CLIMATE TECHNOLOGY AND DEVELOPMENT PROJECT

Innovation systems in developing countries

Policy Brief

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Abstract

This paper provides a review of what every developing-country policymaker should know about low-carbon innovation. It explains what is unique about low-carbon innovation, why low-carbon innovation systems matter, and in what ways they need to be strengthened. However, 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. 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, (research) 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. Successful development and adoption of low-carbon technologies in developing countries depends on the presence of appropriate policies and innovation systems. Appropriateness means they are responsive to their local context in terms of available resources, comparative advantages, societal characteristics and cultural practices. Innovation skills and knowledge should be built in tandem with the adoption of low-carbon technologies and practices. An advantage for poorer developing nations stems from the weaker entrenchment of vested interests and less well established energy infrastructures. These provide opportunities for more easily steering development in low-carbon directions, avoiding the high-carbon pathways that industrialised countries have taken. 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.

INTRODUCTION

Many developing countries are already implementing policies and strategies that could help them shift to a low-carbon development pathway. The development and deployment of lower-carbon fuels, technologies and infrastructures are key components of these strategies. 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.

The aim of this paper is to explain what is unique about low-carbon innovation, why low-carbon innovation systems matter, and how they can be strengthened. Focussing on the information-needs of developing-country policymakers, it provides a comprehensive overview of low-carbon innovation.

What is low-carbon innovation?

In common with innovation in general, low-carbon innovation encompases several stages including research and development (R&D), prototyping, demonstration, market-formation, commercialisation and deployment. The links between these stages are complex and non-linear. The scale and scope of innovation varies widely. In particular, there is a fundamental difference between incremental innovations which lead to improvements in existing products, and radical innovations which yield new inventions and/or methods of production (Freeman 1992). Radical innovations in different parts of the economy can lead to more pervasive and transformational change. The main difference with low-carbon innovations is that, by lowering carbon emissions, they reduce the environmental and social costs associated with using high-carbon technologies, which do not account for such externalities. The markets for low-carbon innovations, therefore, tend to remain weak unless specifically addressed by relevant policy that can force high-carbon options to internalise these externalities.

But incremental change is also an important type of innovation, and can make an enormous difference in low-carbon development. Indeed, incremental improvements can have more economic significance over long periods of time than radical innovations by realising repeated improvements in, for example, the efficiency of production equipment (Bell 2012). In developing countries, the benefits of adopting existing cleaner technologies can be pronounced, as in the example of the Korean steel industry adopting highly-efficient electric arc furnaces (D'Costa 1994; Gallagher 2006).

Where does low-carbon innovation occur?

Both radical and incremental innovations occur in different settings throughout the economy: from production processes to business models; from large industries to small firms to academia; and from consumer-practices to government policies (Hoogma et al 2002). 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. Low-carbon innovation does not necessarily involve high-tech companies or universities (and this is particularly true in poorer developing countries). Rather, there is growing evidence that successful innovations also require changes in areas other than technical hardware. Therefore, a 'socio-technical' approach to the analysis of innovation is required – where changes in technologies are linked to changes in their societal context (Geels 2002). This is important to understanding why and when certain technologies are developed and adopted and others are not – a particularly pertinent concern if low-carbon technology development and adoption is desired.

'Innovation' is also often used to refer to the *process* of innovating, not just the outcome. This is important because it helps to highlight that 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: e.g. see Garud and Karnøe 2001). Innovation emerges from the activities of networks of actors who combine their knowledge, skills and resources in complex ways, as they seek to achieve their various individual and/or collective goals.

Box 1 Policy innovation in Indonesia

The CASINDO programme (Capacity development and strengthening for energy policy formulation and implementation of sustainable energy projects in Indonesia) aimed to build and strengthen institutional and human capacity for energy policy formulation and development of renewable energy and energy efficiency projects in Indonesia, both at the national and regional level.

Within regional governments in Central Java, North Sumatra, West Nusa Tenggara, Yogyakarta and Papua, and as stipulated by national law, institutional structures were created to formulate regional energy policies. Regional governments or private parties developed concrete renewable energy projects, supported by the regional CASINDO technical teams. In some regions projects for micro hydropower and/or waste digesters for biogas were implemented. New education programmes on sustainable energy have been developed and introduced at technical schools and universities to create conditions for continuation of capacity building in the longer term. Under these programmes, demonstration renewable energy technologies were selected, purchased and installed at their campuses.

Figure 1 Opening of a biogas installation at the Diponegoro University in Semarang in Central Java

The programme explicitly developed human capacity at the higher education level as well as at the technical level, as there is a need for engineers skilled at installation, operation and maintenance of renewable energy technologies. The project was staffed mostly with local stakeholders. The programme ended in May 2012. The activities initiated under the CASINDO programme are now continued by the CASINDO technical teams and the Indonesian government.

