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Energy Pathways in Low-Carbon Development: From Technology Transfer to Socio-Technical Transformation

Rob Byrne, Adrian Smith, Jim Watson and David Ockwell

Energy Pathways

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The relationships between energy and development are complex, compounded by increasingly differentiated situations amongst developing countries and within them. Moreover, the manner in which energy services are realised has consequences for our health, environment, wealth, and social relations. Two important issues currently preoccupying the realm of international development are enhancing energy access whilst simultaneously addressing climate change. International climate change negotiations place an emphasis on low-carbon technology transfer, which perpetuates a long history of expectations about technology providing solutions to energy and development challenges.

Drawing upon the history of technology transfer, and discussing the record of the Clean Development Mechanism, this paper questions just how much the dominant 'hardware and finance' framing will help communities explore and develop low-carbon pathways that meet their needs. Our view is that a much broader and ambitions approach to energy and development is needed. We suggest a 'socio-technical transformation' framework for organising low-carbon energy initiatives in development. In making this argument, we use a pathways approach to understanding the challenges of energy and development; an approach being developed by the STEPS Centre at the University of Sussex. Having argued for a broader and more plural perspective, we conclude the paper by suggesting a research agenda for testing its potential.

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About the STEPS Centre

Today's world is experiencing rapid social, technological and environmental change, yet poverty and inequality are growing. Linking environmental sustainability with poverty reduction and social justice, and making science and technology work for the poor, have become central challenges of our times. The STEPS Centre (Social, Technological and Environmental Pathways to Sustainability) is an interdisciplinary global research and policy engagement hub that unites development studies with science and technology studies. We are developing a new approach to understanding and action on sustainability and development in an era of unprecedented dynamic change. Our pathways approach aims to link new theory with practical solutions that create better livelihoods, health and social justice for poor and marginalised people. The STEPS Centre is based at the Institute of Development Studies and SPRU Science and Technology Policy Research at the University of Sussex, with partners in Africa, Asia and Latin America. We are funded by the ESRC, the UK's largest funding agency for research and training relating to social and economic issues.

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About The Sussex Energy Group

The Sussex Energy Group undertakes academically rigorous, inter-disciplinary research that engages with policy-makers and practitioners. The aim of our research is to identify ways of achieving the transition to sustainable, low carbon energy systems whilst addressing other important policy objectives such as energy security. We have funding from a diverse array of sources. We are core partner in the Tyndall Centre for Climate Change Research and part of the UK Energy Research Centre.

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Summary

The relationships between energy and development are complex, compounded by increasingly differentiated situations amongst developing countries and within them. Moreover, the manner in which energy services are realised has consequences for our health, environment, wealth, and social relations. Two important issues currently preoccupying the realm of international development are enhancing energy access whilst simultaneously addressing climate change.

A recurring theme in studies and policies for energy and development is the role innovation can play in improving sustainable energy access. International climate change negotiations place an emphasis on low-carbon technology transfer, which perpetuates a long history of expectations about technology providing solutions to energy and development challenges. Whilst these expectations are not entirely unfounded, this history indicates that solving the many problems associated with the provision of energy services involves a more complex set of interdependent processes than 'straightforward' transfer of technology. And yet, international discussions are intensifying (once again) around innovation in the form of technology transfer; discussions that frame the issue, we argue, in terms of financing the flow of low-carbon technological hardware to developing countries. This 'hardware and finance' framing of low-carbon development has resulted in a limited number of general purpose policy instruments – such as the Clean Development Mechanism – that tend to neglect important details of how technology can be 'transferred' successfully and sustainably. Moreover, they seem to neglect the contestable purposes of low-carbon development more broadly and the limited, though vital, roles technology transfer plays therein. Given the diversity of situations and concerns in energy and development, such a generalised yet narrow framing of the challenge could prove problematic.

Drawing upon the history of technology transfer, and discussing the record of the Clean Development Mechanism, this paper questions just how much the dominant 'hardware and finance' framing will help communities explore and develop low-carbon pathways that meet their needs. Our view is that a much broader and ambitions approach to energy and development is needed. We suggest a 'socio-technical transformation' framework for organising low-carbon energy initiatives in development. In making this argument, we use a pathways approach to understanding the challenges of energy and development; an approach being developed by the STEPS Centre at the University of Sussex. Having argued for a broader and more plural perspective, we conclude the paper by suggesting a research agenda for testing its potential.

