carbon emissions and in developing worlds situations where power outages can be common, better resilience for the user. Solar PV panels are often incorporated into the built environment and there are increasingly flexible applications allowing panels to be incorporated into a wide variety of structures.
- Large scale solar PV panels to generate bulk electrical power that is fed straight into the electrical grid. Requires large scale investment and installation along with significant existing infrastructure to distribute the resulting power. Ultimately could provide large amounts of energy but in areas with poor infrastructure would have no way to distribute to off grid communities.

UK companies establishing specialist niches that are relevant include:

Company	Profile
Azuri [41]	Pay-as-you go home solar systems January 2017 government launched 20,000 of Azuri's PayGo Solar Home Systems to rural households living without electricity. • Nigeria, Ghana,Kenya,Malawi,Rwanda, South Africa,South Sudan, Tanzania, Uganda
Gamos Ltd	eCook - a transformational household solar battery-electric cooker for poverty alleviation
Buffalo Grid	BuffaloGrid (BG) developed solar-powered BG Hubs for affordable and safe off-grid phone charging. BG sees an opportunity to develop portable modular Buffalito batteries, which are charged at BG Hubs and deliver solar-power to households.
Ubuntu Power Ltd	Ubuntu Power provides affordable zero-waste power and internet to off-grid communities. Our innovation lies in integrating these utilities into one modular and scalable system and using the revenue from multiple services to cross-subsidise the provision of affordable electricity. • sub- Saharan Africa, starting with Kenya
Renovagen Ltd	Transportable solar panels for disaster relief
Navarino Electric Systems Ltd	A Hybrid PV-Battery Unit Optimised for LV Grids Using GaN Transistors
Fenix International (Not UK based but part UK	Fenix uses customer-centric design processes to create high-quality, affordable, and long-lasting ReadyPay Solar Home Systems for frontier markets. • Uganda

41 'PayGo Energy Access for Rural, off-Grid Homes', Azuri Technologies, accessed 13 August 2018, http://www.azuri-technologies.com/.

funded)	
BBOX	Rent-to-own. Also sells energy efficient, DC powered appliances to be used with home system. • Kenya, Rwanda, Uganda
E.quinox	E.quinox is a student-led, non-profit humanitarian project In summer 2012, the stand-alone solution Izuba Box (SHS system) was introduced, which is based on the PAYG concept. In the initial pilot phase, a total of 74 systems were installed. • Rwanda and Tanzania
Nava Technology Ltd	Reducing the levelized cost of energy for silicon solar cells through a low-cost efficiency-boosting tandem technology
Dyesol UK Ltd	Surface Treatment of Perovskite Solar Cell Inorganic Titania Meso-Porous Substrates
Solaris Photonics Ltd	Development of Low Cost Alkaline Solar Cells
NSG -Pilkington	Tco coated glass substrates for thin film solar modules, conductivity. Primary supplier of transparent conducting coated glass for Thin Film CdTe module production
Oxford photovoltaics	Developer of MAPI perovskite solar cells. Perovskite-silicon tandem cells for increased efficiency
BIPV Co Ltd	Cladding – building integrated PV – Swansea - Commercial warehousing.
Polysolar Ltd	PV for facades
Johnson and Mathey	Produce ink for interconnects.
Applied Materials Technology Ltd	Low Cost Copper Transparent Electrode Material (LOCUST)
Big Solar	Extremely cheap flexible PV
Above surveying	Drones to detect damage or soiling on panels. Most cost effective when serving large solar farms.
Opus Materials Technologies	Hydrophobic coatings - Reducing soiling on solar cover-glass and making modules easier to clean
SolaPak Ltd	Established solar PV firm with well tested products. Moving into Sub-Saharan Africa to supply small agricultural and industrial users. Are developing visual display to help end users actively manage energy usage. Rwanda - Milk refrigeration at collecting points and community electrical charging hub Uganda - Solar PV systems for aid agencies in refugee camps to run essential services

CONCLUSIONS/POSSIBLE INTERVENTIONS

The UK does not have a distinct lead in solar but it does have capabilities and underpinning strengths that could support developing nations in increasing the penetration of solar technologies. This could entail:

- Adapting UK challenge/competition based innovation models to bring UK companies and host companies together to address specific technical challenges around improving functionality in challenging environments.
- Support in building the relevant technical skills required for operating and maintaining solar technologies by leveraging the UK's expertise in vocational education
- Leveraging the UK's globally renowned standards system to define and develop standards to help build confidence levels around the quality of solar products, in a similar way to the work within the Low Energy Inclusive Appliances programme.
- Consultancy support around taking a user-led design approach to develop business models that are "fit for purpose" in particular communities and help to create wider value chain opportunities

UK capabilities relating to solar could also be integrated within a wider UK programme of support around developing smart energy systems. For example, support in building technical skills through a vocational education intervention.

7 COOLING AND THE ENERGY FOR AND FROM THIS

THE MARKET

Cooling is essential for achieving the UN's Sustainable Development Goals but remains one of the under-researched and under-funded areas of global energy research. Cooling accounts for around 7% of global carbon emissions[42]. It performs a double role, therefore, being important both as a climate change mitigating mechanism and as a cause of global warming. Some examples include:

- ***Food Security & Nutrition*** - Clean Cold Chains: Global food loss could be reduced by 50%, an amount sufficient to feed an additional 1 billion people, if the lowest levels of food loss achieved in any region at each stage of the supply chain were replicated worldwide.
- ***Health*** - Access to vaccine & medicine refrigeration and safe food and drink, as well as the direct loss of life that results from excess heat: An estimated 1.5 million people die each year from vaccine-preventable diseases. The World Health Organization (WHO) estimates that nearly 50% of freeze-dried and 25% of liquid vaccines are wasted each year, with cold chain disruptions being one of the biggest reasons. Annually, 600 million people globally become ill from eating contaminated food and 420 000 die every year, 40% children under 5[43].
- ***Productivity*** - ability to work and depressed incomes due to heat: Overall, by 2050, work-hour losses by country are expected to be as high as 12%—worth billions of US dollars and as much as 6% of annual GDP—in the worst-affected regions of South Asia and West Africa.

There is also a massive energy cost resulting from the cooling technologies (primarily air-conditioning, some of which is very inefficient and contributes to heating the surrounding environment in cities) currently in use to keep the temperature inside buildings within acceptable levels. There is great need to find and implement alternative cooling solutions, partly through building design and partly by more effective and efficient cooling technologies.

Two recent international agreements—the Paris Agreement and the Montreal Protocol's Kigali Amendment—have brought attention to the close linkages between cooling, energy demand, and climate change.

Cooling and energy demand reduction measures (ie less technology heavy options) should be applied first, with the remaining cooling needs met through technical solutions that minimise adverse and maximize beneficial environmental and socioeconomic impacts. This will require a much broader approach. (Sustainable Energy For All, 2018).

---

[42] Carbon Trust, 'New funding available to mobilize finance for efficient clean cooling', accessed 8/1/19 at https://www.carbontrust.com/news/2018/05/k-cep-finance-window-launch/

[43] WHO, Food Safety Facts, accessed 8/1/19 at https://www.who.int/news-room/fact-sheets/detail/food-safety

Ultimately, if cooling is to be sustainable, a system level approach is needed to mitigate demand and understand the totality of multiple cooling needs; the size, location and time-bound availability of the thermal and electrical resources needs to be understood and available to be optimally integrated with sustainable cooling technologies.

In order to achieve this, the question shifts from how to generate electricity to a broader challenge of meeting service needs in the most efficient and climate-friendly way.

The global cooling equipment market is expected to be worth $140bn in 2018 but this figure is projected to grow to approx. $270bn by 2050. The need for technology is extremely broad[44] including:

- Cooking demand reduction from insulation to heat sinks
- Cooling provision covering:
    - Vapour compression cycles
    - Alternative cooling methods (eg magnetic refrigeration, adsorption chilling…)
    - Cold networks
    - Thermal storage (evaporative, ice, cryogenics…)
- And the need for technologies for integrating renewables and energy sources.

The countries facing the biggest risks across all 3 measures of **Extreme Heat**, **Food Losses** and **Damage to Vaccines** are India followed by **Bangladesh** and **Indonesia** in South Asia and **Nigeria, Sudan and Mozambique** in Sub Saharan Africa (Sustainable Energy For All, 2018)**.**

The following groups are the most vulnerable and, it can be argued, have the greatest need:

The Rural Poor – Approximately 470 million people. The rural poor are likely to live in extreme poverty and lack access to electricity. Many of them are likely to engage in subsistence farming and lack access to an intact cold chain enabling them to sell their products further afield at a higher price. Medical cold chains may also not be intact, putting lives at risk from spoiled vaccines.

