Climate technology in context

Synthesis Report on Climate Technology and Development

April 2014

Acknowledgement

The authors and project team would like to thank CDKN for their support of this project; Tilman Altenburg and the German Development Institute (DIE) for hosting the project's final conference; and the members of the advisory committee for their inputs and review – Ron Benioff, Alison Cambray, Jason Eis, Andrew Higham, Matthew Kennedy, Zitouni Ould-Dada and Can Wang.

This final report concludes the Climate Technology and Development project, funded by CDKN and coordinated by ECN. The project's principal aim was to refocus national and international policy agendas in order to improve the prospects for enhancing technology development, diffusion and transfer in developing countries. The overarching question the project attempted to answer was: "What are the conditions for innovation for climate-compatible development for three different categories - the industrial sectors, rising middle class and bottom of the pyramid - in developing countries?" Results were presented in the form of 5 case studies on specific technologies and 5 policy briefs covering these different categories and the UNFCCC Technology Mechanism more broadly.

This report is registered under ECN project number 5.1633. Contact Lachlan Cameron [cameron@ecn.nl]

Authors (alphabetical):
Shikha Bhasin; ECN
Gabriel Blanco; UNICEN
Sophy Bristow; ECN
Rob Byrne; University of Sussex
Lachlan Cameron; ECN
Heleen de Coninck; Radboud University Nijmegen
Zhang Fang; Tufts University and Tsinghua University
Kelly Sims Gallagher; Tufts University
Raluca Ionita; VU University Amsterdam
Tom Mikunda; ECN
Ambuj Sagar; Indian Institute of Technology Delhi
Laura Würtenberger; GIZ

This document is an output from a project funded by the UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS) for the benefit of developing countries. However, the views expressed and information contained in it are not necessarily those of or endorsed by DFID, DGIS or the entities managing the delivery of the Climate and Development Knowledge Network, which can accept no responsibility or liability for such views, completeness or accuracy of the information or for any reliance placed on them.

Contents

Executive Summary

Technology as an enabler of low-carbon development has both enormous urgency, but also opportunities associated with it. From a global perspective it is vital that developing countries are able to improve both access to, and their ability to develop, climate technologies, as it is in these countries that the majority of new GHG emissions will occur. At the same time, there are large potential benefits of low-carbon innovation that countries can gain from; for example in terms of developing new or more competitive domestic industries, or adopting improved technologies that have positive social and environmental impacts.

Yet building the low-carbon innovation systems that can deliver the necessary technologies and services is a resource-intensive and long term endeavour, the outcomes of which are neither guaranteed nor predictable, and no single approach fits all national contexts. To mitigate the risky nature of building innovation systems, the public sector needs to provide financial support alongside private sector investments. Innovations emerge from a system of interconnected firms, organisations and users all operating within an institutional environment that supports the building and strengthening of skills, knowledge and experience, and further enhances the interconnectedness of such players.

The successful development and adoption of low-carbon technologies in developing countries therefore depends on the presence of appropriate policies and innovation systems that suit their local context. However countries are not homogenous, the technology and innovation needs of the poorest can be expected to differ vastly from those of an emerging industrial sector. In order to benefit and reach out successfully to the varying development levels and needs of its populations, nations need to approach goals of sustainable development by targeting their differing demographics through appropriate interventions.

This report synthesises research that was undertaken in the "Climate Technology and Development'' project, which sought to answer the question: "What are conditions for innovation for low-carbon development for three different categories – the industrial sectors, rising middle class and bottom of the pyramid – in developing countries?". Each of these contexts within a country has its own driving forces, in terms of the needs of that portion of the populace, but also has different considerations when designing policy for the development of low-carbon innovation systems (Table 1).

Table 1: Relevance of each target category, and the considerations that influence policy support

Category	Relevance	Considerations for low-carbon innovation
Bottom of the pyramid	- In 2012 nearly 1.3 billion people remained without access to electricity - 2.6 billion still remain dependent on traditional biomass for cooking needs - These numbers will not decline much without major interventions (IEA 2012) - Modern energy provides a range of services – lighting, refrigeration, communication, mechanical power, thermal energy etc. – that are important for households, communities and businesses and underpin development	- Large-scale deployment of suitable technologies is required, developing the technologies themselves is not enough - Technologies and products must be seen by users as offering useful services and at a price point that they can afford - Business-as-usual approaches are unlikely to work at this level as profit margins and timeframes are unattractive (Wilson et al. 2012) - Many within this category live in rural areas of poorer countries, creating limitations on information provision and technology supply
Rising middle class	- Middle class expected to grow from ca 1.5 billion in 2009 to almost 5 billion in 2030 - The share of the middle class outside Europe and North America is expected to rise from 45% in 2009 to almost 80% in 2030 - Middle class consumption patterns are fast approaching 'lock-in' in many developing countries	- Middle class carbon footprints vary greatly depending on e.g. access to public transport, climate and geography, household size etc. - Reducing middle class emissions is often a 'lifestyle' question involving direct and indirect emissions, covering a broad range of sectors including urban planning, transport, household appliances, heating, cooling, food and consumption goods - There is a high risk of the rebound effect for this category
Industrial sectors	- Globally, industry accounted for about one third of final energy consumption in 2010 (IEA 2013) - Non-OECD countries will account for the bulk of industry-related GHG rises under BAU up to 2050 (OECD 2012) - The global average efficiency of energy use in industry is only 30%, so enormous opportunities exist to achieve both emissions reductions and economic benefits (GEA 2012) - Many developing countries are at the crucial stage of defining their industrial development trajectories	- There is a wealth of industrialisation experiences from around the world demonstrating how to take advantage of low-carbon opportunities - Opportunities exist both to improve the efficiency of energy intensive manufacturing, and to exploit export oriented opportunities for low-carbon technologies

The building of innovation systems at the national level needs to emerge as an overarching goal in order to help countries develop in self-directed ways, contributing to sustainability, while adapting to changing circumstances. In this process, national governments and bodies have a key role to play in directing and developing the capabilities of actors and the linkages between them. In this role they must note that:

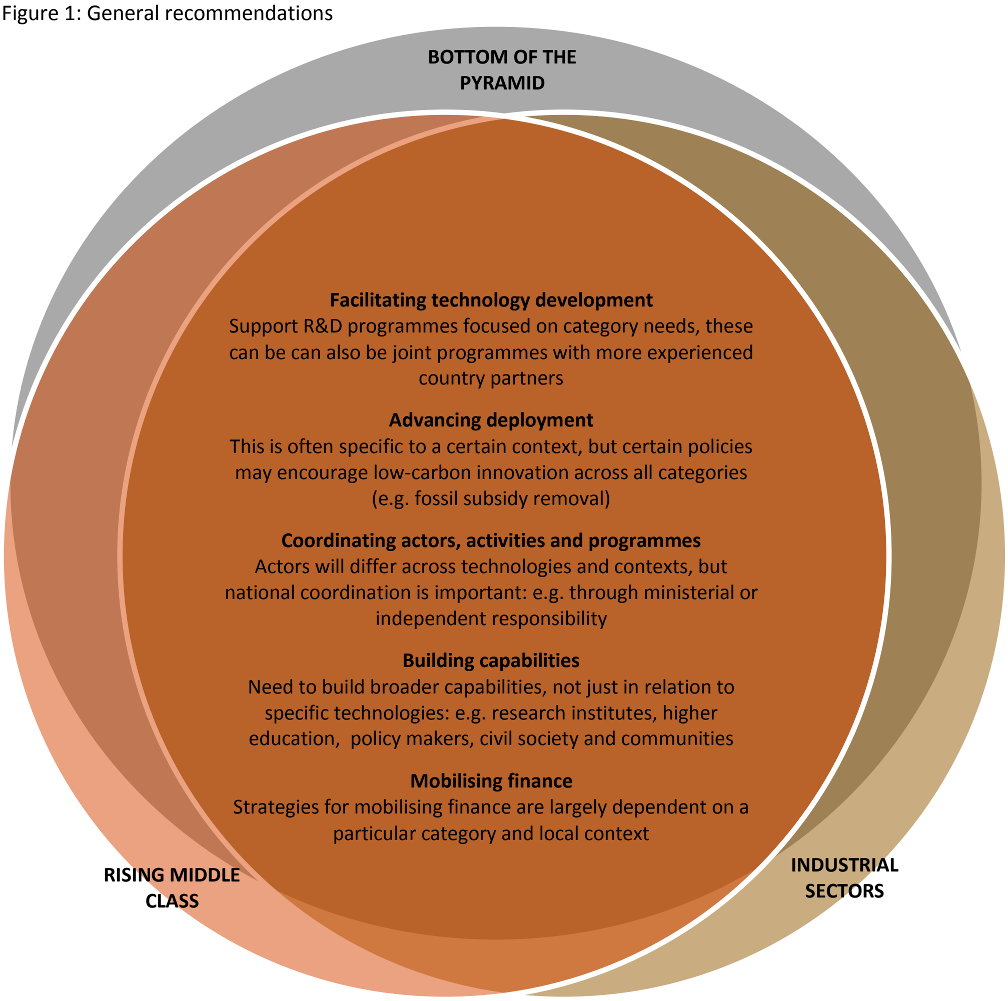
I. **The entire innovation spectrum needs to be taken into account**
Innovation is not just about radical changes in hardware or processes, but also incremental change or the adaptation of existing technologies. Policies need to be able to identify and highlight opportunities across this spectrum.

II. **National circumstances matter**
The context sensitivity of policy design for innovation should be extended beyond the national level to the different demographics within a society who will also have differing needs.

III. **Broader innovation systems need to be considered**
Innovation arise from the activities of networks of actors who combine their knowledge, skills and resources in complex ways. Policies and programmes should also be designed to ensure that the different players in the system are able to coordinate and collaborate to meet their individual and collective goals.

The project presented policy recommendations – targeted to each of the three categories – too numerous to include here (see Table 4). Figure 1 summarises these recommendations and key messages, showing that some common elements can be identified, but that policies and approaches will often need to be tailored to a certain category.