INNOVATION: ALL ABOUT SYSTEMS

It is important to think of innovation taking place within an innovation system. According to Chris Freeman, this system includes the “network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies” (Freeman 1987).

One of the many consequences of this complexity is that innovation outcomes are “irreducibly uncertain” (Gallagher et al 2012). Another is that new innovation systems take time to develop and their development is resource-intensive (Watson et al 2011). It is not possible to predict what specific technology variants, production processes and user-practices will emerge from a particular innovation system and, conversely, it is non-trivial to design an innovation system for a particular outcome. It is also difficult to predict how long the process of innovation will take. The history of low-carbon technologies shows that supporting them to commercial reality can take decades.

Governments can shape the extent and direction of innovation. Experience shows that policy interventions can have a very positive effect, although success requires carefully-designed policy. However, the outcome and level of success is also influenced by factors beyond the scope of governments. Examples such as the Danish wind industry, Brazilian ethanol, and the development and deployment of renewables in Germany show the benefits of ‘systems thinking’ in action (Jacobsson and Bergek 2004). These succcess stories are not only due to the implementation of particular market-creation policies (e.g. German feed-in tariffs). They are 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.

How can low-carbon innovation be influenced?

Research indicates that the influence over the direction of innovations is crucial. It does, however, require an understanding of the enabling and constraining levers that policymakers can bring to bear in order to support low-carbon innovation.

A challenge is that many low-carbon innovations are at a pre-commercial stage of development. Policies therefore need to focus on R&D, demonstration, pre-commercial deployment, market-creation and early commercial viability (Ockwell et al 2008).

Different developing countries will have a range of strategic needs and priorities, comparative advantages, and national socio-economic and institutional structures that influence their innovation policies and strategies (Cimoli et al 2009; Sagar 2011). Considerations could include existing capabilities and skills, natural resource endowments and the potential for particular technologies to improve energy access. This diversity of strategies, combined with the stage of development of particular technologies, will influence the choice of policy interventions and the actors who should be involved (Gallagher et al 2011).

Using social processes for low-carbon innovation

Considering the social, cultural and political dimensions of innovation, and that it is users who adopt new technologies and practices, policy should not only focus on 'supply push' measures such as funding for R&D or demonstration. As the German renewables example mentioned above illustrates, they should also be concerned with 'market pull' measures to create demand for low-carbon technologies. Market-creation is a key function of government, and it is needed to avoid the social costs of using of fossil-fuels and to level the playing field for cleaner technologies. It should also be recognised that when users adopt innovations, they embed them in their lives and may even construct cultural meaning while doing so. The car is an iconic example in many contexts, where it has come to be seen as symbolic of individual freedom.

Conversely, cultural practices and meanings may prevent some innovations from becoming adopted. In Ghana, for instance, some of the benefits of bioenergy technologies might be foregone because of the social stigma associated with using human waste (Bensah and Brew-Hammond 2010). This means that it is important to include users in innovation processes. They can articulate their concerns, needs, wants and market demands – and this could make significant differences to policy strategies. Therefore, an understanding of the social context, and thereby how to leverage social processes to advance innovation, is an important complement to the technical aspects of innovation.

It is also increasingly recognised that consumers or users innovate beyond simply adopting ready-made technologies and practices (von Hippel 2005). Technologies, therefore, can either 'fit' or not with current practices. Alternatively, they can 'stretch' practices: that is, offer opportunities to develop new ways of doing things or new things to do (Hoogma 2000; Raven 2007). Analysing these fit-stretch dynamics could be critical to effective policy interventions, but this requires an understanding of innovation that goes beyond the currently dominant view that "innovation" refers to (radically new) technical hardware (Byrne et al 2012).

Box 2 Fit-stretch dynamics and solar technologies

Solar cookers offer a variety of benefits including reduced needs for biomass collection and lower health-damaging smoke emissions in the home. However, their widespread adoption at the household level is held back because they do not 'fit' well with a number of social and cultural practices prevalent in developing countries. For example, they can only be used during daylight hours, and in the open rather than inside a kitchen. Many subsistence farmers spend daylight hours cultivating their crops, and cooking in the open rather than in an enclosed space is a "major deterrent" to the use of solar cookers for some (Sesan 2012).