The Slum Dweller – Approximately 630 million people. The slum dweller may have some access to electricity but housing quality is very poor and income may not be sufficient to even purchase or run a fan. They may own or have access to a refrigerator but intermittent electricity supplies may mean that food often spoils and there is a high risk of food poisoning. However, given their locations within urban centres, they are likely to at least have access to safe vaccines, where health services are available.

However, those classified by Energy for All as the **Carbon Captive (**approximately 2.3 billion people) represent an increasingly affluent lower-middle class that on the brink of purchasing the most affordable air conditioner or refrigerator on the market. Limited purchasing choices available to this group favour cooling devices that are currently inefficient and could cause **dramatic increases in energy consumption and associated GHG emissions.**

[44] https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf

The global cooling equipment market was believed to be worth $140bn in 2018 but this figure is projected to grow to approx. $270bn by 2050.[45] This is an issue that is already receiving considerable attention globally; for example, the Global LEAP awards programme[46] are currently running their second competition around refrigeration and there is growing interest amongst off-grid companies in the potential productive uses of electricity for cooling in the agricultural sector.

OPPORTUNITIES/CHALLENGES

Two of the critical needs for making cooling efficient and sustainable are research and innovation to enable improvements in building and urban design, technology and behavioural changes to make efficient use of technology and reduce the carbon footprint resulting from cooling.

As previously noted, cooling and energy demand reduction measures should be applied first, with the remaining cooling needs met through technical solutions that minimize adverse and maximize beneficial environmental and socioeconomic impacts. Therefore, in order to meet SDGs, Paris Agreement, and Kigali Amendment, a holistic, systems based approach is required. In this paper, we are only focusing on a limited number of issues and there are many others.

Further, because urban centres in developing countries are extremely heterogeneous, the most effective, promising and cheapest technologies targeted at problems of urban overheating are not renewable technologies *per se* - they are hybrid, context-specific **social and passive technologies.** Also, the same measures that can be used to cool the city have a determinable impact on GHG output: "Cool roofs, cool pavements, and urban vegetation reduce cooling energy use in buildings, lower local air pollution, and decrease greenhouse gas (GHG) emissions from urban areas."[47]

This landscape can be analysed in terms of a number of specific challenges and the associated opportunities they represent.

Opportunities	**Challenges**
Cooling demands can be better integrated using system level design that brings together traditional passive methods, novel technologies, data connectivity and energy management.	Although the efficiency of equipment used for cooling has been improving over time, the demand and resulting energy consumption is growing at alarming rates

---

[45] https://globenewswire.com/news-release/2018/06/26/1529424/0/en/Global-District-Cooling-Market-to-hit-140bn-by-2024-Global-Market-Insights-Inc.html

[46] https://globalleapawards.org

[47] Xu, T., Sathaye, J., Akbari, H., Garg, V. and Tetali, S. (2012) Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse gas emissions, Building and Environment, Volume 48: 1–6.

The role of thermal energy storage needs to be considered as well as the specification of resource pooling protocols.	
New business models to leverage market-based incentives and fit-for-market commercial offerings	Affordability & access to financing
Skills & Education to support research agenda and enable optimum deployment and maintenance of current & future cooling technologies	Technical capability and skills
Education and community involvement to highlight opportunities afforded by adopting cooling strategies and technologies	Lack of awareness/Culture/ consumer attitudes
Changing to refrigerants with lower Global Warming Potential may require manufacturers to redesign cooling products, providing an opportunity to make them more energy efficient, as there is still thermodynamic potential for efficiency improvements.	HFCs, introduced as substitutes for ozone-depleting chemicals and are widely used in air conditioners and other cooling appliances. They are also powerful greenhouse gases that can be thousands of times more potent than carbon dioxide in terms of GWP.
Introduction of renewables and mini-grids providing electricity access to remote communities	Electricity availability
Development of innovative, holistic approaches to cooling & associated energy demand	Lack of innovation
New urban development offers opportunities to radically re-think the design of buildings and cities to optimize cooling loads and the technologies that can deal with them.	Increasing urbanisation and associated demand for energy intensive cooling technologies

EVIDENCE OF UK CAPABILITY/INVESTMENTS

In purely technical terms, the UK already has considerable academic and commercial capability in this area although not much experience outside of Western contexts. Nevertheless there are many companies focused on the UK/Western market who have products that could be re-engineered for markets in the Global South and a number of new companies developing technologies that could have direct relevance to the challenges identified above.

Data from the Energy Catalyst funding rounds show that there was some investment in cooling technologies but as a proportion of the whole funding, investment in innovative cooling technology only represented 6% of the total spend[48].

However, during the interviews underpinning this work, sustainable and cost efficient cooling and refrigeration technologies were several times picked out as a critical new area for research and an area of both increasing need with co-developing market opportunities. Academically, there is cooling research expertise at the University of Birmingham which recently hosted, "A Cool World: 1st International Congress on Clean Cooling" in 2018 bringing together global experts on clean cooling.

The Carbon Trust assesses that Britain is well-placed with a number of clean cold technologies already in development, coupled with world-leading capabilities in cryogenics, engineering, manufacturing and finance[49].

There are already some UK companies doing interesting work in these fields and if it is established that these are high growth potential areas then communicating this message to UK companies and injecting early stage funding would do a lot to create UK strength at the front of these emerging markets.

UK COMPANIES

Company	Technology	Market Segment/s	Funding/Funded Projects
Solar Polar	Solar Cooling	Air Conditioning, Refrigeration for Vaccines & Food Storage	Innovate UK
Camfridge	Gas-free magnetic cooling	Domestic cooling appliances	Carbon Trust, 7th Framework Programme, Innovate UK, Nesta
Polysolar	Building integrated PV glass	Architectural Glazing	
Oxford Nanosystems	Specialist Coatings for Heat Exchangers	Refrigeration Industrial & Waste Heat Recovery	EPSRC, STFC
RD&T Ltd	Cycle optimisation for vapour compression cycles	Refrigeration	

48 'Innovate UK Funded Projects since 2004', GOV.UK, accessed 10 August 2018, https://www.gov.uk/government/publications/innovate-uk-funded-projects.

49 'The Emerging Cold Economy - Carbon Trust'.

The Sure Chill Company	Platform cooling technology	Medical Refrigeration Energy Home appliances Agri-food Retail	Shell Foundation, Welsh Government
Dearman Engine Company	PCMs – Cryogenics – Liquid Air	Transport Refrigeration Data Centres Built Environment Commercial Vehicles (e.g. City Buses)	Innovate UK
Airedale International Air Conditioning Ltd	Air Conditioning	Data Centre Laboratory/Healthcare Commercial Air Conditioning Process Cooling	

ACADEMIC RESEARCH

University	**School/Institute/Group**	**Lead Researcher**	**Area/s of Research**
Anglia Ruskin University	Global Sustainability Institute; Faculty of Science and Engineering	Prof. Aled Jones	climate finance, energy and behaviour, resource management; Government response to the impacts of global resource trends and climate change; global modelling of political fragility from resource crises.
University of Aston	Sustainable Environment Research Group	Dr Philip Davies	Renewable and efficient energy systems for water treatment and agriculture; small scale systems for rural areas and developing countries
University of Birmingham	Institute for Global Innovation Birmingham Energy Institute	Prof. Toby Peters	The Cold Economy
University of Durham	Department of Geography	Dr Andrés Luque-Ayala	Critical geography of urban energy; Scalar re-making of urban energy processes; ‘Smart’ urbanization; Urban responses to climate change; Climate mitigation

			and adaptation in cities.
University of Sussex	Business School, Department of Management	Prof. Nachiappan Subramanian	Supply Chain Innovation, Management, Risk & Resilience; Sustainable Development
University of Cambridge	Cambridge Centre for Climate Change Mitigation Research (4CMR)	Prof. Douglas Crawford-Brown	Future Technology Transformation model; environmental risk assessment; sustainable design; environmental policy analysis
London South Bank University	Centre for Refrigeration & Air Conditioning Research	Prof. Graeme Maidment	Ground Coupled Cooling Heat Powered Cycles (Absorption refrigeration) Refrigeration Systems & Technology Modelling, Thermoeconomics & Optimisation

CONCLUSIONS/POSSIBLE INTERVENTIONS

Based on developing world needs around cooling and the potential market opportunity, there is the potential for the UK to be at the forefront of an emerging and rapidly growing market for novel cooling solutions that are both cost effective and sustainable.

The University of Birmingham, Birmingham Energy Institute has developed proposals for this which would include a culturally context informed needs assessment process and a model (open-source) for all communities (rural and urban) to identify the service needs, so as to both mitigate them and reduce their energy demand, and then marry them to the local energy resources using “fit for market” technology solutions.

The model would help quantify the economic, societal and environmental impact to underpin support investment and financing proposals, as well as support the design of the novel finance and business models required to create an economically sustainable, end-to-end system.