Figure 1: General recommendations



Although developing countries have many instruments available to them to try and establish functional innovation systems domestically, international support to build the required resources and capabilities will be vital in many instances. There is an opportunity for the UNFCCC's Technology Mechanism and other international bodies to take on brokering roles, linking various technology initiatives with finance providers, stimulating and encouraging cooperative R&D, linking innovation processes in different sectors within a country or in different countries, and identifying where lessons learned from successes and failures with technology development, demonstration and transfer in one part or the world can be relevant elsewhere.

This research has shown that developing countries will have different kinds of low-carbon innovation strategies based on their assessment of local circumstances and the categories within their economy. In this regard, national contexts are unique and there is no 'one-size-fits-all'. By looking through a lens of different categories, this project has found that a more targeted approach – in terms of finance, capability building, and policy approaches – can be effective in identifying interventions for building low-carbon innovation in developing countries.

1

Why technology interventions for low-carbon development?

The role of technology as a fundamental driving force of growth and development has long been recognised. Improvements in adopted technologies, whether by firms or individuals, can contribute to delivering economic, social and environmental benefits at different scales. Examples range from the local and individual level – such as improved health from a change in household cooking practices – to issues of international competitiveness and trade – such as the export success of China in the solar PV industry. At the same time, technology is clearly understood as a key aspect of our ability to successfully mitigate climate change. Promoting the development and transfer of 'environmentally sound' technologies is at the centre of the ongoing international discussions on how to meet the climate challenge.

The intersection of these two concepts – technology as an enabler of growth and mitigation, or low-carbon development – has both enormous urgency, but also opportunities associated with it. From a global perspective it is vital that developing countries are able to improve both access to, and their ability to develop, climate technologies. More than 80% of new greenhouse gas emissions by 2050 will come from developing countries without intervention (OECD 2012). Although it is recognised that these countries have historically contributed less to climate change than industrialised countries, limiting climate change to acceptable levels will be impossible if they do not shift towards low carbon development pathways.

The 'silver lining' to this challenge, is that there are large potential benefits of low-carbon innovation that countries can gain from. In addition to the aforementioned example of Chinese solar PV manufacturing, other successful cases include ethanol in Brazil and wind power in India. For decades, Brazil has been investing in a biofuels industry. Its transport sector is the only one in the world that does not depend exclusively on conventional oil. Hundreds of thousands of people are employed in the biofuel sector. In India, an indigenous wind turbine industry has been developing for over a decade. Suzlon started building wind turbines on a small scale in 1995, and has since grown to become the fifth largest global wind turbine producer, employing 13,000 people globally. The Brazilian biofuels and Indian wind energy examples illustrate the potential benefits of low-carbon innovation. These benefits do not only include emissions reductions when compared to an energy pathway powered purely by fossil fuels. They can also include the development of local capabilities within these countries to develop and deploy low-carbon technologies (Byrne et al. 2012).

Although technology and innovation have long been recognised as drivers of economic growth and development, it is only more recently that our understanding has improved of how to influence the underlying systems of innovation that enable technology diffusion and development, as well as the role of governments in this process. Successful development and adoption of low-carbon technologies in developing countries depends on the presence of appropriate policies and innovation systems.

Building the necessary innovation capacity in a country is a risky, systemic undertaking that cannot be carried by the private sector alone. Public sector financial support is required to complement and assist private sector innovation, and to help create markets for the low-carbon energy technologies and services that are required. How this support is delivered is also important. Low-carbon interventions in developing countries can be advanced through the use of technology interventions rather than relying solely on economic incentives, which can be difficult to implement in these countries (Byrne et al. 2012; Sagar 2013).

Appropriate national and international policies and instruments, therefore, play an important role in helping to build the low-carbon innovation systems in these countries. 'Appropriateness' implies that they are responsive to their local context in terms of available resources, comparative advantages, societal characteristics and cultural practices. The challenge is then to better understand local contexts in order to identify appropriate policy and technology interventions.

The usual rhetoric around low-carbon development revolves around national averages of both incomes and emissions, resulting in discussions of policies and measures premised on the notion that the whole population are, for example, living in abject poverty or equally benefiting from a country's economic growth. Even though a large segment of the population of most developing countries remains severely deprived, most developing countries also have a significant and growing part of the population that is more affluent and many have rapidly expanding industrial sectors, driven either by local or external demand (de Coninck and Byrne 2013). In order to benefit and reach out successfully to the varying development levels and needs of its populations, nations need to approach goals of sustainable development by targeting their differing demographics through appropriate interventions; a challenge that has not been adequately explored in the past.

In order to address this gap in thinking, this report synthesises research that was undertaken in the "Climate Technology and Development'' project. The project sought to answer the core question: "What are conditions for innovation for low-carbon development for three different categories (i.e. the industrial sectors, rising middle class and bottom of the pyramid) in developing countries?" It brought together researchers from 6 leading institutions, to propose practical policy interventions for strengthening innovation systems in developing countries based on academic and practical insights; as well as ideas of how to progress the international debate on technology.

Through its course, the project published five policy briefs: i) an introduction to innovation in developing countries; ii) from the international perspective, identifying opportunities for the Technology Mechanism, established under the United Nations Framework Convention on Climate Change (UNFCCC), to contribute to the development and transfer of technologies; and iii) to v) focussed on building appropriate innovation systems for each category – industrial sectors, the rising middle class and the 'bottom of the pyramid'.

These 'category specific' briefs built on case studies of five technology value chains in developing countries, assessing both the barriers to local innovation as well as the potential impact of introducing a technology. This was done to clarify the diversity of technology, capacity and economic challenges in these value chains, as well as to identify the processes, interests and points of intervention for low-carbon development from producer to user.

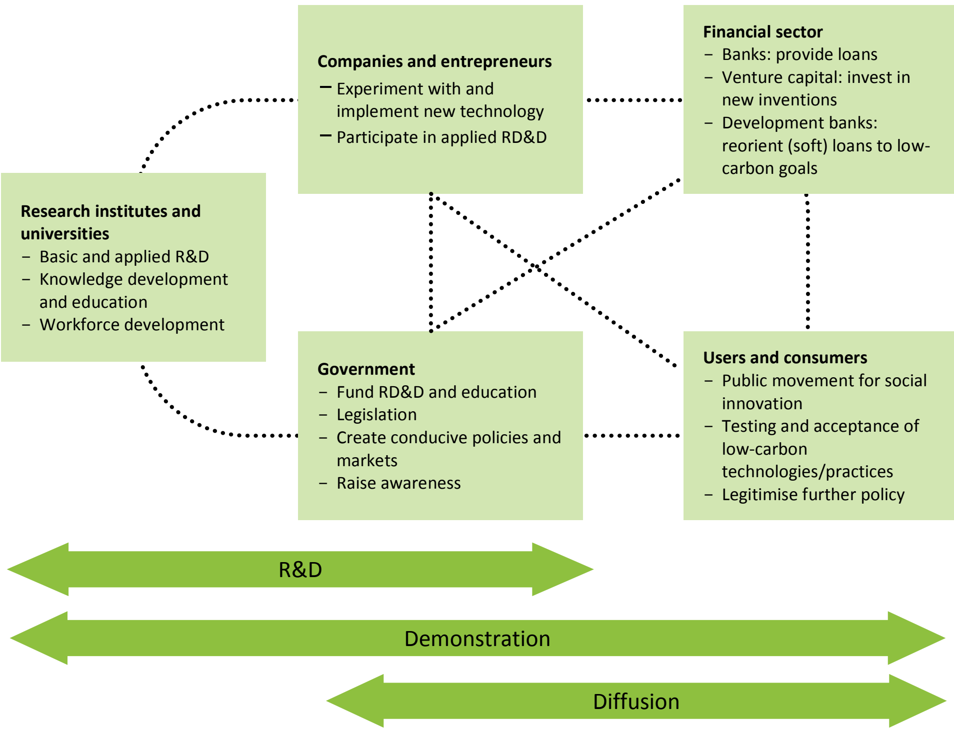
The following chapters of this synthesis report summarise how an examination of different contexts within a population and economy can inform policy interventions for low-carbon innovation systems, as well as what kinds of international efforts by bodies such as the UNFCCC's Technology Mechanism can support appropriate low-carbon innovation system building in developing countries. The following chapter introduces the project's approach of examining different categories within an economy, before considering each specific context in more detail.

2

Low-carbon innovation for different contexts

The context in which innovation takes place matters and will have important implications for efforts to build innovation capabilities and systems. For example, the innovations appropriate to industrialisation will tend to be different to those that service the needs and address the challenges of a rising middle class. The needs of the poor require policy responses that address the urgency of their particular problems, which tend also to be different to those of industrialisation and a rising middle class. Adding to this challenge, building low-carbon innovation systems is a resource-intensive and long term endeavour, the outcomes of which are neither guaranteed nor predictable, and no single approach fits all national contexts. Innovation does not just entail technical changes but can also be social, political or cultural. This makes the range of actors in innovation wider, and the range of activities broader (Byrne et al. 2012).

Figure 2: A representation of functions and linkages between actors in the innovation system and their relation to the technology cycle (source: Blanco et al. 2012)



Experience shows that policy interventions can have a strong positive effect on low carbon innovation systems, although success requires carefully-designed policy. Examples such as the Danish wind industry, Brazilian ethanol, and the development and deployment of renewables in Germany show the benefits of innovation 'systems thinking' in action (Jacobsson and Bergek 2004). These success stories are not only due to the implementation of particular market-creation policies (e.g. German feed-in tariffs), but also due to a combination of high-level political leadership and legitimacy, and complementary policies focussing on areas such as grid access, local financing and industrial development. (Byrne et al 2012)

Setting out policies to support low-carbon innovation in developing countries faces several challenges. For example, many technologies are at an early pre-commercial stage. Also, different developing countries will have a range of strategic needs and priorities, comparative advantages, and national social-economic and institutional structures that influence their innovation policies and strategies (Cimoli et al. 2009; Sagar 2011). However, in addition to capacity limitations (financial, technical and informational) that limit policymakers and stakeholders from developing and strengthening an innovation system, the inadequate attention granted to the topic in developing countries is one of the main reasons for an arguably low number of successful examples.