1. Introduction: purpose and argument of the paper

Improved energy services are an important underpinning for many development processes. Yet the relationships between energy and development are complex, compounded by increasingly differentiated situations amongst developing countries and within them: rural development and urban expansion; industrialisation; household energy needs; mobility; and whether the perspective is from the side of demand for energy services or supply of energy products. Moreover, the manner in which lighting, cooking, mobility, heating or cooling, information and communications, powering equipment, and so on are realised through energy services has consequences (positive and negative) for our health, environment, wealth, and social relations. Two important issues currently preoccupying the realm of international development are enhancing energy access whilst simultaneously addressing climate change.

A recurring theme in studies and policies for energy and development is the role innovation can play in improving sustainable energy access. International climate change negotiations place a particular emphasis on low-carbon technology transfer[1], which perpetuates a long history of expectations about technology providing solutions to energy and development challenges. Whilst these expectations are not entirely unfounded, this history indicates that solving problems of energy access, equity, security, environment, and so on, involves a more complex set of interdependent processes than 'straightforward' transfer of technology. And yet, international discussions are intensifying (once again) around innovation in the form of technology transfer. Negotiations tend to frame the issue in terms of financing the flow of low-carbon technological hardware to developing countries. This is realised through a limited number of general purpose measures, such as the Global Environment Facility, the Clean Development Mechanism, and initiatives such as Advance Market Commitments. These measures, fixing on quite narrow issues of finance and hardware, tend to neglect important details of how technology can be 'transferred' successfully and sustainably. Moreover, they seem to neglect the contestable purposes of low-carbon development more broadly and the limited, though vital, roles technology transfer plays therein. Given the diversity of situations and concerns in energy and development, such a generalised yet narrow framing of the challenge could prove problematic.

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[1] We recognise that the term 'technology transfer' is a loaded one, carrying many assumptions about the process of technical change that are either highly contested or simply inaccurate. The term is used in this paper where it reflects the debate on technical change, whether in international negotiations or academic literature. Our own view is that we need to recast our thinking on technical change in developing countries and to reflect this in more appropriate terms such as 'low-carbon innovation'.

A number of assumptions behind current approaches are questionable. They do not yet adequately capture how a wide variety of other factors interact in complex, emergent ways in energy and development. Current discussions appear blind to lessons from a chequered history of energy 'technology transfer' going back to the 1981 UN Conference on New and Renewable Sources of Energy and before. Drawing upon this and the broader history of technology transfer more generally, this paper questions just how much the dominant 'hardware and finance' framing will help communities explore and develop low-carbon pathways that meet their needs.

Our view is that a much broader and ambitions approach to energy and development is needed. We suggest a 'socio-technical transformation' framework for organising low-carbon energy initiatives in development. In making this argument, we draw upon a pathways approach to understanding the challenges of energy and development, and whose methodology is being developed by the STEPS Centre at the University of Sussex (STEPS – Social, Technological and Environmental Pathways to Sustainability, see www.steps-centre.org). The pathways approach means attending to:

a) How contending narratives about energy challenges in low-carbon development are mobilised in concrete situations

b) How the political economy of those situations favours certain narratives

c) The ways both these processes influence the mobilisation of material and social resources in low-carbon innovation processes

d) What this means for the evolution of energy systems and low-carbon development pathways, particularly for alternative pathways that prioritise the needs of the poor and marginalised.

Having argued for a broader and more plural perspective, we conclude the paper by suggesting a research agenda for testing its potential. As such, this paper is aimed initially at researchers and users of low-carbon development research in policy, business and civil society.

Before entering this discussion and setting out our arguments, it is helpful to make explicit three of our guiding assumptions. First, we hold the view that developing countries need to be fostering indigenous capabilities for low-carbon innovation.[2] This rests on the notion that such capabilities enable developing countries to exercise greater control over the choices they can make in development, wherever such choices are relevant to their own priorities. We do not suggest

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[2] We define indigenous innovation capabilities as the capabilities to adapt, develop, deploy and operate low carbon technologies effectively within specific developing country contexts (Ockwell *et al*. 2009).

that all developing countries (or all countries, for that matter) need to cultivate the entire range of low-carbon innovation capabilities, merely that some of these capabilities will be necessary to achieve self-directed development as economies across the world attempt to decarbonise.