CASE STUDY: SOLAR POLAR

Solar Polar is an SME that over the last ten years has designed, developed and tested an innovative cooling technology using nano materials and powered by the sun. Units designed for farm cooling are currently being tested in India and the first commercially available units are due to go on sale in 2019.

Solar Polar uses a solar thermal powered absorption refrigeration system to make cooling modules that can be joined together to match the required cooling load. The system generates cooling capacity not electricity so once installed it has no ongoing costs aside from maintenance. The lack of circuitry or moving parts make it extremely reliable in off-grid or other challenging conditions and installation is both simple and safe as there are no electrical, or water connections. The system is modular and can be scaled up and down although most use cases are projected at the scale of domestic homes or small farm units. The cooling capacity can be used to deliver refrigeration, cooling or air conditioning.

Solar Power has also worked closely on tailoring the technology to meet the requirements of the developing world. Their initial research has led them to focus on farm refrigeration and vaccine storage as critical needs. They have also identified significant global commercial opportunity where a cheap and low-carbon solution could provide significant cost and environmental benefits replacing energy intensive and expensive air conditioning.

Solar Polar also has a business model that rapidly scales with demand. They plan to license their technology to an in-country manufacturer to produce and sell units. This generates license and royalty revenue whilst leaving the company able to rapidly expand to multiple countries. It also creates economic opportunities for companies in country to manufacture, distribute, install and maintain units.

8 ENERGY STORAGE

THE MARKET

According to the World Bank[50], 'Energy Storage is a crucial tool for enabling the effective integration of renewable energy and unlocking the benefits of the local generation of clean, resilient energy supply'. As clean energy generation becomes more mainstream around the world, its variability and supply fluctuation begin to impact the electricity systems. Storage can help even out spikes and dips in solar and wind resource availability and enable energy distribution to be shifted from the time of generation to the time of peak demand. Therefore, supporting energy storage technology is a strategic focus as a means of extending the reach and uses of renewable energy beyond intermittent power.

Energy storage is therefore crucial in any attempt to effectively integrate renewable energy solutions and achieve the potential benefits of local generation and a clean, resilient energy supply[51]. Energy storage also constitutes a significant proportion of the overall costs of solar systems (both individual household systems and community mini-grids) hence any ways in which the overall costs of energy storage might be reduced, or the efficiency and product lifetime enhanced could have significant impacts on the commercial viability of off-grid energy access solutions.

In SSA with immense untapped hydroelectric potential Pumped Hydro Electric Storage (PHES) can be an attractive energy storage option in areas with variable renewables potential. Solar and wind energy costs are plummeting, as are the costs of storage which opens more opportunities to deploy these technologies together in Africa.[52]

The World Bank Group has recently announced that it is proposing to commit $1 billion for a new global program – the **Accelerating Battery Storage for Development** programme[53] - to help fast-track investments in battery storage for energy systems in developing and middle-income countries.

'Several electricity storage technologies are still too expensive to be viable and others will need more time before being commercialised. However, as it was the case for renewable energy, the costs of many of these technologies are expected to rapidly decline through competitive innovation and economies of scale. Energy storage technologies will be at the centre of the transformation of our conventionally structured energy markets and represent

---

[50] https://blogs.worldbank.org/climatechange/energy-storage-can-open-doors-clean-energy--solutions-emerging-markets

[51] https://www.ifc.org/wps/wcm/connect/ed6f9f7f-f197-4915-8ab6-56b92d50865d/7151-IFC-EnergyStorage-report.pdf?MOD=AJPERES

[52] https://www.seforall.org/content/better-path-africa%E2%80%99s-energy-future

[53] https://www.worldbank.org/en/news/press-release/2018/09/26/world-bank-group-commits-1-billion-for-battery-storage-to-ramp-up-renewable-energy-globally

a unique opportunity for early stage electrical grids to lead the way towards fully optimised energy systems.' Gadi Taj Ndahumba [54]

As well as essential energy sto**rage** in the form of **batteries** for mini-grid development using renewables such as wind and solar, thermal energy storage in the form of **Phase Change Materials** (PCMs) could form a key approach to providing energy storage for developing countries.

PCMs have the ability to store and release large amounts of energy, in the form of latent heat. Although phase changes can occur among any combination of the three phases of a substance - gas, liquid, or solid the most commercially viable transition is between the liquid and solid phases. When a PCM is in its' solid phase it can absorb heat, providing a cooling effect and when a PCM is in its' liquid phase it can release heat, providing a warming effect.

Advanced Phase Change Materials Report, published by Allied Market Research, forecast that the global market is projected to reach $2,434 million by 2022 from $691 million in 2015. Rapid urbanisation in developing countries is one of the factors expected to fuel PCM market growth in the near future.

OPPORTUNITIES/CHALLENGES

Opportunities	Challenges
Awareness raising at high level	Lack of familiarity with storage technology among utilities, regulators and financiers
Capacity Contracts—Capacity contracts involve utilities procuring energy storage-as-a-service from providers that offer reliable load reduction, typically in a set geographic location where there are capacity constraints.	High upfront costs
Development of specialised training programmes	Need for highly skilled and experienced technicians for operation & maintenance
In the Sub-Saharan Africa region, remote power systems are expected to provide roughly 70 percent of energy services over the next few decades given the lack of grid connectivity in the region[55]. It is expected that the majority of these remote power systems will include energy storage as the technology continues to decrease in cost.	Remote Power Systems
PAYGO models	Poor financial viability of customers in remote

[54] Legal Counsel at the African Legal Support Facility (ALSF), an organization hosted by the African Development Bank

[55] https://www.ifc.org/wps/wcm/connect/ed6f9f7f-f197-4915-8ab6-56b92d50865d/7151-IFC-EnergyStorage-report.pdf?MOD=AJPERES

Emergence of new business models that aggregate customer-sited storage to provide a range of services to utilities, grid operators and electricity customers. New developments in highly efficient appliances for productive uses and new income expenditure reassignment (e.g. from biomass to electric cooking)	villages and no access to affordable finance
Anticipated drop in costs of Lithium-ion and increased availability, reliability	Durability, reliability and relatively low cost of hard-wearing lead-acid alternatives
Digital advances enable electricity consumers to participate directly in the energy sector. Several companies are experimenting with blockchain-enabled peer-to-peer (P2P) trading platforms that facilitate the direct sharing of stored and/ or self-generated electricity among home owners or businesses.	Energy subsidies that obstruct new private sector business models
An Increasing uptake of mini-grids as costs fall	Limited renewable energy development to date (SSA)

OPPORTUNITIES/CHALLENGES SPECIFIC TO BATTERY STORAGE

Opportunities	**Challenges**
Emergence of new business models that aggregate customer-sited storage to provide a range of services to utilities, grid operators and electricity customers	Perceptions of high prices
Aggregating groups of batteries or solar-plus-storage systems to provide services to the grid or to participate in energy trading	Lack of standardization
Expanding electric vehicle markets, since each electric vehicle contains a battery that could potentially be pooled with others to provide grid services	Outdated regulatory policy and market design
	Lack of familiarity with the full range of applications for battery storage solutions, along with an incomplete understanding of how to assign value to them

OPPORTUNITIES/CHALLENGES SPECIFIC TO PHASE CHANGE MATERIALS

Opportunities	**Challenges**
Evaporation	
New Developments may offer: - New ways of exploiting the effect or differing packages to suit an application - New materials for storing or distributing the water prior to evaporation - Reduced water consumption	New developments may have to overcome: - High water consumption - Lack of effectiveness in humid environments - Contribution to overall building humidity

	- Performance degradations over operating life
Ice	
New Developments may offer: - enhanced system integration - exploitation of different properties of water for freezing or cooling	New Developments may have to overcome: - increased system complexity vs. numerous incumbents - energy intensive recharging cycles
Cryogenics	
New Developments may offer: - Reduced cryogenic liquid consumption - Higher levels of food quality/preservation - Closer feature sets to incumbent products	New developments may have to overcome: - Challenges in cryogenic liquid handling (e.g. onboard storage losses, refuellers) - Complexity in cascade or mechanical systems - Improving competitor systems
New PCMs	
New Developments may offer: - New temperatures - Increased energy density (or effective holdover times) - More product integration options (e.g. could be integrated into an existing products' housing)	New developments may have to overcome: - Toxicity - High production costs vs the incumbent water and brine solutions - Low energy density - Application integration challenges

EVIDENCE OF UK CAPABILITY/INVESTMENTS

UK has been identified as potential world leader in energy storage technologies. Energy storage was identified by the Government as one of the Eight Great Technologies on which a substantial amount of R&D investment was focused. However, this was largely with the developed world market, and the automotive industry in particular, in mind. Even then, it is not clear that the UK is a world leader with much of the most advanced and promising battery technology coming from Japan and Germany.