This research aims to guide policy interventions, at a domestic and international level, for steering and advancing technological innovation – and key aspects of innovation systems – to contribute to climate-compatible development. To do this, the research perspective is narrowed to focus on three specific categories within a developing country: (i) the so called 'bottom-of-the-pyramid' (BOP), (ii) the rising middle class, and (iii) industrial sectors.

These categories are based on looking at future carbon emissions: a poorer populace with acute development needs but also opportunities to develop in a more sustainable way than the default; a rising middle class with increasing consumption as a result of demand for goods, transport and energy; and a diverse and growing industry with increasing needs for resources and energy. These three categories can be expected to have different innovation and technology needs, and thinking about the specific needs of each one can provide a targeted approach to low-carbon innovation. Each of these categories, along with their contextual considerations and policy implications, are presented in more detail in the following three chapters. Before doing so, it is first useful to understand the importance and relevance of each category in regards to development objectives and climate impacts (Table 2).

The bottom of the pyramid

The 'bottom of the pyramid' represents the largest, but poorest, socio-economic group on the planet; some 3-5 billion people depending on how this group is defined. They are largely unserved by a traditional organised private sector due to individually low purchasing power, living on some 1-2 USD per day. In terms of low-carbon development, the most significant intersection in interests is in the provision of modern energy. It is estimated that nearly 1.3 billion people remain without access to electricity and 2.6 billion still do not have access to clean cooking energy (IEA 2012). Many of these deprived people live in least-developed countries, but, surprisingly, they also are in emerging economies such as India, South Africa and Brazil. The energy situation of this group has major implications for their human, social, and economic development.

The rising middle class

The number of people in the global middle class is projected to increase greatly in the years until 2030, growing from approximately 1.5 billion people in 2009 to almost 5 billion in 2030[i]. This is largely taking place in the developing world. The share of the global middle class outside of Europe and North America is expected to increase from around 45% in 2009 to almost 80% in 2030. While in terms of middle class consumption, the developing-world share will increase from a little over 50% to around 70%. It is clear that the rising middle class, both in numbers of people and in consumption, lives in non-Annex I countries. As consumption is a major driver of CO_2 emissions, how the rising middle class in developing countries will develop – along a low-carbon or a higher-carbon pathway – is a major determinant of the carbon intensity of the world economy and our collective ability to stay below 2°C global mean temperature rise over this century.

Industrial sectors

Although consumption of a rising middle class is a key driver of GHG emissions, these are largely produced by a global industrial sector that is rapidly growing in parallel. Without interventions, industries being established in developing countries are likely to move along traditional carbon-intensive or inefficient pathways – in a manner similar to those in many industrialised countries in the past – increasing emissions in the short term and the likelihood of establishing high carbon lock-in over the longer term. A combination of rapid economic growth and differences in technologies means that developing countries could account for up to 90% of increases in industrial GHG emissions by the middle of the century under business as usual assumptions (ECN forthcoming).

There are also interdependencies across these contexts. Industrialisation can generate innovations that provide improved technologies relevant to the needs of the middle class and/or poor, or secondary effects such as creating jobs in low-carbon industries. Market demand expressed by the middle class, and perhaps by the poor, can influence directions of industrialisation. But there are likely to be important distinctions too. For example, the poor may have little option but to adopt innovations based on price, while the middle class may have options to demand innovations that provide more sophisticated functionality or are status-enhancing. (Byrne et al. 2012).

[i] when defined as daily expenditures between US $10 to 100 based on purchasing power parity

Table 2: The relevance of each target category, and the specific considerations which should influence policy support for low-carbon innovation

Category	Relevance	Considerations for low-carbon innovation
Bottom of the pyramid	- In 2012 nearly 1.3 billion people remained without access to electricity - 2.6 billion still remain dependent on traditional biomass for cooking needs - These numbers will not decline much without major interventions (IEA 2012) - Modern energy provides a range of services – lighting, refrigeration, communication, mechanical power, thermal energy etc. – that are important for households, communities and businesses and underpin development	- Large-scale deployment of suitable technologies is required, developing the technologies themselves is not enough - Technologies and products must be seen by users as offering useful services and at a price point that they can afford - Business-as-usual approaches are unlikely to work at this level as profit margins and timeframes are unattractive (Wilson et al. 2012) - Many within this category live in rural areas of poorer countries, creating limitations on information provision and technology supply
Rising middle class	- Middle class expected to grow from ca 1.5 billion in 2009 to almost 5 billion in 2030 - The share of the middle class outside Europe and North America is expected to rise from 45% in 2009 to almost 80% in 2030 - Middle class consumption patterns are fast approaching 'lock-in' in many developing countries	- Middle class carbon footprints vary greatly depending on e.g. access to public transport, climate and geography, household size etc. - Reducing middle class emissions is often a 'lifestyle' question involving direct and indirect emissions, covering a broad range of sectors including urban planning, transport, household appliances, heating, cooling, food and consumption goods - There is a high risk of the rebound effect for this category
Industrial sectors	- Globally, industry accounted for about one third of final energy consumption in 2010 (IEA 2013) - Non-OECD countries will account for the bulk of industry-related GHG rises under BAU up to 2050 (OECD 2012) - The global average efficiency of energy use in industry is only 30%, so enormous opportunities exist to achieve both emissions reductions and economic benefits (GEA 2012) - Many developing countries are at the crucial stage of defining their industrial development trajectories	- There is a wealth of industrialisation experiences from around the world demonstrating how to take advantage of low-carbon opportunities - Opportunities exist both to improve the efficiency of energy intensive manufacturing, and to exploit export oriented opportunities for low-carbon technologies

In addition to addressing the considerations and needs highlighted above, assessing the linkages across the three categories, and between actions targeted at those categories, will be an important part of the national policy making process. Complementary to national efforts, there can also be a valuable role for international mechanisms and bodies, for example the UNFCCC's Technology Mechanism. Chapter 6 outlines roles and possible interventions for national and multilateral/international agencies to support technology innovation and deployment towards low-carbon sustainable development.

3

Stories from the bottom of the pyramid[ii]

While energy is seen as being essential to human, economic, and social development, wide swathes of humanity still do not have access to adequate and modern forms of energy. It is estimated that nearly 1.3 billion people remain without access to electricity and 2.6 billion still remain dependent on traditional biomass for their cooking needs, with most of these being in developing Asia and Africa. Furthermore, these numbers will not improve much by 2030, even under cautiously optimistic assumptions; over 1 billion people would still not have access to electricity and 2.6 billion people would not have access to clean cooking energy (IEA 2012).

The implications of this on health and welfare of this part of the population are large. Modern energy sources provide a range of services – lighting, refrigeration, communication, mechanical power, thermal energy, etc. – that are important at the household, community, and enterprise level (Practical Action 2013). A lack of access to modern energy, especially electricity, can limit the availability of these kinds of amenities that underpin development. And, in many cases, reliance on traditional or polluting forms of energy can also have deleterious health, environmental or other consequences.

As with the energy sector more broadly, technology is seen as a critical element of efforts to address energy access in a climate-compatible manner. Yet, a number of issues impede the leveraging of technology for meeting this challenge. Much of the world's innovation capabilities are located in industrialised countries, and principally within the private sector, with scientific and technical research being driven largely by market opportunities and, to some extent, the personal motivations of researchers. Not surprisingly, then, the BOP remains mainly neglected, in part also because exploiting the market at the BOP is not trivial. As Wilson et al. (2012) note, "'Business as usual' is unlikely to reach the poor as profit margins and time frames are less attractive." At the same time, it also is well recognized that there is a market failure for public goods such

[ii] Adapted from the policy brief "Innovation for climate-compatible development for the 'bottom of the pyramid'" (Sagar 2013)

as cleaner energy in the absence of clear market signals (which do not exist yet). The confluence of these two under-represented areas – clean energy for the world's poor – is a devastating combination.

It is further complicated by the fact the much of this target group lives in rural areas of poorer countries. Therefore dissemination strategies and channels – be they efforts to deliver cook stoves or bring electricity – have to work across large and disparate geographies and cultures. Given this, it is not a surprise that despite recognition of the modern energy gap for the BOP, progress in addressing this challenge has been rather limited. Consequently, particular attention has to be paid to design programmes and policies to overcome the kinds of constraints noted above to deliver at scale modern and cleaner energy technology options for the poor.

Broadly, the success of any technology is contingent on its delivering performance characteristics that are perceived as desirable by users at a price they can afford. But ensuring that such a technology exists and, as and when it does, that it is disseminated to the users – and that it indeed stays in use and delivers the promised performance or service – all requires careful attention to the programme design.

Facilitating suitable technology development and deployment

As a first step, innovation policy must focus on the development/adaptation of technologies and systems that have suitable and well-defined performance characteristics. In the case of cookstoves, this would be low-cost, cleaner-burning designs with emissions low enough to adequately protect human health (since that needs to be a primary focus of improved household energy programmes) while being cheap enough to allow for large-scale dissemination.

The development of such low-carbon technologies could be facilitated through traditional policy levers such as public R&D investments or through novel mechanisms such as incentive prizes or advance market commitments that aim to create incentives for technology developers to motivate them to turn their attention to neglected problems. Of course, it is not necessary that technologies must be developed locally – international collaboration, or even transfer of technology from other countries, may be effective options. Regardless of the approach, it must be again emphasized that the design of the final product must reflect the needs of local users.