Figure 2 Solar cooker

Solar home systems (SHSs), in contrast, can 'fit' easily into current practices around the use of light while offering higher quality lighting than from kerosene lanterns. But SHSs also create opportunities for 'stretching' practices. For example, the small quantities of electricity generated by SHSs can be used to power TV, radio and mobile phones, all attractive because of what Jacobson (2007) calls their "connective" quality. That is, they enable people to connect to the world beyond their household.

Figure 3 Solar home system

POWERFUL EXISTING COALITIONS AND LOCK-IN

Because of the systemic characteristics of low-carbon innovation, policymakers need to be aware of broader sources of inertia which may hamper the effectiveness of innovation policies. High-carbon technologies, fuels and practices are often deeply entrenched in energy systems. The result is that these systems include powerful vested interests, meaning that the politics of change can be far from straightforward. In many countries, developing low-carbon energy systems is not only a case of supporting new technologies. It also means dismantling and replacing old high-carbon technologies, and challenging the institutions, interests, market structures and social norms that go with them.

Moreover, there are technological lock-ins. Long life-times of existing high-carbon infrastructure, countless jobs, expectations of modern life-styles, status of consumption and favourable regulatory environments evolve interdependently, together strengthening high-carbon lock-in (Unruh 2000). This presents an immense challenge to low-carbon innovation that leads to meaningful emission reductions. The relative lack of established high-carbon infrastructure in developing countries, therefore, presents an opportunity for low-carbon innovation.

Industrialised countries are finding it difficult to overcome carbon lock-in. Middle- and low-income countries also have industrialising sectors and a rising middle class that have – to some extent – embarked on high-carbon development pathways.

LOW-CARBON INNOVATION IN DEVELOPING COUNTRIES

The transition to low-carbon energy systems is a common global challenge. However, the starting points for low-carbon innovation in lower-income countries differ from those in industrialised countries. The less developed energy-provision infrastructures in poorer developing countries offer opportunities to pre-empt technological lock-in, and to bypass the carbon-intensive pathways that some industrialised and middle-income countries have followed. Also, the innovation systems in poorer countries for low-carbon technologies are often underdeveloped. At the same time, the financial, human, and institutional resources in these countries are often limited, thereby making the process of developing and strengthening innovation systems much more difficult.

In addition, addressing the needs of the energy-poor is urgent. Essentially, there are two takes on this: some suggest that the needs of the energy-poor could be met using cheaper high-carbon energy solutions now, without compromising greenhouse gas emissions reductions (e.g. see Sanchez 2010), while others consider the socio-technical nature of innovations and raise questions about whether such high-carbon development would simply lead to high-carbon lock-in, and would therefore store up difficult problems for the future (Byrne and Watson 2012). In many countries, though, low-carbon solutions (such as micro-hydro power generation) are already being used to enhance energy access for the poor.

SPECIFIC INNOVATION NEEDS OF DEVELOPING COUNTRIES

As we have seen, the successful development and adoption of low-carbon technologies depends on the presence of an appropriate innovation system with its host of supporting policies, activities and skills. Underpinning such innovation systems is the range of relevant capabilities (i.e. skills and knowledge) of important actors such as firms, research institutes and communities – and how these are connected together through market or other relationships. Many developing countries possess these capabilities in only weak or fragmented terms, and the systems of interconnection are often undeveloped (Gallagher et al 2011).

The national contexts of developing countries often differ considerably from those of industrialised countries. The innovation needs for low-carbon pathways in those countries are therefore also different. Table 1 (adapted from Sagar 2009) explains three areas of innovation-related activities where developing countries have distinct needs.

So, given the discussion of the need for strong capabilities and interconnections, a focussed effort on building and strengthening skills, knowledge, experience and interconnectedness relevant to low-carbon development is urgently needed. The development of a skilled workforce is a key pre-condition, and international experience in education or work will facilitate technology acquisition and export. But, the precise capabilities required in any particular developing-country context will depend on many factors and must be self-determined[1].

This in itself will require capabilities for making and implementing policy (Bazilian et al 2009). But, as noted above, the legitimacy of policies is important. This can be enhanced through participative approaches that will also require capabilities amongst civil society.

[1] This stands in contrast to an extreme example in which a developing country chooses to deploy existing technologies which are obtained from foreign manufacturers and installed and operated by foreign parties. But self-determined innovation can operate at different levels. For example, it could mean that a developing country only innovates in certain areas such as in technology installation and operation. Or, it could mean attempts to move up the value chain to become original equipment manufacturers; the kind of trajectories cultivated in parts of Asia (Hobday 1995).