As a result of the investment, growth in UK patenting activity in this area was 10% over 2004-2013[56] (cf 3% in China and 4% in USA). There is no doubt that the UK has world class companies in this area. Amongst the top bodies submitting patents in energy storage in 2014 included the following UK-based companies:

- Intelligent Energy - a global power company and work in three main sectors: automotive, consumer electronics and distributed power distribution. They specialise in modular, low carbon fuel cell systems. The company developed the world’s first hydrogen fuel cell motorbike, the ENV, and powered the world’s first manned fuel cell power flight.

[56] Eight Great Technologies: Energy Storage A patent overview IPO June 2014

- Ceres Power were founded in 1991, based on patents relating to fuel cell technology. They work in developing fuel cell technology which operates on natural gas using conventional materials and processes.
- OXIS Energy are working with Oxford University materials department as well as ABSL power solutions. The company has developed technology around sulfur based cathode materials, highly stable electrolyte systems and anode made of lithium metal and intercalation materials.
- Nexeon was founded in 2004, as a "spin off" company based on research completed in the electrical engineering department in Imperial College. The company develops anodes for the next generation of lithium-ion batteries.

The Faraday Institution, based outside of Oxford, has substantial Government funding to support this sector and is offering a range of facilities for the development of battery technologies and solutions. It is acting as a focus for bringing together leading players in this sector in the UK but the emphasis is very much on the developed world – seeking to both contribute to reducing UK carbon emissions while opening up new economic opportunities through the development and support of electric vehicles as part of the wider automotive sector industrial strategy.

Phase Change Materials (PCMs) companies include:

- Dulas, a Welsh renewable energy technology company, first developed solar powered refrigerated blood banks and operating theatre lighting thirty years ago in war torn Eritrea, and then went on to develop the first solar powered vaccine refrigerators for use globally. They are using PCMs in place of batteries as an essential component of solar-powered direct-drive refrigerators for off-grid vaccine storage in developing countries.
- Phase Change Material Products Limited, has been involved in the development of Phase Change Materials (PCMs) for more than a decade. Their PlusICE range of PCM solutions and associated products cover a wide range of applications between -100°C (-148°F) and +885°C (+1,625°F) and are available either as the standard PCM solution, or in a variety of formats and encapsulated versions. They have carried out numerous R&D projects (see Annex XXX).
- Sunamp have a patented a Heat Battery energy storage technology. Sunamp's heating and cooling technology enables new ways of tackling existing industrial challenges, such as being able to use a container-scale Heat Battery to store waste heat where it is created, and move it to a point where it is needed.
- The Sure Chill Company was founded in 2009 and secured a $1.5 million award from Bill & Melinda Gates Foundation in 2014. The award was to help speed the development of a passive vaccine cooler that would allow vaccination programmes to reach children living in some of the remotest places on the planet. Sure Chill is a platform cooling technology that harnesses a unique property of water to enable continuous cooling from inconsistent power. At four degrees, water is at its heaviest. At four degrees it sinks, while at any other temperature it rises. This inspired the creation of a new kind of refrigeration system.
- Dearman Engine Company Ltd is a British company pioneering the development of clean liquid air technology to achieve improvements in resource efficiency, greenhouse gas

emissions and air pollution of power and cooling. The Dearman engine is a novel piston engine powered by liquid air/nitrogen – that generates both cold and power from a single tank of 'fuel'. In partnership with academics, industry leaders and experts in energy and cryogenics, they are developing applications of the Dearman engine which are efficient, low carbon, zero-emission, quiet and cost-effective.

CONCLUSIONS/POSSIBLE INTERVENTIONS

In order to attract the attention of commercial players, the focus must be on developing strong business propositions to demonstrate the market potential and specific energy storage requirements of the developing world.

Taking an approach that starts by identifying the business opportunities that can be scaled up but that will only be viable if technology solutions can be identified that meet particular criteria, would provide a route to a constructive conversation with the UK's energy storage institutions and community.

We will also need to see research funding targeted specifically at the energy storage challenges in the developing world. We are aware that some discussions focusing specifically on internationalising the focus of the Faraday research and considering the potential for the deployment of used electric vehicle batteries in off grid energy access initiatives have already been launched. There are, however, significant opportunities to expand beyond this initial focus on batteries to consider a wider range of alternative forms of energy storage. There are strong potential links to existing DFID investments where ongoing research could help determine the level of opportunity.

For example, opportunities in relation to grid-connected renewables (the Energy and Economic Growth programme), mini-grid developers (Transforming Energy Access projects including those run by the African Mini-Grid Developers Association and the Global Distributors collective) and household and institutional electric cooking (the Modern Energy Cooking Services programme). Central to the opportunities here are the formation of strong partnerships between researchers, technology developers, project implementers and consumers.

9 APPLIANCES

This opportunity focuses on the need to complement advances across the Global South in off-grid energy access with the provision of suitable appliances (low cost and high efficiency) that can provide valuable services in ways that reflect the local availability of energy and the usage context.

THE MARKET

This is an area that is already receiving a considerable amount of interest from the international community. Existing UK involvement includes DFID funding for the Global LEAP awards (with Power Africa) and the recently launched Low Energy Inclusive Appliances programme which aims to double the efficiency and halve the cost of a suite of appliances that are well-suited for energy access contexts.

In order to drive economic growth and poverty reduction through enabling access to clean energy, it is critical to look at the demand side as much as the supply side. There are many challenges relating to domestic and business energy users in terms of:

- their understanding of the new potential that energy can provide and building business models around these,
- appreciating the nature of energy, its value and cost, and how to make efficient use of it (eg. not leaving the fridge door open to cool your house)
- the availability of suitable appliances to take advantage of the particular forms the energy takes in the environmental and other conditions that prevail, and
- in the overall conditions to facilitate change, where the user base may take some time and need some persuading that the changes are beneficial, especially if they have had some experience or heard of products being sold that did not match up to expectations.

In many respects the main challenge is not generation of energy, as there are plentiful sources of this, but the ability of the market to take advantage of this and to identify Productive Users of energy generated – ie the challenge is growing the demand.

A 2017 survey of energy access professionals assessed the expected demand for and impact of off-grid, solar-powered appliances, including household, small-medium enterprise (SME), and clinical applications[57] found:

- LED lighting, televisions, mobile phones, mobile phone charging banks, household refrigerators, fans, and light commercial/SME refrigeration are viewed as the household/SME appliances with the highest likely demand.
- The appliances with the highest potential contribution to socioeconomic development and poverty reduction are LED lighting, mobile/smart phones, solar water pumps (SWPs), agriculture cold chain refrigeration, and light commercial/SME refrigeration.

[57] https://storage.googleapis.com/e4a-website-assets/2017-Off-Grid-Appliance-Survey-Summary.pdf

- Vaccine refrigeration, lighting, ICT equipment (computer, cell phone chargers, printer, radio), neonatal infant warmers, and vital sign monitors (e.g. NiBP, SpO2, HR, RR, EtCO2 and ECG) as the highest impact applications in relation to improving healthcare.
- Refrigeration for clinical applications, such as vaccine refrigeration, is ranked highest in terms of demand.

This shows that there are considerable market opportunities in relation to healthcare providers as much as domestic and business users.

Studies have found a range of issues that can affect domestic and business energy users and their ability to make cost-effective use of such appliances, in addition to those mentioned above:

- the drivers and motivations of the user community that will affect the perception of the value or otherwise of a potential appliance,
- the culturally determined patterns of behaviour that will determine what form of appliance will be fit for purpose (e.g. types of food when considering clean cooking appliances) and that may need to be adapted to suit the appliances available (i.e. retraining requirements).

OPPORTUNITIES/CHALLENGES

BEHAVIOURAL

There are a range of behavioural and knowledge-related aspects of energy use. Thus, we understand that studies have found that general levels of education/skill correlate with the ability to make good use of electricity. Common problems are from overloading of appliances such as fridges and an inability to understand how solar energy generation translates into ability to charge devices, etc.

There are complex issues in the interface between a local energy provider and a customer base of small businesses, where the business owners may have limited ability to anticipate energy demand and what they can afford, and the energy provider therefore be unable to accurately predict the required generation levels and what represents the best investment that will pay back in a reasonable time. A very useful paper on this provides extensive empirical evidence and case studies while also illustrating the complexities and challenges in this area - https://storage.googleapis.com/e4a-website-assets/Productive-Use-of-Energy-in-African-Micro-grids.pdf

The paper reviews the main risks associated with this dynamic of energy production and use:

- assessing the power needs of productive users. Most developers overestimate the demand from existing or new PUE, leading to underuse of the micro-grid which is likely to drive up costs. The demand assessments may be unrealistic, the entrepreneurs may lack the necessary skills and access to finance and PU equipment, or they may simply have limited appetite for risk because of a lack of information about market opportunities.