Box 1: Household energy

For household energy, liquefied petroleum (LP) gas or natural gas is seen as the most desirable option due to the efficient and clean combustion that is possible with these energy sources (Smith 2002). Some developing countries, in fact, have in place major programs to provide cooking gas to their poorer citizens – for example, 90% of Brazil's population and 75% of Indonesia's population now uses LP gas. More recently, the Cooking for Life campaign of the global LP gas industry aims to move one billion people to cleaner-burning LP gas by 2030. However, the high cost of gas necessitates subsidies for poor people, which, combined with the volatility in the prices of this energy source, renders this solution impractical for lower-income, and even many middle-income, countries. Thus, it seems that biomass is likely to remain a mainstay of the energy supply for poorer households in developing countries. In such a situation, the possibility of using cleaner biomass cookstoves emerges as an obvious possibility and one that has been explored for many years across many countries.

There now exists a plethora of cookstove designs, with variations in performance, as well as dissemination programmes, both national and global in nature. In recent years, though, our understanding of the household energy problem also has changed: mitigation of household air pollution and climate change are now seen as the main drivers of technical change in this arena; at the same time, better knowledge of exposure-response relationships and technological possibilities have also allowed us to better specify the desired performance characteristics of cookstoves. While some of the recent designs have made significant progress, we still need to push further since it has become clear that we need radically-clean technologies that approach the emission of gas stoves to adequately protect human health. At the same time, other product features such as attractive and robust design and low cost are critical for facilitating uptake among the users. However, the mere existence of suitable cookstoves is not enough to guarantee, or even drive large-scale dissemination. Successful deployment at scale of such technologies requires overcoming a range of cultural, organizational, and resource-constraint challenges and requires careful attention to design of the dissemination programmes, including strategic and flexible approaches to dissemination, as well as supporting activities such as development of standards, certification, and information dissemination activities.

Source: Sagar (2013b)

Advancing deployment

Dissemination of these technologies, given the geographical, cultural, and socio-economic diversities of the target groups, requires a flexible and strategic approach that very much takes into account the specifics of the locale under consideration. Thus it may be easier to initiate a programme by focusing on users and environments that are seen as most conducive to success, as was the case in cookstove programmes in Kenya and China (Smith 1993; Ramani 2009). Once the market has been created and there is confidence in the technology, further scale-up likely will be easier.

Particular effort may be needed in early-stage dissemination, where users may be risk-averse in trying out new technologies. This is as true in the case of households, where 'tradition' may be well entrenched as in the case of local entrepreneurs or existing industries in rural areas, where the margins are small enough that any perturbation may have catastrophic financial consequences. Financiers may also view the deployment of untested technologies as a credit-risk (Martinot 2001). Therefore, alleviating the risk perception of the early users and other relevant actors is key to successful market creation; at the same time, early market-penetration programmes can also yield valuable insights about programme design for scale up.

Exploration with various models for deployment for sustainability and replicability may be required (see, for example, Martinot 2001; Karekezi 2002; Shrimali et al. 2011). Local entrepreneurs and ESCOs may be particularly key players in these activities because of their understanding of the local context – engagement with them can not only increase the likelihood of successful delivery to end-users (and some level of follow-on support) but also create livelihood opportunities at the local level. Piggy-backing on existing dissemination channels in rural areas – for example, those for agricultural technologies or household appliances – may also be fruitful in some cases. It may also be possible to provide energy access via community-scale services, e.g., children studying at school after sunset where the lighting might be provided by climate-compatible technologies, village agricultural processing equipment provided as a community service; or even small business services provided at the community scale.

Coordinating actors, activities and programmes

As in any case of technological innovation, multiple actors and networks need to be coordinated, with different actors and networks operating for different parts of the innovation chain. For example, for the early stage, coordination includes bringing together actors with relevant technical expertise and bringing clarity to performance specification and assessment. The constellation of actors will also be different for different technologies and often even in different locations – in fact, in the case of technologies for the BOP, non-traditional actors such as NGOs may play an important role. The design of policies and institutions to promote the development and dissemination of these technologies has to take this variation into account. This is precisely why it is imperative to learn from past experiences and give systematic thought to the design of innovation policies and institutions to promote climate-compatible technologies for helping provide modern energy services to the poor.

As mentioned earlier, there also has been the emergence of numerous new initiatives to address the energy access challenge. While the implementation of any programme to disseminate climate-compatible technologies to provide modern energy services to the poor is at the local level, coordination with such international programmes – to exchange experiences and learning as well as to possibly leverage synergies on technology development – is particularly important. While such coordination is not easy, it does deserve some attention since the potential gains are substantial. Again, this will require local capacity to facilitate such coordination and synergy to maximize gains on the ground.

Policy support may also be needed to facilitate the establishment of production facilities (again, through market creation mechanisms and/or by making available to firms technical and financial resources that may be required for such purposes). Additional policy elements such as development of standards and certification help manufacturers by bringing standardization and transparency to the market; in addition, certification also gives confidence in the products to the users. In many cases, users may also require financing support if they do not have the financial wherewithal for the up-front purchase of the technologies. Additionally, just as with commercial technologies, information dissemination and marketing efforts that bring awareness to consumers are key to large-scale uptake.

Building capabilities

Furthermore, as can be imagined, all of the above activities require a range of local capabilities and resources – technical, business, financial, policy – at both the individual as well as organizational level, as is the case for almost any process of technological change. In fact, the gap between the kinds of capabilities needed for BOP innovation, given the additional complexities as compared to innovation for more traditional markets, and what capabilities exist is particularly large. Yet if this gap is not addressed, it is difficult to implement the kinds of innovation processes outlined above. Perhaps the most important of these capabilities for the topic of this report is the capability to take a 'bird's-eye view' for the design of specific programmes that cover the relevant aspects of the innovation cycle for particular technologies in the local context and to coordinate various actors and activities (Chaudhary et al. 2012). Policies aimed at building these kinds of capabilities, especially learning from past experiences, are particularly critical and therefore need special attention, even though capacity-building efforts are notoriously difficult to implement effectively (Sagar, 2000).

Mobilizing finance

Lastly, it must be noted that while much of this discussion has focused on outlining the key issues regarding elements of the innovation cycle, the availability of financing is necessary to support activities aimed at advancing modern energy access for the poor. According to the IEA, while currently about $9 billion is invested annually in energy access globally, investments of about $49 billion per year would be needed to ensure universal energy access by 2030[iii] (IEA 2012). Therefore there is a need to enhance the public and private funding for supporting these activities. Some portion of the flow of funds expected under the Climate Convention could also be directed towards this goal, as a way to compensate the world's energy poor for their low greenhouse gas emissions. Health ministries as well as health-oriented programmes in donor agencies (multilateral, bilateral, or private) could be another potential source of funds, given the significant health benefits from improved access to modern and clean forms of energy (Smith 2013).

[iii] This includes investments expected under their New Policies scenario as well as additional investments needed to meet the universal energy access objective

4

Stories from the rising middle class[iv]

The coming decades will see hundreds of millions of people being born into or migrating into a global middle class, with access to modern energy, transport and consumer goods with considerable embedded GHG emissions. The choices, behaviours and lifestyles of this middle class, which is spread out over industrialised and developing countries, will to a significant extent determine whether GHG emissions will peak and decline during the next decades, or whether they will continue to rise to levels that result in dangerous climate change.

Based on consumption patterns and emission profiles, what are low-carbon contexts and options for the rising middle class? What could a low-carbon lifestyle look like? Table 3 provides a comparison of the "business as usual" development as we see it currently developing in growing cities all over the developing world; and as we have already seen it developing in many cities in developed countries, with the United States and currently also the citizens of wealthier Gulf states representing of the most high-carbon lifestyles. Characteristics of such lifestyles include: high demand for individual, motorised transport based on fossil fuels; large, energy-inefficient houses with high heating and/or cooling demand; a high meat consumption and high material consumption levels.

The progress of many people into a life in which material wealth buys freedom of choice and health of course has many advantages. Yet examples indicate that these positive developments do not need to be accompanied by fast rising energy use and greenhouse gas emissions that we have seen in the industrialised world in the second half of the 20th century, and that we are presently witnessing in many developing countries. Table 3 indicates several options that contrast high-carbon, business-as-usual options to fulfil demand in the rising middle class with options that are low-carbon and that can prevent much of the projected rise in emissions.

There may even be other benefits. In industrialised countries, economic development has resulted in more dissociated societies and consumerism, leading to sometimes lower levels of happiness than in developing countries, despite much greater material wealth (Jackson 2009), and wealth-related problems (such as rising levels of obesity). It is sometimes hypothesised (although evidence is not conclusive) that a greener lifestyle prevents such issues.

[iv] Adapted from the policy brief "Low-carbon technology for the rising middle class" (de Coninck and Byrne 2013)

Table 3: Elements of business as usual and lower-carbon (urban) lifestyles of the rising middle class

Consumption sector	Business as usual	Lower-carbon variant
Urban planning	Sprawling suburbs with mainly road connections for access to shops and recreation	Neighbourhoods planned to accommodate sustainable transport means and shops and recreation within walking distance
Transportation	Private car, several per household	Partial modal shift to foot, bicycle and mass public transit
Electric household appliances	Normal-efficiency fridges, washing and drying equipment	High-efficiency fridges, washing and drying equipment
Lighting	Use of incandescent light bulbs	Use of high-efficiency LED or CFL lighting
Cooling	Conventional air-conditioners	Energy-efficient housing design or adaptations, efficient air-conditioners
Heating	Water and space heating using oil, gas or electricity	Energy-efficient and passive-energy housing design or adaptations, solar boilers
Food patterns	Daily meat consumption, carb-rich diet	Reduced meat consumption, e.g. to two times per week, fresh food
Consumption goods	One-way use of materials, limited re-use and recycling, poorly organised waste collection and conversion	Move towards circular economy, extensive re-use, recycling and waste reduction, waste-to-energy

The low-carbon options listed in Table 3 are all different in terms of mitigation potential, stakeholders involved, costs and institutional complexity of implementation. Some would rely more on consumer choice while others require centralised planning processes, yet all can be influenced by appropriate policies and institutional support. Food consumption patterns, for instance, in part rely on individual choices, but the sustainability of the food system is as much due to systemic characteristics and wide-spread agricultural practices as due to consumer behaviour. The options in Table 3 can often be implemented at relatively low costs and impacts to consumers if organised well. Some may even lead to a reduction of so-called 'diseases of affluence', such as obesity.