Our second main assumption is that low-carbon development pathways need to be socially just. As such, we agree with the Brundtland definition of sustainable development, for which ‘over-riding priority’ must be given to the needs of the poor (WCED 1987: 43). One important aspect of this assumption is that any ‘chosen’ pathway needs to be legitimate for poor and marginalised groups as well as delivering wider public goods; otherwise it is unlikely to provide sustainability benefits and may well be self-defeating. Our final guiding assumption is that climate change is real and increasingly immanent, and that it will impact on many developing countries disproportionately, if it has not already begun to do so.

The paper is organised as follows. In the next section, we outline what we see as an increasing diversity of energy challenges in the context of low-carbon development (more information relating to this can be found in Annex A). Following this, in section 3, we give a brief discussion of the STEPS pathways approach to understanding this diversity of challenges. We apply this approach in section 4 to identify the currently dominant low-carbon development framing that understands the challenge to be one of technology and finance. This is further elaborated in section 5, using the example of the Clean Development Mechanism (CDM). Section 6 discusses a range of insights that have emerged from ‘technology transfer’ literatures; insights that the dominant low-carbon development pathway appears unable to accommodate. Part of the reason for this inability to frame the challenge wider than technological hardware and finance, we argue, is rooted in a history of international political economy, and narrow understandings of technology and development (Annex B explores this history in more detail). In section 7, having made these arguments, we suggest that the challenges of low-carbon development could be more usefully framed – both analytically and normatively – by taking a socio-technical transitions approach. However, we do not claim that the transitions framing is without difficulties. Rather, we suggest that it offers a way to gather the many insights referred to in the paper – from the pathways approach and the ‘technology transfer’ literatures – and begin to integrate them. As such, section 8 sketches what emerges from all the discussions here to outline a research agenda for energy sustainability in development. Finally, in section 9, we draw the paper to a close with some conclusions.

2. Diverse energy challenges in low-carbon development

The energy-development relationship is complex. There is heterogeneity among developing countries, a diversity of motivations and drivers of energy-development interdependencies, and inter-linkages among these motivations and drivers. The classification 'developing countries' belies an increasing differentiation: low-income, middle-income, least developed, and highly-indebted poor countries; and emerging and transition economies. Energy and development are interdependent through many motivations and drivers, including rural development and urban expansion, industrialisation, household energy needs, mobility; and whether our perspective is the demand for energy services or the supply of energy products. Moreover, these motivations and drivers themselves are inter-linked. Rural development may involve agricultural production that requires energy inputs for farming and processing; the processed goods need to be transported to markets; and rural areas need supplies of other goods, manufactured equipment and services (including energy products and carriers) that also need to be transported. Domestic markets – rural and urban – may be important for industrialisation, so progress in rural and urban development will tend to raise domestic demand for energy. Annex A explores the energy situation in developing countries and provides background for the subsequent discussions. It underscores the need to understand the diversity and extent of the energy challenges that developing countries now face.

Taking households for example, families need energy for a variety of services, the most basic of which are lighting, thermal comfort and cooking. Lighting can be important to facilitate productive night-time activities such as children's homework, of course, but also for immediate quality-of-life activities such as socialising. Different lighting technologies open up or close down various possibilities, whose meanings in terms of everyday life become entwined in those technologies. Technology studies scholars prefer to talk of socio-technical arrangements or configurations in order to capture the deeply social aspects of many technological artefacts.

Meanwhile, in the industrial sector, energy supply that is intermittent, unreliable or unstable can cause loss of production as well as raise costs, with implications for competitiveness. Again, the forms and reliability of energy systems have social and economic implications, and whose significance to key interests may have some bearing on the maintenance of those systems and whose energy needs are prioritised. These socio-technical points highlight that secure energy access is not only about the quantity of energy made available by technologies at a particular time for a particular service, but also its quality, predictability and versatility for different energy-development services. Moreover, the significance of the activities underpinned by energy gives the latter its real meaning in peoples' lives and in economic activity. These socio-economic aspects of energy can reinforce material requirements for energy when they become indispensable. The manufacturer's need for stable electricity currents to power her sensitive production equipment suggest a different quality of energy security criteria compared to lighting the bulb in her home at night. The ability to power both these activities has wider implications for her standard of living and quality of life. In other words, energy is an intimate and influential thread in a web of socio-technical practices, and should be understood in these socio-technical terms (Shove 2003; Rip and Kemp 1998).