- Payment risk is another challenge for developers. Some customers may be unable to afford the initial connection charge or ongoing electricity bill, and PUE are not immune to this problem.
- Another challenge for micro-grid operators is social acceptance by the local community and positioning within the local culture.
- Technical challenges and risks can be mitigated through appropriate systems design and analysis of PU loads.

QUALITY

We have had repeated stories told us of the damaging impact of appliances being sold into Africa that do not live up the promises made – this can have long term consequences in terms of the perception of technology and the willingness of people to invest in these.

As a result, a key intervention is ensuring the quality of products prior to deployment and effective testing of these in the UK in ways that simulate the realistic market conditions and environment could be very beneficial both for companies developing these and for those representing consumers.

Under the Low Energy Inclusive Appliances (LEIA) programme a comprehensive approach to benchmarking and testing of appliances is underway with findings published so that the market has better information on which to base decisions. This is invaluable data on the types of performance characteristics that are required and the opportunities for new products to enter the market if they can be developed to exceed current standards.

GENERAL

However, obstacles remain to achieve a more flourishing market. These represent opportunities to develop new solutions if the right collaborations can be facilitated among product designers and distributors, technology specialists, agriculture sector experts, and other key stakeholders. Areas highlighted by the industry experts are:

- Consumer & Market Intelligence
- Distribution, Installation, and Service
- Financing & Business Support
- Design & Development
- Capacity Building
- Testing and Quality
- Policy Environment
- Environmental Sustainability.

Building on the above, we suggest the following as key areas that can represent market opportunities where UK companies and researchers may be well placed to make important contributions:

- There are major opportunities to **develop and manufacture appliances** that reflect the diverse and complex needs of the developing world as access to new more sustainable sources of energy open up, however these need to reflect the user profiles, affordability requirements, access to maintenance and spare parts, and energy profiles.

- There are a range of **behavioural, educational and knowledge-related aspects** of energy use. Thus, we understand that studies have found that general levels of education/skill correlate with the ability to make good use of electricity. Common problems are from overloading of appliances such as fridges and an inability to understand how solar energy generation translates into ability to charge devices, etc.
- There is considerable focus on the damaging impact of appliances being sold into Africa that do not live up the promises made – this can have long term consequences in terms of the perception of technology and the willingness of people to invest in these, and points towards the need for **standard setting, quality control, certification** in supporting confidence amongst country administrations and individual consumers.
- Other areas highlighted by industry experts are:
    - Consumer & Market Intelligence
    - Distribution, Installation, and Service
    - Financing & Business Support
    - Design & Development

REFRIGERATION

In May 2018, the Efficiency for Access Coalition hosted a "Global Market Development Roundtable" in Amsterdam to discuss opportunities to advance markets for off- and weak-grid refrigeration[58].

They concluded that highly energy-efficient, affordable, and appropriately designed refrigerators hold unique potential to improve livelihoods and achieve broader development impacts in off- and weak-grid communities. This can have wide ranging benefits from facilitating income-generating to enhancing diets, from benefiting women and girls who can spend large amounts of time in labour intensive food related activities to reducing food waste[59].

A 2016 study by Global LEAP estimated that the annual market for off- and weak-grid refrigerators could be $1.1 billion. However, overall market penetration remains low – less than 40% in Nigeria and 30% in India – and is even lower in rural areas at just 6% in Bangladesh and 1% in Kenya[60].

SOLAR WATER PUMPS

There are huge opportunities relating to the provision of effective solar water pumps given the huge numbers that rely on agriculture as their main source of income but lack access to

58 https://efficiencyforaccess.org/publications/refrigeration-global-market-development-roundtable-workshop-report-june-2018

59 http://www.iifiir.org/userfiles/file/publications/notes/NoteFood_05_EN.pdf

60 https://bit.ly/2libedo

traditional energy infrastructure. A meeting in Kenya in April 2018 brought together industry leaders to explore this[61]. Efficient solar water pumps (SWPs) could deliver modern irrigation and drinking water services to the nearly 500 million small-scale farmers worldwide.

- Improving farm productivity has a direct impact on poverty alleviation. Studies show that a 10% increase in agricultural productivity for smallholder farmers in Africa leads to a 7% reduction in poverty.
- SWPs also present a far-reaching opportunity to reduce the labour burden on women and girls who commonly bear the brunt of agriculture and water-ferrying work in rural areas.

However, obstacles remain to achieve a more flourishing market. These represent opportunities to develop new solutions if the right collaborations can be facilitated among product designers and distributors, technology specialists, agriculture sector experts, and other key stakeholders.

EVIDENCE OF UK CAPABILITY/INVESTMENTS

The UK is not a major manufacturer of appliances but has real strength in design, innovation and related disciplines (for example, the UK has strong leadership within research into consumer behaviour, user-centred design and behaviour change which has not been strongly applied within this context to date). In order to provide appliances that are affordable for the developing world, manufacturing would need to be off-shored in most cases.

The UK's Energy Saving Trust is one of the two organizations leading the LEIA programme described above. Considerable research has been done into the market for appliances and the best way to support the interactions between energy providers and energy users. Under the LEIA programme a comprehensive approach to benchmarking and testing of appliances is underway with findings published so that the market has better information on which to base decisions. This is invaluable data on the types of performance characteristics that are required and the opportunities for new products to enter the market if they can be developed to exceed current standards.

Through the British Standards Institution (BSI) and UK Accreditation Service (UKAS), the UK has an internationally regarded quality infrastructure that helps support the safety, quality and accessibility of products, services and systems. Both organizations have experience in assisting emerging economies in developing and strengthening their own quality infrastructures.

[61] https://storage.googleapis.com/e4a-website-assets/EforA-SWP-Rountable-Summary-May-2018-1.pdf

The UK has strong design capability and expertise in user led design approaches to ensure products and services meet user needs.

Useful resources on the appliance market exist at: The State of the Global Off-Grid Appliance Market. (2016). Retrieved from Global LEAP website: https://bit.ly/2Iibedo

CASE STUDY: SOLAPAK LTD

Not all innovative solutions involve new technical solutions and not all innovation comes from new companies. As an established SME and provider of solar PV technology in remote and off grid locations world-wide for the last thirty years Solapak has a long history working in renewable energy. Until now their core customer base has been oil and gas companies who needed stable, reliable and cheap electrical supply to power vital components over a period of 20-30 years in the field. As fossil fuels continue to decline SolaPak started assessing the transferability of the technology to other markets particularly in the developing world. They have just completed feasibility studies in Rwanda working with domestic and agricultural partners.

Whilst the technology is tried and tested in the field with well understood performance and the business is experienced working globally with international partners, Solapak rapidly identified that the core area for R&D was in understanding user behaviour and use cases in their target countries. What they found was that the intrinsic energy use of connected devices is not immediately clear to the average consumer - particular in locations where electrical devices are relatively new. For example, does leaving your fridge door open to cool your room use more energy than using an electric fan? The fan is noisy and has moving parts therefore looking like the most energy intensive. Inefficient energy use can lead to dissatisfaction with the system and a false presumption that solar is not a good solution.

Solapak's solution to these challenges is not just hardware, but a partnership approach that actively engages end-users and stakeholders to encourage efficiency. They have developed a visual display for users to build energy efficiency into their use of their system. Designed to be cross-cultural and pictorial the display promotes efficient and economic use of the system.

CONCLUSIONS/POSSIBLE INTERVENTIONS

Helping companies meet and work with potential partner organisations from the developing world is essential in helping companies work overseas successfully. Some form of "match-making" could help UK companies understand how best to position their products and to understand social and cultural contexts that will shape behaviours towards products. This is the kind of approach which is already being developed within DFID's new Modern Energy Cooking Services programme [62]which could be extended into other appliance areas

Other interventions to consider:

- Exploring the potential for a user-led design approach to prototype and pilot new appliances, thus drawing in a key area of UK research expertise and improving relevance to local conditions and developing community buy-in
- Encouraging the quality assurance of products prior to deployment and effective testing of these in the UK, which can include making use of facilities already invested in within our research base, in ways that simulate the realistic market conditions and environment could be very beneficial both for companies developing these and for those representing consumers.
- Building on current UK capacity building around standards and accreditation, opportunities should be explored to help Governments and policy makers in emerging markets to create systems for product quality that can help build consumer confidence
- There are a range of areas around which a collaboration between the UK and China to establish a pipeline of appliance solutions for the developing world could be based, reflecting our respective capabilities. We have had informal communications with the head of the team responsible for UK-China collaboration within the Chinese Ministry of Science and Technology that suggests a willingness to explore this. Politically this would play well in the UK's ambition to expand collaboration with China and open up market opportunities in Africa.

[62] https://www.mecs.org.uk

10 CONCLUSIONS AND NEXT STEPS

There are considerable strengths across the UK energy sector – both across and between industry and the research base - however there are many challenges to translating this into successful commercial operation in developing countries.