While discussing the reduced spending on energy, transportation, meat, etc., the so-called "rebound effect" needs to be taken into account (Sorrell 2009): emissions due to spending of the saved money on carbon-intensive activities can be considerable. No rule-of-thumb number for the rebound effect can be established, as the results depend on a range of factors. But, as an indicative figure, studies that have averaged a large number of data sources put the rebound effect at around 30% of the total emissions reduced (Gillingham et al. 2013).

Two case studies were undertaken on technologies relevant to this population category to illustrate two of the options in Table 3. These were, first, the implementation of compact fluorescent lamp (CFL) programmes in two African countries and, second, bus rapid transit (BRT) systems in various cities around the world (Box 2; Box 3). Both options are faced not so much by technological and economic issues, but in particular by issues around the political economy and capabilities of their contexts.

Box 2: Case study: CFLs in Ghana and Kenya

Both Ghana and Kenya rightly consider their CFL exchange programmes to have been successful. The analysis from the study found that these programmes have indeed been effective when considered in a narrower sense of immediate greenhouse gas (GHG) emissions reductions, lower electricity bills for consumers and an easing of pressure on electricity supply. However, there are questions that arise from considering the experiences from a broader innovation system and political economy perspective. These suggest that further benefits may be possible through CFL exchange programmes that are designed with this broader perspective in mind.

Key messages that emerge from this analysis include the need for research into technology programmes, such as those implemented in Ghana and Kenya as well as other approaches, to investigate the extent to which further benefits are achievable. Such development benefits might mean the building of indigenous technological and innovative capabilities that could provide higher value-added economic gains, and contribute to self-directed low-carbon development over the long term. Such research could be facilitated by international agencies, such as the UNFCCC's Climate Technology Centre and Network, and could assist developing country parties in implementing the lessons from such research by supporting experimental projects that can help local firms, research organisations, policy makers and others to build the broader systems necessary for encouraging further low-carbon technological developments and innovations to emerge.

Source: Byrne (2013)

The CFL cases in Kenya and Ghana reveal that the programmes for CFL replacement were successful at the most immediate level, but raised a dilemma of instituting performance standards to allow only high-quality CFLs on the market, versus allowing local producers to benefit from the programme. In the case of BRT systems, a key learning was that the political economy around the informal public transport that the BRT system replaces is important: re-employment programmes for former public transport drivers increases the chances of a successful transition. In addition, good planning of BRT routes and integration in the general transport system is essential.

In both cases, capacity development plays an important role in the eventual success of a measure. For African CFL manufacturers to meet the quality standards, rapid capacity development can help. In the case of BRT, the former informal public transport drivers need to be re-trained, and capacity for planning BRT routing needs to be developed or purchased from international companies.

Box 3: Case study: bus rapid transit (BRT)

Of the almost 150 BRT systems in operation globally today, many are highly successful, the most famous example being Bogota's TransMilenio system. However, not all BRT systems show such results. The most reported problems include resistance from the existing, informal public transportation operators or car owners, poor implementation as a result of underperforming local institutions, and overcrowding and resulting lower levels of comfort where BRT is in high demand.

The case study reveals several messages for policymakers. First, local circumstances matter tremendously and need to be studied well in order to make good decisions on routes, capacity, feeders, and type of BRT system. Globally operating transport service companies as well as local companies can provide this, although with the former the sensitivity for local circumstances remains a point of attention, while for the latter, capabilities and independence have sometimes shown to be problematic.

Second, the political economy and public acceptance of BRT need to be taken into account early on: sizeable, successful BRT systems can damage incumbent transport providers. There are many ways to reduce resistance, including providing compensation for the incumbents in the form of training and re-employment of drivers of the old public transport systems for the BRT system.

Third, BRT systems are always part of a broader transport system. Good and well-managed links to other public and private transport means need to be planned. Moreover, ambassadors and advocates of BRT systems should avoid pitting BRT against other public transit systems, such as rail-based systems; they can enhance each other's effectiveness and be complementary in an overall system.

Lastly, even when the initiation of BRT systems is done successfully, the system needs maintenance, good financial management, and continued adjustment and resizing to deal with new circumstances. Proper institutional organisation lays at the basis of a BRT system that also functions in the longer run

Source: de Coninck (2013)

A conclusion from the case studies, which can be generalised to other options in Table 3, is that often-suggested economic policies, such as a carbon tax or a subsidy, cannot be expected to suffice for incentivising a change in the carbon development pathways for the rising middle class in developing countries. Moreover, in many developing countries, strong climate policy instruments such as emissions trading or feed-in tariffs can be difficult to implement. This is due to a variety of potential reasons, such as: immature or distorted markets, a lack of institutional and technical capacity to implement complex policies, or politically hard to remove energy subsidies, which render subsidising renewable energy unaffordable and energy efficiency policies unattractive.

Policy interventions in the field of technology and innovation that enable lower-carbon pathways for a growing middle class need to take into account the behaviour, capabilities and the political economy of the sector in question. As part of building support for low-carbon technologies and innovations, policy agents must work with local stakeholders to identify where the positive development opportunities might lie in exploiting low-carbon innovations. For these to be successful technology policies, specifically for low-carbon development in the rising middle class, they must be integrated with larger national and urban plans on climate change, spatial planning and welfare: e.g. develop urban planning policies that enable sustainable lifestyles and include policies on efficient technical appliances, but also on behavioural matters such as transportation and food.

5

Stories from the industrialising economy[v]

Industrialisation is, by itself, a significant challenge for many developing economies. But this is now compounded by the need to follow low-carbon development pathways to help address the climate challenge. More positively, such nations – especially those with less developed infrastructures – have the opportunity to define their industrial development trajectories in ways that position them for a climate-compatible future. Not only can they avoid the carbon lock-in currently challenging industrialised countries, they can also reap valuable development benefits to achieve self-directed sustainable development goals, long-term energy security and access to markets that have environmentally stringent regulations.

There is plentiful evidence from studies of economic development that provides useful insights for creating low-carbon industrial pathways. For example, we can draw from ‘catching-up’ strategies and experiences of successful countries around the world since before the British industrial revolution. Creating and managing markets, and protecting local firms from international competition, have been abiding features of such strategies. Many of the policy tools used for these actions are relevant to low-carbon industrialisation. For example, creating markets can be achieved by incentivising firms to invest in particular technologies – i.e. creating above-average profits or rents – whilst subsidising their adoption. Of course, we should be careful about the use of such policies. There are inherent uncertainties in creating markets and using protectionism. Instead of firms investing in new technologies, and building capabilities, they might simply engage in rent-extraction – profiteering from rents without accumulating capabilities – and it is not clear how to mitigate or analyse these uncertainties.

To look in more detail at these issues, let us consider two major opportunities for low-carbon innovation in industrial sectors. First, we explore the low-carbon and energy efficiency gains that are possible in energy-intensive manufacturing. Second, we discuss the opportunities for developing countries to insert themselves into global low-carbon value chains by developing manufacturing capacity in energy-supply technologies.

[v] Adapted from “Low-carbon innovation for industrial sectors in developing countries” (Byrne et al. 2014)

5.1 Energy-intensive and manufacturing industries

Globally, industry accounted for about one-third of final energy consumption in 2010 (IEA 2013), and much of the growth in energy-intensive industrial sectors is taking place in developing countries, so we should examine what innovation opportunities exist for improving[vi] their performance. An outline of the cement industry in sub-Saharan Africa (SSA) is presented in Box 4, and relevant policy implications are described in the text below.

Box 4: Case study: cement manufacturing in SSA

The cement industry in SSA is oligopolistic, with just a few firms competing in some countries. Many of the large companies are multinationals headquartered in Europe or North America, but there is also a Nigerian international cement producer (Dangote). The structure of the industry, together with a legacy of former widespread state-ownership of cement production, means that innovations that could have reduced costs may have been avoided through lobbying against imports of cement so as to maximise returns on existing production facilities.

However, import-bans have been lifted in some countries in order to try to meet high demand. The outcomes have been mixed. In Kenya, for example, there have been investments in new plant and innovations towards lower costs. In Tanzania, this has not been the case and demand was still not met.

Whilst some of the innovations that occurred as a result of market price pressure have reduced carbon intensity – such as using less clinker in the production process – others have increased carbon intensity by switching to cheaper coal to power the production process.

Source: Ionita et al. (2013)

African-owned cement multinationals are generally as efficient in their production as multinationals from Annex-I countries. However, locally-owned companies producing for their local markets are typically less efficient (especially in countries with high import barriers for cement), have poorer access to knowledge on low-carbon technologies, and have weaker incentives to innovate. Locally-weak price pressure from an absence of competition explains some of the disparity between locally-owned and multinational performance. Additionally, this performance-disparity could be due to weak innovation capabilities among local firms. Protectionism might help local firms build such capabilities, but could also be ineffective – or worse – for achieving low-carbon and efficiency goals if it only results in rent-extraction. The key is to use – and

[vi] There are several international efforts to improve efficiency in industrial production, the most long-standing of which is the joint UNIDO-UNEP Resource Efficient and Cleaner Production (RECP) Programme (see http://www.unep.fr/scp/cp/).

withdraw – protectionism strategically and avoid fostering rent-extraction behaviour (Schwarzer 2013).

In any case, increasing demand in SSA is driving investments in new cement plants and they tend to be based on best available technology – usually, dry-process[vii] production equipment (Ionita et al. 2013). Multilateral development bank lending has played a role in these investments, with some loans conditionally tied to the use of best available technologies. However, to cut production costs, there is also a move towards coal as the main energy source (Ionita 2012), thereby undermining efficiency gains.

More promisingly, low-carbon innovation policies in the cement sector in SSA are beginning to develop. There are innovation efforts around equipment manufacturing (type of kiln) and basic R&D. Research institutes are opening in SSA countries, and knowledge-sharing networks are being supported between European and African countries. However, poor communication between research institutes and industry is hindering these innovation efforts and so this aspect of collaboration needs enhancing (Nassingwa and Nangoku 2012).