Governments in many countries recognise the strategic significance of energy, and have policies in place to maintain or enhance energy services. Non-governmental actors, of course, are also involved in building, maintaining and enhancing energy systems. As these systems evolve over time actors develop rules, procedures and specialised skills; they form associations, make investments and establish material infrastructure; they invest and seek returns through the expansion of markets; and consumers become familiar with particular lifestyle norms (or aspire to them), entrenching certain behaviours that are resistant to alternative practices. Together, these and other processes can be mutually reinforcing, resulting in dominant pathways of development that constrain or marginalise alternative choices (Smith *et al*. 2005).

An important new consideration in the meaning of energy internationally is climate change. It is high on policy agendas, and further complicates energy-development relationships. Conceptually, attempts to address climate change have been separated into mitigation and adaptation, although there may be solutions that are positive in both respects as well as some that impact positively on one but negatively on the other. For example, in adaptation, mechanical air conditioners may be used more widely in response to higher temperatures (and rising incomes) but this will raise energy demand (in contrast to, say, passive cooling in building design or clothing conventions). Conversely, responses to flooding can involve increased pumping of water, which also requires considerable energy. If energy is generated using carbon-intensive sources then mitigation will be undermined, further adaptations required, and so forth.

Having said this, we will not discuss climate change science and impacts much further in this paper as we are more interested in responses to climate change in the context of development. Instead, we assume climate change is a physical reality – largely caused by greenhouse gas (GHG) emissions resulting from human activity – that will have disproportionately serious impacts in developing countries for many decades to come. Globally, we need to stabilise within the next few decades the total GHGs in the atmosphere in order to lower the risk of dangerous climate change. One of the more important ways in which we can achieve this stabilisation is to dramatically reduce GHG emissions associated with human activities, and to do so urgently. Energy-use is implicated significantly in this challenge because much of our demand for energy is currently met by the combustion of energy carriers that emit CO2 (carbon dioxide) in their exhaust gases. The challenge is intensified because we expect global energy demand to continue to rise in tandem with development and economic growth, both of which are particularly important ambitions in developing countries.

Notwithstanding our points about the socially constructed meaning of energy, how we generate, convert, transport and use energy are all processes in which technology still plays an important role. This is so whether we are using sophisticated hardware such as photovoltaic modules or simple techniques such as burning biomass. No technology can solve problems perfectly and some have (good and bad) unintended impacts. But each energy technology is a tool that can help us service needs and wants in ways that (we hope) may be convenient, productive, affordable, safe and sustainable. The record of safety and sustainability of energy technologies in the industrialised economies is somewhat chequered. For developing countries, the record is considerably more uneven across many criteria. Of course, each criterion can be unpacked: it may be convenient to drive but roads become congested, need more costly maintenance and repair, the risk of accidents increases, and GHG emissions grow. A technology may raise individual productivity, but at what social cost and to whom elsewhere? The distributional contours of sustainability (beyond general normative principles like Brundtland) can be defined in different ways by and for various groups (Jacobs 1999). It might, for instance, be the generation and trade in carbon emission reduction credits that are deemed important, since they create revenues from offsetting the carbon emissions arising from wealth-generating activities elsewhere. Or sustainability might be understood as requiring more immediate and wider development gains locally from any given energy project. Of course, the former may help the latter. Sustainability involves a perpetual, reflexive linking and trading off of different environment-society-economy relations.

Box 1 illustrates the importance of taking a socio-technical perspective on alternative technologies in the case of biofuels, where the practical particulars have an important bearing on the sustainability features of development.

However, our purpose here is not to evaluate different energy sustainabilities. Even the priorities for poverty reduction and social justice in the pathways approach below can be met in a number of ways. Rather, our purpose is to point out that different sustainability concerns intersect with, and are variously taken up by, other issues and interests. These processes for mobilising different sustainability values work to frame development pathways and inform governance strategies for promoting some pathways over others, or for contesting them. With this brief characterisation of the multi-faceted energy-development challenge in mind, we introduce the pathways approach.

Box 1: Biofuels and the complexities of sustainability in energy-development relationships

Biofuels are energy carriers that exemplify the potential for both positive and negative impacts on, and by, rural development and industrialisation, as well as demonstrating the complexities of the relationships between the two endeavours. The growing of biofuel crops could mean significant income for farmers, the processing of biofuel feedstocks could mean the development of important technological capabilities that offer opportunities for industrialisation (and beyond the immediate needs of the biofuels industry, but for similar processing industries), and biofuels may become an important low-carbon source of energy to mitigate climate change. For these reasons, amongst others, there have been periods of enthusiastic international support for biofuels from both industrialised countries and the developing world (e.g. in the 1980s and in the 2000s). For industrialised countries, biofuels have been seen as a means to reduce the climate change impacts of energy-hungry lifestyles with minimal disruption to those lifestyles (Dauvergne and Neville 2009). For developing countries, they have been seen as a means to generate income, reduce oil-dependency and meet the rising energy needs of economic growth (Sulle and Nelson 2009).