This report has started to outline specific interventions for key technology opportunity areas and a systems-based approach to effectively marrying UK technology and expertise to Global South needs. We have focused on Energy Systems, Bioenergy, Solar, Thermal Energy, Energy Storage and Appliances.

However, there is a need to consider the wider systemic challenges and issue that were identified through this report, that will require a long-term, sustained and collaborative approach between UK partners.

To take this forward, a partnership of key organisations should be convened to build a multi-faceted programme that covers the following themes:

Leveraging UK expertise in fundamental research,

The UK's expertise in fundamental research, engineering and materials science means that UK companies working at the cutting edge of innovation are not always working directly on end-user products but working on technical developments that add value to existing technology either through reducing cost, improving efficacy or overcoming specific challenges or limitations. This is particularly clear in solar PV for example, where UK companies are using novel materials to create a dust resistant covering or in biofuels where UK companies are working on engineering solutions to improve the efficiency of first and second generation production units.

Facilitating complementary partnerships between UK companies

Facilitating UK companies who use established technologies developing partnerships with companies who are developing particular improvements, applications or cost reductions would help create stronger and better commercial offerings and would help companies expand their capacity to offer products commercially in the developing world.

Additionally, as communities in the developing world may be missing multiple elements of key energy infrastructure energy solutions often need to include several elements to fulfil the needs of customers. For example, energy generation needs to also include storage and distribution options alongside affordable payment structures, so bringing together UK companies to offer combined solutions may lead to more successful interventions.

Facilitating international partnerships

Companies who received DFID funding from the energy catalyst were all required to have an overseas partner join the project. In follow up interviews with these companies they all found the international partnership invaluable as it provided on the ground expertise, knowledge and connections and ensured that projected plans were based on real word conditions and expectations.

Helping companies meet and work with potential partner organisations from the developing world is essential in helping companies work overseas successfully. This is particular true in helping UK companies understand local barriers and challenges as well as social or cultural expectations that may impact on energy attitudes and behaviours.

Leveraging UK expertise around systems thinking

A harder to define and quantify, area of UK expertise is in a UK company's ability and willingness to solve problems to meet local requirements, to understand wider system wide issues and to bring together innovative and new solutions. The expertise is not always in new technologies or systems but in new applications, structures or combinations of technologies.

Aligning innovations with targeted, user-informed, business models

By the same measure, a great product or an innovative solution to a local requirement does not guarantee either commercial success and long term market viability. It is bringing together great technologies with business models that work in the context of the developing world that makes the difference.

Africa Power for example have a very robust and effective business model that is helping them forge ahead in providing electrification to off-grid communities. Their A(nchor)-B(usiness)-C(ommunity)-D(omestic) model, focuses on using mobile cell towers as their anchor customer. Mobile networks across Africa have expanded at an incredible rate and cell towers need reliable and low cost energy so fitting solar panels is an obvious and commercially successful step. The next step is to expand electrification to local businesses, then to communities and finally to domestic customers.

Catalysing value chains and local entrepreneurship

As with ensuring the right fundamental business model, business models that incorporate opportunities for the local entrepreneurship ensure wider community benefit and create a value chain of opportunity. Examples include Mobile Power who are setting up mobile battery charging stations and envisage a network of local people offering this as a service. Equally Solar polar who provide solar cooling solutions intend to license their product to in-country partners who can then manufacture, distribute and install the units. Whilst Solar polar will benefit from license and royalty costs, this will also create significant opportunities for in-country firms to successfully grow and profit from the technology.

Capacity building around institutions and governance

A recurring theme in interviews and analysis is the difficulty for UK firms to navigate the complex and varied regulatory environments in different countries across the developing world. This is made even more difficult where regulations are unclear, contradictory or not clearly communicated.

There is a significant role for the UK in working with and supporting governments to strengthen their institutions and regulatory frameworks. Strong institutions, fit for purpose regulatory environments and strong governance will all improve outcomes at the delivery level.

Helping UK Companies to operate in the Global South

Whilst long-term solutions can work on creating a clear regulatory framework, short term solutions to this include better support for UK companies operating in the developing world. This could include a single point of contact for advice, better resources, promoting sharing lessons learned between companies operating in the same countries. This would increase the ease of doing business in those countries as well as increase UK companies confidence and willingness to do so.

Better availability of research, information and intel

During the course of our investigations it has become clear that there is a significant body of research and information already available that would be useful for companies and researchers, but that this is not always easy to find or well publicised. Exploring this wealth of knowledge and bringing together a UK collection of reliable and well-researched resources or publicising existing repositories and knowledge banks would bring considerable benefits. Examples include Energypedia and the green help desk (see Annex 2).

More actively positioning the UK in emerging markets

UK companies are already very active in multiple parts of the energy sector, often in areas that correlate strongly with UK needs and requirements. During the course of research several companies and academics identified cooling and the built environment (zero energy buildings and smart grid etc.) as being key future sectors. There are already some UK companies doing interesting work in these fields and if it is established that these are high growth-potential areas then communicating this message to UK companies and injecting early stage funding would do a lot to create UK strength at the front of emerging markets.

ANNEX 1: PROGRAMMES THAT SUPPORT ENERGY ACCESS IN DEVELOPING COUNTRIES

The current Transforming Energy Access Programme, managed by the Carbon Trust, has a number of different components that reflect the complex and multi-faceted nature of the challenges that exist in facilitating access to energy for those in the developing world.

The main programmes to date that relate to the desire to connect UK commercial capability to this are the Newton Programme and the Energy Catalyst programme.

The Newton Programme was launched in 2014 (and is currently funded to run to 2021) to develop a set of collaborative activities with 15 different developing countries (generally those classified as mid-developed) that spanned pure research, people exchanges and capacity building and projects that support the translation of knowledge into actual impact, largely through commercial activity.

Innovate UK is the delivery partner for a substantial component funding collaborative R&D projects where there are commercial and academic partners from both the UK and from one of the partner countries, in each project. The specific themes for each country programme are negotiated and agreed by the respective innovation agencies, facilitated by Embassy specialists and seek to reflect an analysis of where there was a combination of needs in the developing country and relevant capacity to develop solutions in both the developing country and the UK, around which projects could be formed.

The Energy Catalyst programme has been running for a number of years and the sixth call has recently been announced. Originally this was purely funded by Innovate UK with the stated aim "to help the UK meet its target to generate 15% of its energy from renewable sources by 2020 and put the UK at the forefront of this growing sector."

In rounds 3-6 DFID has contribute to the funding where the projects include partners in a developing country and the target market is that developing country.

Interestingly, CAFOD has published research it commissioned from the ODI about UK Government support between 2010 and 2014 for energy in developing countries[63]. The highlight figures are:

- The UK disbursed £6.13 billion for energy in developing countries between 2010 and 2014 - including £4.201 billion of ODA.
- 46% of the total support went to fossil fuels and 22% to renewable energy.
- Almost all (99.4%) of UK Export for Finance (UKEF) support for energy went to fossil fuels. 32% of ODA goes to support renewable energy, more than the amount spent on fossil fuels (22%).
- Almost half of the total support, 47%, went to upper middle-income countries (UMICs).
- 8% of total support and 12% of ODA went to support energy access.

[63] https://cafod.org.uk/About-us/Policy-and-research/Climate-change-and-energy/Sustainable-energy/Analysis-UK-support-for-energy

This illustrates the imbalance in a wider picture of Government support in this space beyond R&D programmes, that could have a material impact on the impact of such programmes.

The focus of DFID on poverty alleviation and populations that are at the "bottom of the pyramid" tends to be challenging to combine with that of BEIS/DIT where the emphasis is on the most promising commercial opportunities. As this report shows, there are real issues with the energy space in this regard given that the least developed will a) have limited energy demand at least until they develop economic activity and b) have limited and erratic ability to pay.

In many respects the best common ground will be slightly higher up the continuum of poverty where some economic activity is in place. This would support economic growth while offering more promising return on investment potential.

There is a much wider global landscape of initiatives to support energy access hosted and funded by international bodies or other countries – World Bank's Climate Technology programme, Mission Innovation, Sustainable Energy for All, and others. The UK has engagement in most of these but this all creates a complex landscape of resources and programmes for UK firms looking to tap into the support available.