Industry associations and initiatives offer one avenue for this type of collaboration. Some of the main players in SSA are members of the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI), which includes emissions reduction commitments (WBCSD 2012). CSI members have access to the latest technologies, the best capabilities, and to finance that could further low-carbon options in the cement sector in SSA (Ionita et al. 2013). As they have largely exhausted current energy efficiency opportunities in other parts of the world, they are more likely to drive low-carbon innovation in the SSA market next (Ionita 2012).

Moreover, whilst there are market forces encouraging low-carbon innovation, there are also factors hindering these investments. So there is still much that policy can do to foster low-carbon innovation in energy efficiency in the SSA cement industry, and other energy-intensive industries. Relevant policy interventions include: regulation to ensure the use of best available technologies; enhancing knowledge-sharing networks; strategic use of foreign investments to build local capabilities (e.g. joint ventures between foreign and local firms); and policies that favour low-carbon energy sources over fossil fuels.

5.2 Energy supply technology manufacturing

Favouring low-carbon energy over fossil fuels requires huge scaling-up of investment and capability-building throughout the low-carbon energy supply system, as well as complementary measures against fossil fuels. Again, this challenge offers opportunities for developing countries. Some lie in the use of low-carbon energy technologies to service demand at all levels from the household to industry, while others lie in the manufacture of low-carbon technologies for local energy systems and for export.

[vii] Dry-process cement production is considerably more energy-efficient than the older wet-process method (Müller and Harnisch 2008).

Box 5 outlines the experience of India's wind energy industry. Research shows that Indian firms have built their technological capabilities through a sequence of licensing the production of foreign technologies, joint ventures with technology leaders and collaborative R&D.

Box 5: India's wind energy industry

India has long supported the development of a domestic wind power industry, beginning in the 1990s (Sharma et al 2012). However, policy support has not always been stable, reflected in uneven growth of the industry (Lewis 2007). Still, support has included aggressive market-creation policies (e.g. Feed-in Tariffs, FITs), protectionism through the use of import tariffs on complete turbines (to encourage local assembly and, perhaps, reverse-engineering of components), state-level targets for wind-powered generation, tax breaks, and many others.

The domestic firm Suzlon has evolved as a major presence, alongside international wind turbine manufacturers. Suzlon has taken advantage of increasing global specialization of knowledge and manufacturing – seen in the emergence of global value chains – to establish itself within a relatively short time frame. Following its successful rapid growth, Suzlon has also bought specialist firms in other countries, diversifying its capabilities and building its own international networks.

Source: Byrne et al. (2014)

In China's solar PV manufacturing experience, several strategies were used by firms to develop manufacturing capabilities (Box 6). Initially, capabilities were developed by buying production equipment from foreign suppliers but more complex knowledge was developed through the recruitment of foreign expertise, as well as benefits gained from foreign-trained Chinese engineers returning home to start or join new companies (Gallagher and Zhang 2013). However, increasing competition in the manufacturing market led to reduced profits, and unstable supplies of increasingly costly silicon ingots. Chinese firms responded by vertically integrating both upstream and downstream segments of the PV value chain. By capturing more of the value chain within single firms, Chinese companies have reduced their costs, increased their profits and maintained or improved their global competitiveness. This vertical integration has led to better communication between engineers, even in different plants, and world-leading process innovations. For example, it is claimed that some firms are able to cut PV wafers thinner than their foreign competitors, reducing waste and cutting costs. Still, some firms are getting access to 'frontier' knowledge by acquiring or investing in foreign firms – a strategy seen in other Chinese industries, and in India's wind power sector (Lema and Lema 2013) – which also gives them better access to foreign markets.

Box 6: Case study: PV manufacturing in China

Although China only entered the global PV industry in 2001, its experience with the technology is long-standing. It first fabricated a silicon solar cell in 1958, soon after the United States, and subsequently used the technology in space applications. By the mid-1970s, China was using PV in rural areas and established small-scale manufacturing in the 1980s. Starting in 1985, it began importing production lines from the US, Canada and others, increasing its production capacity to 4.5 MW per year. China could be seen, therefore, as building some PV manufacturing capabilities by servicing this local demand. Later, growing demand in Japan and Germany – driven by their market-creation policies – spurred the company Suntech to establish a 10 MW production line in 2002. Many Chinese firms subsequently entered the module-manufacturing market and China became the world's leading producer of PV modules in 2007, reaching 20 GW annual capacity in 2010. But the global financial crisis has resulted in scaled-back market-creation policies in many of the countries to which China was exporting and so China has compensated by introducing domestic market-creation policies instead. Furthermore, it is hoping that PV can play a role in mitigating climate change and enhancing energy security. Its 12th five-year plan has domestic targets of 35 GW installed PV by 2015, and 100 GW by 2020.

Source: Gallagher and Zhang (2013)

These cases from the Chinese PV industry and wind power in India illustrate more general findings in studies of industrialisation. We could, therefore, suggest that countries with weak technological capabilities – in general, the less-developed countries – might prefer to pursue industrialisation by helping local firms build their technological capabilities to service local protected markets and gradually transition to opening up those markets to increasing international competition. Local firms would then be able to build their absorptive capacity before they can begin to benefit from knowledge 'at the frontier' and face increased exposure to international competition.

6

National and international action: conclusions

6.1 National measures

Appropriate innovation systems are central to delivering low-carbon development and providing associated social, economic and environmental benefits within a country. The building of innovation systems at the national level needs to emerge as an overarching goal in order to help countries develop in self-directed ways, contributing to sustainability, while adapting to changing circumstances. National governments and bodies have a key role to play in directing and developing the capabilities of actors and the linkages between them. Technology focussed policies are important in this process, but they are only one aspect of building innovation systems. It is also important to consider links and interactions with other policies – such as for education, industrialisation, energy, and environment. For innovation systems to then yield results, demand side measures are also often needed for dealing with market-creation, or improving the private sector's ability to exploit existing markets.

This project has focussed on three categories that can be found, to varying degrees, in all developing countries and the policy implications resulting from these different contexts . Yet some broader messages can be drawn out of this work when considering policy interventions for low-carbon innovation systems.

I. The entire innovation spectrum needs to be taken into account

Innovation is not just about radical changes in hardware or processes. Innovation includes incremental change of existing technologies, processes, techniques, and practices of various kinds. Indeed, incremental improvements can have more economic significance over long periods of time than radical innovations by realising accumulated improvements. Or innovation can refer to the adaptation of existing technologies to make them more appropriate to a local context. Policies aimed at the development of innovation capabilities need to be able to identify and highlight opportunities across this spectrum (Byrne et al. 2012). For example, the CFL case studies in Kenya and Ghana reveal that the programmes for CFL replacement were generally successful, but faced challenges in including local manufacturers in the CFL roll-out. Rapid capacity development programmes could have been initiated alongside the CFL replacement programmes to allow local manufacturers to meet the necessary quality standards and help deliver local innovation capabilities through the adoption of new technologies and processes (de Coninck and Byrne 2013).

II. National circumstances matter

The findings of this project and case studies show the need to consider local contexts at a non-aggregated level. Different developing countries will have a range of strategic needs and priorities, competitive advantages, and national socio-economic and institutional structures that influence their innovation policies and strategies (Cimoli et al. 2009; Sagar 2011). This project argues that the context sensitivity of policy design for innovation should be extended to the different demographics within a society who will also have differing needs. For example, there are market failures in innovation for BOP technologies, political economies of low-carbon interventions for the rising middle class, or the need to balance the pros and cons of protectionist policy for low-carbon industrial development in a country. Policy considerations should refer to existing capabilities and skills, natural resource endowments and the potential for particular technologies to meet development challenges being faced by the particular country, such as improving energy access. This diversity of strategies, combined with the state of development of particular technologies, will influence the choice of policy interventions and the actors who should be involved (Gallagher et al. 2011).

III. Broader innovation systems need to be considered

Innovations do not simply emerge from the activities of exceptionally talented or charismatic entrepreneurs (although entrepreneurs can be critical to the success of particular innovations). Innovations arise from the activities of networks of actors who combine their knowledge, skills and resources in complex ways. Policies and programmes should also be designed to ensure that the different players in the system are able to coordinate and collaborate to meet their individual and collective goals (Byrne et al. 2012). Recognising this need for coordination, strategies for building innovation systems include:

i. Supporting projects that involve actors of different kinds along the value chain. This helps to build the fundamentals of innovation systems
ii. Linking individual projects and programmes over time. This builds knowledge amongst actors and can help to inform new projects. This can also increase the coherence in an overall strategy and allows learning from support efforts to inform adjustments of a strategy

Against the backdrop of these broader considerations, the project presented a number of policy recommendations targeted to each of the three categories throughout the published policy briefs. Table 4 summarises these recommendations, categorised across five key aspects of building low-carbon innovation systems and successfully deploying appropriate technologies – facilitating technology development; advancing deployment; coordinating actors, activities and programmes; building capabilities; and mobilising finance.