However, numerous uncertainties over whether biofuels will have positive or negative effects have also emerged periodically (often shortly after the enthusiasm). Most recently, this has included the 'food riots' (or 'fuel riots', depending on the perspective taken) of 2007/8 (Dauvergne and Neville 2009). These uncertainties span the range of economic, environmental and social dimensions of sustainability. Economically, biofuel production has been long-supported by government subsidies, particularly in the US, encouraging the displacement of food crops in favour of biofuel feedstocks and raising the price of food. Environmentally, there are serious concerns that some biofuels will add to GHG emissions, and that there could be many direct negative impacts in developing countries. One of the more obvious of these is increased pressure for deforestation to clear land for large-scale production of biofuel crops. Socially, there is growing concern that the poor in developing countries will be further marginalised as large companies turn 'common' land over to commercial production, depriving the poor of their livelihoods. Furthermore, there is some indication that land grabs mean even the economic benefits of biofuels will not be realised by the least developed countries. Dauvernge and Neville (2009), for example, analyse how richer developing countries are beginning to exploit poorer countries as sources of cheap feedstock extraction, in similar ways to the historic extraction of minerals and other resources by industrialised countries.

None of these outcomes is either certain or unchangeable. The point here is to illustrate that there are many complexities in energy-development relationships beyond the technique of turning biomass into fuel, and that we need to be able to unpick carefully if we are not to create more problems than we solve. These complexities co-evolve on many dimensions: social, ecological, technical, political. Our use of the term socio-technical is intended to capture, in shorthand, these multiple dimensions.

3. A pathways approach to understanding energy challenges

The starting point for the pathways approach is to recognise that energy services in any particular setting comprise complex systems of social, technological and environmental components interacting across multiple scales. These components co-evolve over time, which means that systems of energy service tend to develop along path-dependent trajectories. The previous section indicated that energy practices are the emergent outcome of complex, intimate and evolving relations between technologies, institutions, markets and people. The processes that result in a meaningful energy service operate across overlapping and temporally distinct scales. This includes the routines of daily life intersecting with the turnover of energy-using goods, equipment and infrastructure.

The pathways approach recognises this, but is reflexive in the way it does so. This means recognising that there are many ways of 'framing' (i.e. bounding and understanding) any given energy system. Reflexivity means considering the ways in which different groups of actors 'frame' the complex energy system under consideration (including our own analytical framing) (Schön and Rein 1994). These framings inform generic narratives that guide both analysis and action. A framing will delimit the energy system boundaries, and privilege certain dynamics, functions and outcomes, but which all remain open to different interpretations under contrasting framings.

> "Narratives are created and promoted by particular actors, networks and institutions. They often start with a particular framing of a system and its dynamics, and suggest particular ways in which these should develop or transform to bring about a particular set of outcomes. Narratives therefore suggest and justify particular kinds of action, strategy and intervention. Some narratives, in turn, come to be supported by institutional and political processes – governance – so as to define and shape pathways: particular directions in which interacting social, technological and environmental systems co-evolve over time. Other narratives, meanwhile, may not become manifested in actual pathways of intervention and change, remaining marginalised." (Leach *et al*. 2010: 371).

Energy system framings inform the strategies pursued for governing that system. The more persuasive a framing (and the more influential its advocates), the more in tune it is with powerful perspectives on reality; and the greater the interests it mobilises, then the more likely it is to enrol support for its strategies, and become institutionalised into the energy system, thereby becoming part of the reproduction of the system. As we shall see, international negotiations over climate change frame the development of low-carbon energy services chiefly as a question of financing the transfer of low-carbon technologies. This narrative has implications for the forms and distribution of low-carbon development around the world (see sections 4 and 5).

To the extent that the outcomes of any action confirm, legitimise and reinforce a framing, then a mutual correspondence between the pathway and the framing will persist. To the extent that outcomes confound expectations, then the narratives justifying that framing will need to work hard to maintain legitimacy, or be revised, or be replaced.