Table 1 Capabilities for technology and innovation

Adaptation and modification of existing technology	capabilities to appraise, select and support technology adoption capabilities to operate, maintain and further develop technologies once they are deployed
Addressing needs ignored by markets	capabilities to identify needs, to select and implement policies to support new markets
Joint R&D for long-term innovation capabilities	innovation capabilities: what, why and how they can be enhanced

It is also important to note that low-carbon innovation and development means more than just low-carbon electricity generation, distribution and use (Watson 2008). It cuts across all sectors and development strategies: e.g. transport, energy efficiency (in industry, commerce, agriculture, households), spatial and infrastructural planning, and the technologies and practices associated with other services such as education, water, sanitation, health, communications, waste, entertainment, leisure, and so on. Therefore, capabilities are requried to analyse needs comprehensively, and to prioritise the most important sectors, technologies and institutions.

IMPLICATIONS

National and international policies and instruments can play an important role in helping to build low-carbon innovation systems in developing countries that further human development. This is intrinsically linked with capacity building and technological cooperation – which are therefore core policy areas of the international climate and energy negotiations.

The context in which innovation takes place matters and will have important implications for efforts to build particular 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. Of course, there are interdependencies across these contexts. The process of industrialisation can generate innovations that provide technologies relevant to the needs of both the middle class and the poor, and can provide jobs that help to spread the income gains of the industrialisation process. Market demand expressed by the middle class, and perhaps even 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.

Internationally-driven policy initiatives such as the Technology Mechanism of the UN Framework Convention on Climate Change (UNFCCC), and its associated Climate Technology Centre and Network (CTC&N), open up opportunities to help build low-carbon innovation systems of the kind described here. Likewise, other multilateral or bilateral initiatives such as Climate Innovation Centres (CICs) could also contribute to innovation system building in developing countries (Sagar 2011). However, it is important to remember that these will need to be aligned and synergistic with national policy frameworks if developing countries are to realise self-determined low-carbon innovation.

Interactions of this kind can be powerful, as demonstrated by the experiences of China around, most notably, innovation in the wind power sector (Watson et al 2011). Of course, we should be careful not to generalise too freely from the Chinese context to others but useful lessons are available from such experiences, as they may be from others such as in India and Brazil.

We will explore the context issues mentioned above in three seperate briefings over the coming months. Before doing so, we will focus on the UNFCCC Technology Mechanism and CTC&N in our second briefing. This we intend to release in August.

RECOMMENDATIONS

This briefing has highlighted aspects of innovation systems for low-carbon development that will be explored in detail in our future briefings and case studies. It leads to several policy recommendations.

First, it is important to understand innovation in broader terms than the introduction to the world of radically new technical hardware. This is innovation, of course, but is at one end of a continuum that stretches all the way to incremental changes of hardware and to the first adoption of such hardware by any market actor. Furthermore, innovations can occur in processes, techniques and practices of various kinds: social, cultural, political, and so on.

Second, it is crucial to recognise that innovations emerge from systems of interconnected actors – firms, (research) organisations and users – all operating within an institutional environment. This means that there are opportunities to influence the processes of innovation. Possible levers available to achieve such influence include implementing policies, laws and regulations to support low-carbon innovation. Policies should also be designed to ensure that the different kinds of players in the system are able to coordinate and collaborate to meet their individual and collective goals.

Third, low-carbon innovation encompasses the cultivation of indigenous capabilities to develop and deploy low-carbon technologies. These capabilities for low-carbon innovation must be built in tandem with actions to support the adoption of low-carbon technologies and practices in order to facilitate their long term sustainability. Moreover, low-carbon innovation capabilities need to be built in ways that are sensitive to the local context, exploiting comparative advantages such as existing research capacity, skills and local availability of natural resources. And, of course, the local context includes social and cultural practices that could impede or facilitate the development of certain innovations, whether addressing the needs of the energy-poor or a rising middle class. A focussed effort on building and strenghtening knowledge, skills, experience and interconnectedness is much needed in developing countries.

Fourth, there are different starting points for industrialised countries and lower-income countries taking up the global challenge of building low-carbon energy systems. The weaker entrenchment of vested interests and high-carbon energy infrastructures in poorer developing countries could provide opportunities to develop self-determined low-carbon innovations and circumvent the high-carbon pathways that industrialised countries have followed.

Fifth, international initiatives such as the Technology Mechanism of the UNFCCC, CTC&N and other initiatives such as CICs could contribute to innovation system building in developing countries. However, it is important to remember that these will need to align and be synergistic with national policy frameworks if developing countries are to realise self-determined low-carbon innovation.

Finally, international assistance for building low-carbon innovation systems must recognise that such an endeavour is both resource-intensive and long term. Outcomes cannot be guaranteed or predicted with complete certainty. It is therefore 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.

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A full overview of data and assumptions is available from the authors.