Table 4: Recommendations targeted to the three categories

Category	Bottom of the pyramid	Rising middle class	Industrial sectors
Facilitating technology development	- Focus on the development/adaptation of technologies that have suitable and well-defined performance characteristics - Incentive prizes or advance market commitments can motivate technology developers to turn their attention to neglected problems - Support may be needed for the establishment of production facilities	- Develop innovation systems for technologies that can reduce emissions relative to a baseline – such as CFLs, LEDs, energy-efficient "wet" and electronic appliances, air conditioning etc. Integrate micro-, meso- and macro- level support of the innovation systems	- Evidence shows that creating markets, for example by incentivising firms to invest in particular technologies, can lead to improved technological learning and technology development - Less developed countries can help local firms build their technological capabilities to service local protected markets and gradually transition to opening those markets to increasing international competition - Technology learning can also be achieved locally, building from a starting point of technology/expertise import, as with the case study of PV in China
Advancing deployment	- Diverse contexts require deployment approaches to be flexible and strategic - Build programmes with an initial focus on market/user segments most conducive to success. Then further scale up will be easier - Alleviating risk perception of early users and actors is key to market creation; early market-penetration programmes can yield valuable insights for scaling up - Various models for deployment may be required; e.g. local entrepreneurs and ESCOs, or piggy-backing on existing dissemination channels - In many cases, users will also require financing support to purchase technologies	- Conventional interventions, such as a carbon tax or subsidy, are unlikely to incentivise a change for the rising middle class in developing countries. Instruments that take into account behaviour, capabilities and the political economy are needed - As part of building support for low-carbon technologies and innovations, work with local stakeholders to identify where the positive development opportunities might lie in exploiting low-carbon innovations	- Market creation policies have proven successful; including Feed in Tariffs, protectionism through the use of import tariffs on items of low-carbon technology, state level production targets and tax breaks - Market creation policies should be designed to remove rents over time to encourage long-term, sustainable change, and have removal of the policies built in for when support is no longer needed - For sectors where significant cost-effective efficiency gains can be achieved, it may be effective in the short term to open up markets, to let price pressure and international competition drive innovation - Consider regulation to ensure the use of Best Available Technologies in emissions/energy intensive industries

Coordinating actors, activities and programmes	- Involve non-traditional actors such as NGOs and users - Coordinate with international programmes to exchange experiences and to possibly leverage synergies on technology development	- Integrate technology policies, specifically for low-carbon development in the rising middle class, in national and urban plans on climate change, spatial planning and welfare: e.g. develop urban planning policies that enable sustainable lifestyles and include policies on efficient technical appliances, but also on behavioural matters such as transportation and food	- Enhancing knowledge sharing networks – for example, building better communication between industry and research institutes is crucial for fostering innovation
Building capabilities	- Capabilities need to be built at both the organisational and individual level. Policies aimed at this are crucial - The capability to take a 'bird's-eye view' for programme design and coordination is important	- Develop national innovation plans, and aim innovation ambitions to be aligned with strong capabilities in a country or area. Identify where capabilities can be usefully built up	- Capabilities need to be built across innovation systems, not just within firms - Provide support to local research institutes and particularly their efforts to be involved in knowledge sharing networks internationally - Firm's capabilities can be built by recruiting talent from abroad, foreign-educated/trained staff, licensing production of technologies, joint ventures with technology leaders and as cooperative R&D agreements. Support to these initiatives of firms and individuals can be useful
Mobilising finance	- Climate finance flows are a potential source, arguably as compensation for the low GHG emissions of the word's energy poor - Health ministries as well as health oriented programmes in donor agencies are another potential source of funding, given the significant health benefits of modern energy services - Mobilising finance also means supplying finance to end-users (see above)	- Taking a stakeholder focused approach could, in turn, feed into: national level needs assessments (such as, but not limited to, TNAs); requests for assistance directed to the CTC or other low-carbon technology centres (such as Climate Innovation Centres); and requests for support to bilateral and multilateral sources	- Strategic use of foreign investments to build local capabilities (such as through joint ventures between foreign and local firms)

For the best chance of success, these policies need to be implemented in a stable environment. Demonstrating longer term commitment to the development of low-carbon innovation systems is vital for leveraging existent capacities, as well as attracting new investments and collaboration. Emerging concepts from the international climate negotiations, such as nationally appropriate mitigation actions (NAMAs) and low emissions development strategies (LEDS) could be useful tools for policy makers to help articulate clear visions and policies that enable such stable environments (Byrne et al. 2014). Further to this, there are international efforts (see below) that have the potential to contribute to the building of domestic innovation capabilities and markets

6.2 International measures

Developing countries have many instruments available to them to try and establish functional innovation systems domestically, as outlined in the previous section. National ownership and alignment with national priorities is crucial for successful implementation of such international measures. However, international support to build the required resources and capabilities will be vital in many instances.

There are different expectations over what role the international community should take. Industrialised countries have focused on 'creating an enabling environment' or 'functioning markets' for innovation (pull factors), for the private sector to be able to invest in and implement projects involving climate-friendly technologies and practices. An alternative vision, supported mainly by developing countries, argues that every step in the technology cycle, from RD&D to commercialisation and deployment, is equally important, and in this vision the public sector, and international institutions alike, has a more active role to play (Blanco et al. 2012).

Building low-carbon innovation systems in developing countries will require a synthesis of these views. New international bodies, such as the UNFCCC's Technology Mechanism (TM), are faced with the challenge of finding common ground between the different perspectives, as well as in further defining a set of effective interventions and finance mechanisms. Just like national governments, these international bodies must take into account the broader context of innovation if they are to design interventions which are successful over the long term (Blanco et al. 2012).

6.2.1 Evidence of international technology interventions

The case studies on CFLs, cook stoves, BRT, cement and solar energy have pointed at international interventions that have worked for lower-carbon development. For example, financing requirements from multilateral development banks have led to the use of more efficient technologies in cement plants in SSA countries. Also, international cooperation in BRT has led to mutual learning and more implementation of such systems in more cities, along with incremental improvements within the deployed systems. Moreover, private sector technology from abroad was often needed for the best-functioning integrated BRT systems. In cook stoves, international work has contributed to a much better understanding of the issues around health, indoor air pollution and cooking; revitalising the attention for this important technology, as well as stimulating new research to improve technologies for local circumstances.

The case studies have also highlighted areas where international interventions could be expected to make positive contributions to national technology-oriented programmes. International interventions could prove helpful in standardisation and verification of efficient lighting solutions, solar PV or cook stoves, preventing poor-quality products to enter the market and lower consumer trust. International activities could also contribute to global harmonisation of policies around renewable energy and energy efficiency, benefiting industries such as PV and CFLs.

Three general areas of where international interventions could make a difference could be identified from the case studies:

i. International organisations could do more to build national capabilities in innovation in developing countries. As long as the aims of international initiatives are exclusively focussed on reducing carbon emissions or providing energy access, local capabilities remain limited and it is unlikely that a country will develop a similar project on its own.
ii. International organisations could do more for learning between countries (and similar groups within countries).
iii. International organisations could invest in R&D for technologies for the bottom of the pyramid, preferably through R&D cooperation so innovation capabilities are also built across borders.

Many international institutions are involved in technology development and transfer in the field of climate technology, in particular in the field of mitigation. The most focussed initiative is the Technology Mechanism in the UNFCCC, which aims to facilitate climate technology development and transfer in adaptation and mitigation. The Technology Mechanism has a Technology Executive Committee, discussion policies, and a Climate Technology Centre and Network (CTC&N), where requests for technical assistance can be sent.

Likewise, other multilateral or bilateral initiatives are active in promoting low carbon technology development and deployment. Under the UNFCCC, the Green Climate Fund is in the process of being set up. Discussions on the role of technology and technology transfer in the Green Climate Fund (GCF) are ongoing. The World Bank's Climate Innovation Centres (CICs) are focussing on later-stage innovation actions and business development. The multilateral development banks are important actors and often hold the key to financing. They could also contribute to innovation system building in developing countries (Sagar 2011) or to encouraging best available technology use (Ionita et al. 2013). There are many bilateral initiatives that relate to technology, such as the Japanese Crediting Mechanism, and several cooperation programmes between the EU and, for example, India, China or Africa.

6.2.2 Recommendations at the international level

These international efforts will need to involve the countries they are designed to assist. Initiatives must be aligned and synergistic with national policy frameworks if developing countries are to realise self-determined low-carbon innovation (Byrne et al. 2012). Furthermore, the aims of international institutions to stimulate learning between countries require clear linkages between the UNFCCC bodies, and between other international support mechanisms, as well as involvement of a wide range of countries and institutions in the TM (see Blanco et al. 2012).

Building enabling environments in developing countries means targeting support at:

i. creating the appropriate regulatory framework that provides incentives for the private sector to invest in, develop and implement projects that can bring along climate friendly technologies that are usually at the commercial stage (Bruggink 2012); and
ii. building technical and institutional capacities necessary to adopt and adapt technologies or their implementation at local level (Blanco et al. 2012).

However, this approach by itself is unlikely to bring support across the technology cycle, or to activities within all priority areas, or to certain technologies at a pre-commercial stage. Examples include some technologies needed for adaptation to climate change. Creating enabling environments should therefore also focus on push factors: for example, stimulating private sector participation, initiating government-to-government transfers in bilateral agreements, and increasing financial and technical support for enhancing indigenous technical capabilities and cooperative R&D.

Cooperative RD&D could also lead to the creation of new private enterprises and public-private joint ventures, and, through joint patents, to the solution for some intellectual property rights controversies. In addition, cooperative R&D would support the demonstration of new technologies, the stage of the technology cycle where neither the public nor the private sector are willing to take investment risks, although demonstration of new technologies is key to successfully close the technology cycle (EGTT 2009). Finally, cooperative R&D activities, together with public-private joint ventures, promote cross-border movements of skilled scientists, technicians and workers exchanging know-how and experiences; two forms of embodied knowledge that can be crucial for the effective transfer of technology (de la Tour et al. 2010; in Blanco et al. 2012). International collaborative R&D programmes between industrialised-country research institutions and those in developing countries can be functional. International research funding programmes are necessary for this (de Coninck 2013).

There is also a role to play investigating the long-term benefits of existing programmes, such as hit-and-run programmes like CFL in Ghana and Kenya (de Coninck 2013). The TM could support the development of innovation capabilities when responding to country requests (Byrne et al. 2014). The World Bank's Climate Innovation Centres (CICs) have less of a focus on innovation capabilities but could expand their aims to support such elements.

The link with financing institutions is also key. The GCF is another new institution that ought to be discussing a technology facility which could include a sizeable collaborative R&D facility with explicit aims around low-carbon innovation in industry. In the same facility, the GCF could also set up a revolving fund where efficiency gains could be used to repay loans. The CTCN could play a role in managing the application process and providing technical advice to the GCF (Byrne et al. 2014). The Technology Mechanism should support the GCF in operationalising a funding window on technology development and transfer. To argue for this, the Technology Mechanism should demonstrate the value and necessity of technology R&D and demonstration activities in developing countries in the GCF and to the financial and business communities and international donors (Blanco et al. 2012). The UNFCCC could agree on international environmental regulations and standards and with MDBs and/or the Green Climate Fund on provisions for financing and assistance to countries with weaker capabilities to implement or fund these. Furthermore, international business could form coalitions around low-carbon options, such as BRT systems, in order to make decision-makers aware of the possibilities and create more business.