ANNEX 2: DIRECTORY OF SUPPORT ORGANISATIONS

Organisation	Description
Carbon Trust https://www.carbontrust.com/home/	Carbon Trust is a large consultancy providing advice to Governments and running programmes focused on the transition to low carbon economies.
Low Carbon Energy for Development Network https://www.lcedn.com/	The network looks to expand research capacity around low-carbon energy development in the Global South by bringing together researchers, practitioners and policy-makers.
Knowledge Transfer Network (KTN) https://www.ktn-uk.co.uk/	The Knowledge Transfer Network is Innovate UK's network partner and also provides innovation networking for other funders in line with its mission to drive UK growth
European Enterprise Network (EEN) https://een.ec.europa.eu/	Support network for SMEs looking to export through finding partnership overseas.
Department for International Trade (DIT) https://www.gov.uk/government/organisations/department-for-international-trade	UK Government department responsible for developing UK trade policy and promoting British trade and investment.
Department for International Development (DfID) https://www.gov.uk/government/organisations/department-for-international-development	UK Government department responsible for tackling extreme poverty and supporting development in the Global South.
Energy System Catapult https://es.catapult.org.uk/	One of a network of Catapult centres funded by Innovate UK to drive economic growth through supporting the UK's strengths around energy technology and systems.
British Council https://www.britishcouncil.org	The UK's international organization for cultural and educational relations.
UK Commission for UNESCO https://www.unesco.org.uk/	UNESCO (United Nations Educational, Scientific and Cultural Organisation) is the United Nations body responsible for coordinating international cooperation in education, science, culture and communication.
Innovate UK https://www.gov.uk/government/organisations/innovate-uk	The UK's innovation agency. It helps drive productivity and growth by supporting businesses to develop and realise the potential of new ideas, including those from the UK's research base.
Farraday Institution https://faraday.ac.uk/	The Faraday Institution is the UK's independent institute for electrochemical energy storage science and technology, supporting research, training, and analysis. It brings together scientists and industry partners on research projects to reduce battery cost, weight, and volume; to improve performance and reliability; and to

	develop whole-life strategies from mining to recycling to second use.
Supergen Biogen hub http://www.supergen-bioenergy.net/	The Supergen Bioenergy Hub aims to bring together industry, academia and other stakeholders to focus on bioenergy research and knowledge challenges.
Supergen solar hub http://www.supersolar-hub.org/	The Supergen Solar Hub aims to bring together industry, academia and other stakeholders to focus on solar research and knowledge challenges.
Renewable energy hub https://www.renewableenergyhub.co.uk/	The Renewable Energy Hub is a national organisation that sells and promotes renewable energy equipment and services.
https://bbsrc.ukri.org/funding/grants/priorities/ibb-bioenergy/ https://bbsrc.ukri.org/funding/filter/industrial-biotechnology-bioenergy-in-the-developing-world/	Focuses on UK achieving aims of sustainable energy through bioenergy.
International renewable energy agency. http://www.irena.org/	The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the adoption and use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy.
Climate and Development Knowledge Network https://cdkn.org/	The Climate and Development Knowledge Network supports decision-makers in designing and delivering climate compatible development. It does this by combining research, advisory services and knowledge management in support of locally owned and managed policy processes.
Green Mini-Grids Africa https://greenminigrid.se4all-africa.org/	The programme aims to help develop the Green Mini-Grids (GMGs) sector in Africa.
GOGLA https://www.gogla.org/about-us	GOGLA is the global association for the off-grid solar energy industry.

ANNEX 3: INTERVIEWEES

Alongside desk based research the project team conducted a series of in depth interviews with business leaders, academics and policy makers.

Company/ Org	Name	Technology/ Sector
Straw Innovations Ltd	Craig Jamieson	Biogas using waste straw
Steama Co Ltd	Alistair Starkie	Energy IoT platform for wireless smart metering
Solarpak	Mark Spratt	Solar PV for off-grid communities
Solar Polar Ltd	Robert Edwards	Cooling
Green Fuels Ltd	Paul Hilditch	Biodiesel
OakTek	Tom Harrison	Engineering research specialist working on low carbon engine
Grafmarine	Martin Leigh	Early stage entrepreneur
Green Directions	Mark Woodward	UK low carbon solutions
Gamos Ltd	Dr Simon Batchelor	Skills and training in developing countries
Mobile Power	Luke Burras	Electrical device charging
Independent consultant	Alex Badley	Energy systems and load sharing
Engas UK Ltd	Dr Amit Roy	Energy storage solutions using bio-CNG.
Dearman Engine Company Ltd	Florian Wagner	Zero-emission technologies, powered by the expansion of liquid air or nitrogen.
Buffalo Grid Ltd	Daniel Beccera	Portable solar powered charging units.
RWE	Catherine Wainwright	Energy Technology investment
British Council	Shaun Holmes	Partnership facilitation
Loughborough University	Prof Michael Walls, Prof Ed Brown and colleagues	Range of areas of research around low carbon energy for development.
Aston University	Prof Patricia Thornley	Bioenergy Supergen Hub
Birmingham University	Prof Toby Peters	Cooling technology
Energy systems Catapult	Andrew Stokes	Supporting innovation in energy systems in the UK
Impellor Ventures	Jim Dawton	Reverse Funnel Innovation
ODI	Andrew Scott	International Development and Energy
UK Commission for UNESCO	James Bridge	Network for research to meet developing country needs.
World Bank	Jean-Louis Racine	Climate Technology Programme
BEIS	Matthew Billson	Energy policy
DFID	Alex Moscuzza	Bioenergy lead
Innovate UK	Janet Geddes	Head of ODI and Asia programmes
Innovate UK	Alice Goodbrook	Energy Technology Lead
KTN	Louise Jones	Distributed Energy and Grids
KTN	Nazanin Rashidi	Energy Storage

KTN	Jenni McDonnell	Heating and cooling
KTN	Jonathan Abra	Waste

ANNEX 4: BIBLIOGRAPHY

‘A Practical Guide to the Regulatory Treatment of Mini Grids’. Accessed 14 August 2018.

https://pubs.naruc.org/pub/E1A6363A-A51D-0046-C341-DADE9EBAA6E3.

‘About – Straw Innovations Ltd’. Accessed 11 August 2018.

https://strawinnovations.com/about/

Alam, Firoz, Saleh Mobin, and Harun Chowdhury. ‘Third Generation Biofuel from Algae’. *Procedia Engineering*, The 6th BSME International Conference on Thermal Engineering, 105 (1 January 2015): 763–68.

https://doi.org/10.1016/j.proeng.2015.05.068

Araujo, Kathleen. *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation*. Oxford, New York: Oxford University Press, 2018.

Aro, Eva-Mari. ‘From First Generation Biofuels to Advanced Solar Biofuels’. *Ambio* 45, no. Suppl 1 (January 2016): 24–31.

https://doi.org/10.1007/s13280-015-0730-0

‘Biomass Sector Review for the Carbon Trust’. Accessed 13 August 2018.

https://www.carbontrust.com/media/77236/ctc512_biomass_sector_review_for_the_carbon_trust.pdf

‘CO2 Emissions from Fuel Combustion Highlights’. Accessed 13 August 2018.

https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf

‘Cooling - Energypedia.Info’. Accessed 13 August 2018.

https://energypedia.info/wiki/Cooling

Das, Ipsita, Pamela Jagger, and Karin Yeatts. ‘Biomass Cooking Fuels and Health Outcomes for Women in Malawi’. *EcoHealth* 14, no. 1 (March 2017): 7–19.

https://doi.org/10.1007/s10393-016-1190-0

Department for Energy and Climate Change. ‘Smarter Grids: The Opportunity’. UK Government, December 2009.

http://webarchive.nationalarchives.gov.uk/20100512190105/http:/man270109a.decc.gov.uk/media/viewfile.ashx?filepath=what we do/uk energy supply/futureelectricitynetworks/1_20091203163757_e_@@_smartergridsopportunity.pdf&filetype=4.

‘DevTracker Project GB-1-204867 Documents’. Accessed 11 August 2018.

https://devtracker.dfid.gov.uk/projects/GB-1-204867/documents.

'DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2018'. Accessed 13 August 2018.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/731235/DUKES_2018.pdf.

Dr Natalia Gomez-Marin, and Prof Tony Bridgwater. 'MAPPING UK BIOENERGY RESEARCH STAKEHOLDERS: A Systematic Review of Bioenergy Capabilities and Expertise in Academia and Research Centres in the UK, 2016-2017'. Aston University, 2017.

https://www.aston.ac.uk/EasySiteWeb/GatewayLink.aspx?alId=351155.

'Durham Energy Institute: Biofuels - Durham University'. Accessed 13 August 2018.

https://www.dur.ac.uk/dei/biofuelsresearch/.

Elzinga, David. 'Smart Grids Roadmap'. International Energy Agency, April 2011.

'Energy Catalyst Programme'. *PNO Consultants United Kingdom* (blog). Accessed 10 August 2018.

https://www.pnoconsultants.com/uk/grants/energy-catalyst/

'Energy Catalyst: What It Is and How to Apply for Funding'. GOV.UK. Accessed 10 August 2018.

https://www.gov.uk/guidance/energy-catalyst-what-it-is-and-how-to-apply-for-funding.

'European Bioenergy Research Institute (EBRI)'. Accessed 13 August 2018.