Outcomes that confound expectations under the framing that informed an activity can open space for alternative narratives to be heard more attentively, thereby raising the salience of those alternative framings of the energy system. There might be processes beyond the frame of the dominant narrative, such as the importance of hard won indigenous capabilities for successful technology transfer, and whose absence (within the framing and associated governance strategies) account for problems along the pathway being pursued. These processes can work to expand the frame, broaden the actions, and enrich the governance of the development pathway. The history and scholarship around technology transfer in industrialisation, for instance, offers a broader set of insightful contributions to international negotiations and mechanisms for low-carbon development. We pick this up in section 6.

At times, however, there can be more fundamental challenges that cannot be accommodated within a dominant frame, and which demand a complete re-orientation of framings and pathways. Persistent difficulties in achieving deeply decarbonised development outcomes might be an example here; especially when existing approaches are working well on their own terms (e.g. cheap energy supplies through competitive markets), yet do not deliver sufficient emissions reductions, or neglect other important dimensions to sustainability, such as equity. Under such circumstances, a need for a more radical re-framing might become accepted more widely; again opening space for alternatives to have some influence over governance strategies and outcomes.

> “Building pathways to sustainability must involve recognising and addressing the power-laden interplay between pathways. This includes being explicit about conflicts and trade-offs between them, as well as areas where there is scope for complementarity, alignment and integration. It includes challenging pressures that enable certain pathways to remain dominant to the exclusion of others. And it involves actively highlighting and building political and institutional support for less dominant alternative

> pathways, including those that address the full range and implications of dynamics, and which support the goals of particular marginalised groups." (Leach *et al*. 2010: 376)

Consequently, a pathways approach is open about the unavoidably normative and plural implications of any energy and development analysis and action. It involves a pragmatic awareness of the limits, as well as the advantages, arising from the situated and partial characterisation of any given framing. We argue that a broader framing than technology transfer is required in international negotiations for energy and low-carbon development. Such a framing must be capable of recognising and supporting a plurality of environmentally sustainable and socially just development pathways appropriate to specific situations. Negotiations over the financing and administration of technology transfer are certainly helpful to some low-carbon development situations. But other development situations are less susceptible to these measures as currently constituted, and are being neglected as a result. Criticisms of the CDM reported in section 5 illustrate this problem. Indeed, there is a risk that these neglected sites, with legitimate and desperate needs for development, and in the absence of low-carbon capability building, will turn to well-known carbon intense energy solutions, which are more institutionalised in the international trade of technology, and thereby 'readier' to implement. The risk here is that communities 'relieved' of carbon reduction commitments over the medium term become locked into more carbon intense trajectories, and that these store up problems for future changes of direction. Carbon intense energy pathways remain likely in the absence of effective low-carbon development policies and locally meaningful and powerful alternative pathways.

There is a rich research literature that identifies important social processes and outcomes necessary for innovations to move and embed in different contexts, including those beyond the technology-and-finance frame. We contend, moreover, that even a broader technology transfer framing, cognisant of these processes, may not be sufficient to deliver radically decarbonised development. This is because the challenge, as we see it, is not simply to embed lower-carbon technologies in diverse contexts, but to transform those contexts and engender self-reinforcing low-carbon development pathways. 'Contexts' have to be unpacked and endogenised within the analysis; they need to be considered as part of the transformation process with which policy support must engage.

Low-carbon development is not simply a more carbon efficient reform of existing (technological) trajectories. Whether it is emerging economies or desperately poor communities, the conventional view of technology and development, which largely involves firms catching up with the technological frontiers, may not be the best route to sustainability anyway (Berkhout *et al*. 2009). Highly novel sustainability innovations can arise in a variety of settings, and involve actors beyond firms, in both public and civil society arenas, as well as operating through international networks. The whole notion of what gets transferred, from where, by whom, and for whom, looks increasingly problematic. Rather, low-carbon development has to involve the creation of new development pathways, and therefore policies to support low-carbon development have to include the capabilities and resources for communities to realise their goals sustainably. Our claim is that international negotiations need to reframe their debate in terms of seeking transitions to low-carbon energy practices across diverse development pathways.

Before introducing our reframing of energy challenges in low-carbon development, we elaborate some of our criticisms of how current international approaches frame the challenge. This also serves to illustrate the pathways approach to understanding the challenges. The next section discusses how international policy negotiations have tended to frame their energy and development discussions. These narrow down around questions of finance and hardware. This orientates governance strategies, activities and outcomes along particular pathways whose distribution and diversity is suspect. We illustrate these characteristic pathways with the case of the CDM in section 5.