Countries should promote the participation of their technological, scientific and academic institutions in the TM's CTC&N to be built in the coming years (Blanco et al. 2012). Linked to this, there is the need for the international community to ensure that the positive opportunities associated with such low-carbon innovation policies can be placed in the context of green growth – new jobs, alongside health and environmental benefits. This will help policy-makers who must take into account political-economy aspects in implementing policy.

International initiatives could help to build low-carbon innovation systems in developing countries, but they should align with national policies of countries in order to better enable self-determined low-carbon innovation (Byrne et al. 2012). The approach of distinguishing between the bottom of the pyramid, the rising middle class and growing industry can guide decisions on international interventions. Depending on the category and how the national government is approaching that category, different actions can be agreed depending on a better understanding of the different needs. For instance, an intervention may not just focus on market creation, which may not deliver the needs of the bottom of the pyramid or to which the rising middle class is not responsive, where a more comprehensive approach would be necessary.

Taking into account the above recommendations, there is an opportunity for the TM to take on a brokering role, linking various technology initiatives with finance providers, stimulating and encouraging cooperative R&D, linking innovation processes in different sectors within a country or in different countries, and identifying where lessons learned from successes and failures with technology development, demonstration and transfer in one part or the world can be relevant elsewhere (Blanco et al. 2012)

7

Future work

This research has shown that developing countries will have different kinds of low-carbon innovation strategies based on their assessment of national circumstances and different categories within their economy. In this regard, national contexts are unique and there is no 'one-size-fits-all'. By looking through a lens of different categories, this project has concluded that a more targeted approach – in terms of finance, capability building, and policy approaches – can be effective in identifying interventions for building low-carbon innovation systems in developing countries.

At the international level, bodies such as the UNFCCC's TM can play a role in coordinating and supplementing information on what has and has not worked at the national level. By gathering, analysing and actively sharing this information, international organisations can also help to target finance more effectively, and to build capabilities where they are needed.

Building on the work of this project, more work is needed to dig deeper into the three categories as an approach for framing innovation needs and interventions. Examples of further research questions include:

1. How would this approach impact the structuring of policy actions and interventions in a test country?
2. How could a more targeted focus on these three target categories help mobilise climate finance?
3. How would international mechanisms such as the TM best support interventions focused on the three target categories?
4. How can a category based framing contribute to bringing together the development and mitigation discussions, in regards to providing clarity around opportunities and trade-offs?

References

Blanco, G., de Coninck, H. and Wuertenberger, L. (2012) The Technology Mechanism under the UNFCCC: Ways Forward. Policy Brief for the Climate Technology and Development project. Available on www.climatestrategies.org.

Bruggink, J. (2012) Energy aid in times of climate change: Designing climate compatible development strategies. ECN-E--12-006: Petten, Netherlands. Available via www.ecn.nl.

Byrne, R. (2013) Compact Fluorescent Lamps. Case study for the Climate Technology and Development project. Available on www.climatestrategies.org.

Byrne, R., de Coninck, H. and Sagar, A.D. (2014) Low-carbon innovation for industrial sectors in developing countries. Policy Brief for the Climate Technology and Development project. Available on www.climatestrategies.org.

Byrne, R., K. Schoots, J. Watson, D. Ockwell, H. de Coninck, K. Gallagher and A. Sagar (2012) Innovation systems in developing countries. Policy Brief for the Climate Technology and Development project. Available on www.climatestrategies.org.

Chaudhary, A., Sagar, A.D., and Mathur, A. (2012) Innovating for energy efficiency: A Perspective from India, Innovation and Development 2(1): 45-66.

Cimoli, M., G. Dosi and J. Stiglitz (eds.) (2009) Industrial Policy and Development: The Political Economy of Capabilities Accumulation, Oxford University Press, New York NY

de Coninck, H. (2013) Bus Rapid Transit. Case study for Climate Technology and Development project. Available on www.climatestrategies.org.

de Coninck, H. and R. Byrne (2013) Low-carbon technology for the rising middle class. Policy Brief for the Climate Technology and Development project. Available on www.climatestrategies.org.

de la Tour, A., Glachant, M. and Me, Y., (2010) Innovation and international technology transfer: The case of the Chinese photovoltaic industry. Energy Policy 39 (2011) 761–770.

ECN (forthcoming) Development of global greenhouse gas emissions in the baseline scenario derived from TIAM-ECN model, obtained from model results database of the EU FP7 project LIMITS: www.feem-project.net/limits

EGTT (2009) Strategy paper for the long-term perspective beyond 2012, including sectoral approaches, to facilitate the development, deployment, diffusion and

transfer of technologies under the Convention, Expert Group on Technology Transfer, FCCC/SB/2009/3.
Gallagher, K. and F. Zhang (2013) Innovation and Technology Transfer Across Global Value Chains: Evidence from China's PV Industry. Case study for the Climate Technology and Development project. Available on www.climatestrategies.org.
Gallagher, K., J. Siegel and A. Strong (2011) Harnessing Energy-Technology Innovation in Developing Countries to Achieve Sustainable Prosperity, Background Paper for World Economic and Social Survey 2011
GEA (2012) Global Energy Assessment: Towards a Sustainable Future, Key Findings, Summary for Policymakers and Technical Summary, International Institute for Applied Systems Analysis, Cambridge University Press
Gillingham K., M.J. Kotchen, D.S. Rapson, and G. Wagner (2013). Energy policy: The rebound effect is overplayed. Nature 493, 475–476.
IEA (2012) World Energy Outlook 2012, International Energy Agency/Organisation for Economic Co-operation and Development, Paris
Ionita, R. (2012) Greening Africa's Growth: Low-carbon innovation in the cement industry in Sub-Saharan Africa, Masters dissertation, VU University Amsterdam
Ionita, R., L. Würtenberger, T. Mikunda and H. de Coninck (2013) Energy efficiency improvements and CO2 reduction in the cement industry, Climate Strategies, Cambridge, October
Jackson, T. (2009) Prosperity without Growth – Economics for a Finite Planet. London: Earthscan.
Jacobsson, S. and A. Bergek (2004) Transforming the energy sector: the evolution of technological systems in renewable energy technology, Industrial and Corporate Change 13(5): 815-849
Karekezi S (2002) Renewables in Africa - meeting the energy needs of the poor, Energy Policy, 30(11–12): 1059–1069.
Lema. A. & R. Lema (2013) Technology transfer in the clean development mechanism: Insights from wind power, Global Environmental Change 23: 301-313
Lewis, J. (2007) Technology Acquisition and Innovation in the Developing World: Wind Turbine Development in China and India, Studies in Comparative International Development 42: 208-232
Martinot, E, Cabraal, A, and Mathur, S (2001) World Bank/GEF solar home system projects: experiences and lessons learned 1993–2001, Renewable and Sustainable Energy Reviews, 5(1): 39–57
Nassingwa, R. and M. Nangoku (2012) State of the cement and steel industry in Uganda, available at: http://www.spin.bam.de/en/spin_media/spin_proceedings-cement_concrete_for_africa.pdf [accessed 6 June 2012]
OECD (2012) OECD Environmental Outlook to 2050: The Consequences of Inaction, Organisation for Economic Co-operation and Development, Paris
Practical Action (2013) Poor people's energy outlook 2013: Energy for community services, Rugby, UK: Practical Action Publishing.
Ramani, N (2009) Scale-Up and Commercialisation of Improved Cookstoves in Sri Lanka: Lessons Learnt from the Anagi Experience, London: Practical Action.
Sagar, A.D. (2000) Capacity Development for the Environment: A View for the South, A View for the North, Annual Review of Energy and Environment 25: 377-439.
Sagar, A.D. (2011) Climate Innovation Centers: Advancing Innovation to Meet Climate and Development Challenges, Climate Strategies, Cambridge, UK

Sagar, A.D. (2013) Innovation for climate-compatible development for the 'bottom of the pyramid'. Policy Brief for the Climate Technology and Development project. Available on www.climatestrategies.org.

Sagar, A.D. (2013b) Advanced cookstoves to meet climate and development challenges. Case study for Climate Technology and Development project. Available on www.climatestrategies.org.

Schwartzer, J. (2013) Industrial policy for a green economy, IISD Report, June 2013

Sharma, A., J. Srivastava, S. Kar and A. Kumar (2012) Wind energy status in India: A short review, Renewable and Sustainable Energy Reviews 16: 1157-1164

Shrimali, G., Slaski, X., Thurber, Mark C. and Zerriffi, H. (2011) Improved stoves in India: A study of sustainable business models, Energy Policy, 39(12): 7543–7556.

Smith, K.R. (2002) In Praise of Petroleum? Science 298(5600):1847.

Smith, K.R. (2013): Global and Indian Burdens of Disease from Household Air Pollution: the GBD 2010 Study, presentation at the Indian Institute of Technology Delhi,

Smith, K.R., G. Shuhua, K. Huang, and Q. Daxiong, (1993) One hundred million improved cookstoves in China: How was it done?, World Development, 21, 941-961

Sorrell, S. (2009) Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. Energy Policy 37, 1456–1469.

WBCSD (2012) Cement Sustainability Initiative, World Business Council for Sustainable Development, available at: www.wbcsdcement.org/ [accessed 4 April 2012]

Wilson, E, Wood RG, and Garside, B (2012) Sustainable energy for all? Linking poor communities to modern energy services, IIED Sustainable Markets Linking Worlds Series Working Paper 1. London: International Institute of Environment and Development (IIED).

Project contact:
Lachlan Cameron
ECN
cameron@ecn.nl
www.ecn.nl