Http://www.aston.ac.uk/eas/research/groups/ebri/.

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. 'Land Clearing and the Biofuel Carbon Debt'. *Science (New York, N.Y.)* 319, no. 5867 (29 February 2008): 1235–38.

https://doi.org/10.1126/science.1152747.

'Finance and Investment in the Biofuels Sector - Carbon Trust'. Accessed 14 August 2018.

https://www.carbontrust.com/news/2013/10/finance-and-investment-in-the-biofuels-sector/

'Fee-For-Service or Pay-As-You-Go Concepts for Photovoltaic Systems - Energypedia.Info'. Accessed 11 August 2018.

https://energypedia.info/wiki/Fee-For-Service_or_Pay-As-You-Go_Concepts_for_Photovoltaic_Systems.

'2010 to 2015 Government Policy: UK Energy Security'. GOV.UK. Accessed 14 August 2018.

https://www.gov.uk/government/publications/2010-to-2015-government-policy-uk-energy-security/2010-to-2015-government-policy-uk-energy-security.

‘File:Graphik PicoPV.JPG - Energypedia.Info’. Accessed 13 August 2018.

https://energypedia.info/wiki/File:Graphik_PicoPV.JPG.

Goodall, Chris The Switch – How solar, storage and new tech means cheap power for all. Profile Books, 2016.

Grethe, Harald, Andre Deppermann, and Sandra Marquardt. *Biofuels: Effects on Global Agricultural Prices and Climate Change*, 2013.

‘Innovate UK Directory of Projects - Energy Catalyst – Round 4’. Innovate UK, 25 January 2018.

‘Innovate UK Funded Projects since 2004’. GOV.UK. Accessed 13 August 2018.

https://www.gov.uk/government/publications/innovate-uk-funded-projects.

Joint Research centre. ‘Smart Grid Projects Outlook 2017: Facts, Figures and Trends in Europe’. Joint Research centre, 2017.

http://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/u24/2017/sgp_outlook_2017-online.pdf.

Kathleen Araújo, Devinder Mahajan, Ryan Kerr, and Marcelo da Silva. ‘Global Biofuels at the Crossroads: An Overview of Technical, Policy, and Investment Complexities in the Sustainability of Biofuel Development’. Agriculture, 29 March 2017.

http://www.mdpi.com/2077-0472/7/4/32/pdf.

KTN. ‘UK Capability in Relation to Low Carbon Energy, Built Environment and Water Technologies’, n.d.

‘Land and Power The Growing Scandal Surrounding the New Wave of Investments in Land’. Accessed 13 August 2018.

https://oxfamilibrary.openrepository.com/bitstream/handle/10546/142858/bp151-land-power-rights-acquisitions-220911-en.pdf;jsessionid=BF55861DDEFADDBF9A8E26C4C857640B?sequence=32.

‘Malawi Energy Situation - Energypedia.Info’. Accessed 11 August 2018.

https://energypedia.info/wiki/Malawi_Energy_Situation.

‘Methanol Economy for India: Energy Security, Make in India and Zero Carbon Foot Print’. Accessed 13 August 2018.

http://pib.nic.in/newsite/PrintRelease.aspx?relid=174919.

‘Microbial Production of Fourth-Generation Biofuels | REF2014 | University of Exeter’. Accessed 14 August 2018.

https://www.exeter.ac.uk/ref2014/impact/lifesciences/biofuels/

'Mini-Grid Regulation and Practical Experiences from Kenya'. Accessed 14 August 2018.

https://www.giz.de/fachexpertise/downloads/2016-en-kenya-regulation-experiences-jasmin-fraatz.pdf.

'Northern Ireland Renewable Heat Incentive', 14 June 2016.

https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/about-non-domestic-rhi/northern-ireland-renewable-heat-incentive.

Owaineh, Alaa, Matthew Leach, Paul Guest, and Walter Wehrmeyer. 'Policy, Niches and Diffusion in UK Smart Grid Innovation', n.d., 25.

'PayGo Energy Access for Rural, off-Grid Homes'. Azuri Technologies. Accessed 13 August 2018.

http://www.azuri-technologies.com/.

'Policy Factsheet - Smart Grid'. Accessed 14 August 2018.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321852/Policy_Factsheet_-_Smart_Grid_Final__BCG_.pdf.

'Renewable Transport Fuel Obligation Statistics: Period 10 2017/18, Report 1'. Accessed 13 August 2018.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656292/rtfo-year-10-report-1.pdf.

Ruud Kempener, Olivier Lavagne d'Ortigue, Deger Saygin, Jeffrey Skeer, Salvatore Vinci, and Dolf Gielen. 'Off-Grid Renewable Energy Systems'. International Renewable Energy Agency (ARENA), 2005.

http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Off-grid_Renewable_Systems_WP_2015.pdf.

'Rwanda Energy Situation - Energypedia.Info'. Accessed 11 August 2018.

https://energypedia.info/wiki/Rwanda_Energy_Situation_-_Rural_electrification_Strategy.2C_2016

Sargsyan, Gevorg, Mikul Bhatia, Sudeshna Ghosh Banerjee, Krishnan Raghunathan, and Ruchi Soni. *Unleashing the Potential of Renewable Energy in India*. The World Bank, 2011.

https://doi.org/10.1596/978-0-8213-8780-1

Silva, Izael Pereira Da. 'Lessons from Kenya about What's Holding Back Solar Technology in Africa'. The Conversation. Accessed 11 August 2018.

http://theconversation.com/lessons-from-kenya-about-whats-holding-back-solar-technology-in-africa-64185

'Smart Grids for Improved Grid Performance in Developing Countries -'. Accessed 14 August 2018.

https://energypedia.info/wiki/Smart_Grids_for_Improved_Grid_Performance_in_Developing_Countries

'Smart Meters: A Guide'. GOV.UK. Accessed 14 August 2018.

https://www.gov.uk/guidance/smart-meters-how-they-work

'Solar Oil'. UK Research and Innovation. Accessed 14 August 2018. https://gtr.ukri.org/projects?ref=EP%2FP03103X%2F1.

'Solar Polar'. Accessed 11 August 2018.

http://www.solar-polar.co.uk/'Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.Pdf' Accessed 13 August 2018

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593465/Solar_PV_Thermal_Tech_TINA_Summary_Report_March2016.pdf

'Sunshine to Petrol - Solar Recycling of Carbon Dioxide into Hydrocarbon Fuels'. Accessed 14 August 2018.

https://energy.sandia.gov/wp-content//gallery/uploads/S2P_SAND2009-5796P.pdf

'Sustainable Biofuels in the Global South'. Accessed 13 August 2018.

https://research.cbs.dk/files/46592272/stefano_ponte_sustainable_biofuels_postprint.pdf

Swemmer, Tarryn, Mikhail Nikomarov, Antonio Castellano, and Adam Kendall. 'Brighter Africa The Growth Potential of the Sub-Saharan Electricity Sector'. McKinsey & Company, February 2015.

https://www.mckinsey.com/~/media/mckinsey/industries/retail/our insights/east africa the next hub for apparel sourcing/brighter_africa_the_growth_potential_of_the_sub saharan_electricity_sector.ashx

'The Cold Economy - University of Birmingham'. Accessed 13 August 2018.

https://www.birmingham.ac.uk/research/activity/energy/policy/cold/cold-energy.aspx

'The Current Status of Biofuels in the European Union, Their Environmental Impacts and Future Prospects'. Accessed 13 August 2018.

https://www.easac.eu/fileadmin/PDF_s/reports_statements/Easac_12_Biofuels_Complete.pdf

'The Emerging Cold Economy - Carbon Trust'. Accessed 13 August 2018.

https://www.carbontrust.com/resources/reports/technology/the-emerging-cold-economy/

The German Climate Technology Initiative. 'How Do We License It? A Guide to Licensing a Mini-Grid Energy Service Company in Kenya'. Deutsche Gesellschaft für Internationale Zusammenarbeit, July 2015.

https://www.giz.de/en/downloads/GIZ2015-ProSolar-Licensing-Guidebook.pdf

'Transportation Sector Energy Consumption'. Accessed 13 August 2018.

https://www.eia.gov/outlooks/ieo/pdf/transportation.pdf

'UK Energy Statistics, 2017 & Q4 2017'. Accessed 13 August 2018.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695626/Press_Notice_March_2018.pdf

'United Nations Sustainable Development: Energy'. *United Nations Sustainable Development* (blog). Accessed 10 August 2018.

https://www.un.org/sustainabledevelopment/energy/

'Water Use and Sustainable Biofuel Production - eXtension'. Accessed 14 August 2018.

http://articles.extension.org/pages/27663/water-use-and-sustainable-biofuel-production

'Welcome to Solapak- Solar Power Systems'. Accessed 11 August 2018.

http://www.solapak.co.uk/our-technolog