4. The technology and finance framing of the challenges

In this section we focus on the dominant pathway for energy and development being pursued at the international level. This dominant pathway focuses on technology transfer and finance, and constitutes an enduring and influential framing of energy and development issues. Technology certainly plays an important role in the provision of the energy services that underpin development processes. Historically, energy technologies have tended to be designed and manufactured in the industrialised economies. As a result, the developing countries have been pre-occupied with gaining access to these technologies through development assistance. Since the early 1960s, several institutions have been created – multilateral and bilateral – to help developing countries in terms of science and technology in general and, since the 1980s, in energy technology in particular. Annex B traces this history, which was dominated by arguments between the industrialised and developing countries over technology and finance, especially as played out in international forums. This history is important for understanding the way in which ‘technology transfer’ – as it is usually called – became highly politicised and for understanding the emergence of the CDM and market-based approaches to low-carbon development, as well as the reasons for the current impasse in negotiations over the climate regime.

Many of the current and proposed arrangements for financing low-carbon development (conceived principally as an issue of technology transfer) are discussed in Annex B. Donor countries tend to have their own bilateral agencies that include some form of technical assistance but our discussion here (and in Annex B) focuses on those institutions that are multilateral. In part, this is to simplify the discussion but also it is in the multilateral institutions that we can see most clearly the negotiations over technology access and how to improve it. There has been or continues to be the Energy Assessment Programme (EAP), Energy Sector Management Assistance Programme (ESMAP), Global Environment Facility (GEF), the Clean Development Mechanism (CDM), Climate Investment Fund (CIF), and possibilities of using Advance Market Commitments (AMCs) and a new Copenhagen Green Climate Fund. Each has different motives and forms of engagement, but all except ESMAP and the GEF (to some extent) emphasise finance for ‘technology transfer’.

The GEF works through both the World Bank and the UN systems, and involves innovative financial arrangements (World Bank) as well as attempts to disseminate technological hardware through projects (the UN). The CDM is entirely a finance instrument, overseen by the UNFCCC. The CIF is also a finance instrument that is currently with the World Bank but includes a committee of bilateral development agencies, developing-country representatives and civil society observers. AMCs are a topic of discussion at the time of writing (June 2011). These would provide a form of finance for risky technologies but are not yet in operation, although

DFID (UK Department for International Development) has shown a keen interest in deploying them in the near future. The Copenhagen Fund was only agreed in principle at the Copenhagen Climate Conference in December 2009. There is no space to provide detailed discussions of each of these modalities. However, most arise in the course of our discussion in Annex B on the history of international negotiations over technical assistance.

Later we elaborate upon one of the most successful of them to date (in terms of finance deployed) – the CDM. But, just how much finance is at stake? Various estimates for the amount of finance necessary to meet the climate challenge in developing countries have been suggested. Stern (2007), for example, estimates the figure to be USD 300 billion per annum. While investments in sustainable energies worldwide have been increasing rapidly in recent years, there is still a long way to go before they reach the requisite levels in developing countries. Figure 1 shows estimated world investments in sustainable energies (low-carbon technologies and energy efficiency) between 2002 and 2009, with a projection for worldwide investments in 2010 (PCT 2010). These are disaggregated into an approximate developing-country group and registered CDM projects, in order to compare the levels of finance with worldwide investments. The 'developing-country' group actually includes some of the richer countries [3] and so overstates the levels of finance to developing countries, and is likely to include the CDM (although it is not clear whether this would be registered projects only or include those further upstream in the CDM pipeline). However, the point here is to examine indicative figures rather than to perform statistical analysis, so the accuracy of the numbers is not critical to our needs.

[3] The figures are from the UNEP and NEF (2009) report in which the world is divided into the following regions: Europe, North America, South America, Asia and Oceania, and the Middle East and Africa. The 'developing countries' shown in the charts (Figure 1 and Figure 2) are comprised of these regions excluding Europe and North America.

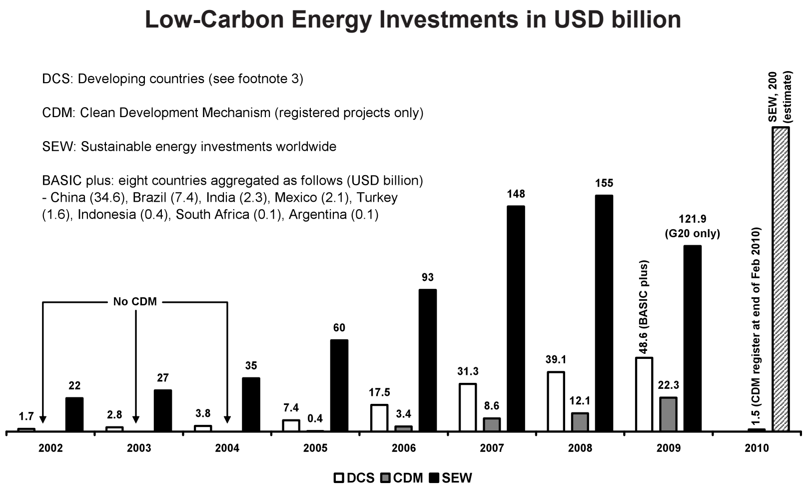
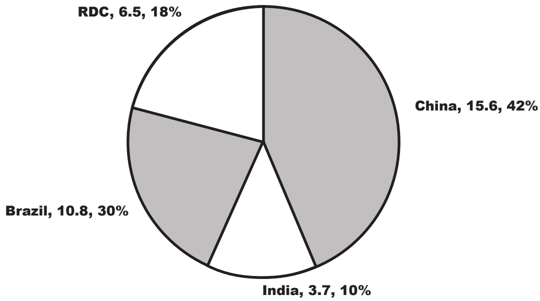


Figure 1: Estimated investments in low-carbon energy technologies, 2002 to 2010; comparing developing countries, the CDM, and the world.
Source: UNEP and NEF (2009), UNEP Risø (2010), pct (2010)

Some disaggregation for 2008 of the developing-country group is possible with the data given in UNEP and NEF (2009). This is shown in Figure 2 as a pie chart and clearly displays a heavy bias towards just three countries: China, Brazil and India.

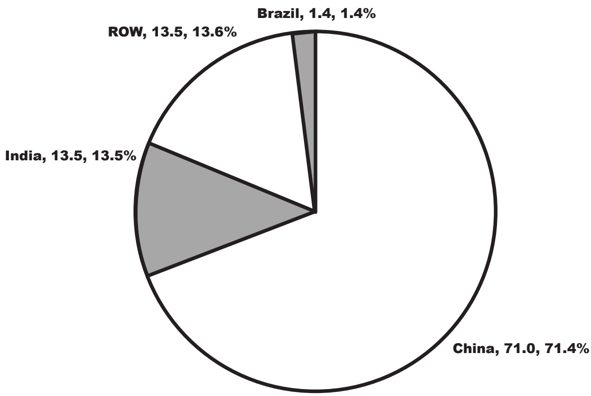
This bias is reflected in the CDM (see section 5); indeed it is even more skewed. Figure 3 shows the accumulated investments made through the CDM since 2005, based on registered projects only. China has received over 70% of the finance available so far, while India has been the next best beneficiary with 13.5% of the investments. Brazil has received 1.4%, leaving the rest of the participating countries with 13.6% among them.



Key

Country, USD billion, percentage

Figure 2: Sustainable energy investments in developing countries, 2008.
Source: UNEP and NEW (2009)



Key

Country, USD billion, percentage
ROW: Rest of the world

Figure 3: CDM registered projects and accumulated investment value, as at end of May 2011.
Source: UNEP Risø (2011)

Based on the figures given in UNEP and NEF (2009) for the developing-country group, the rate of growth of investments in low-carbon technologies in developing countries will need to be about 18% per year in order to reach the suggested level of USD 300 billion by 2020.

Questions about whether such growth in finance is achievable over an extended period, and how investments are going to be administered (e.g. if they include a significant amount of multilateral aid and/or work through a CDM-like framework) are the subject of intense debate in international forums. There has been some movement in recent years but there is still a long way to go.

Important as these financing and administrative debates are, they tend to miss the point because they remain within a technology and finance framework. Experience with other pathways should make us reflect on just how much technology and finance will assist widespread and deep low-carbon development (in contrast to just the accumulation of low-carbon hardware in countries or regions capable of absorbing those technologies). As we explore in the next two sections, to the extent that technology can assist in development, theories of ‘technology transfer’ and development have become more sophisticated over time, but practice has been highly uneven – geographically and temporally. Moreover, whilst predominantly market-framed approaches to technology transfer continue to dominate, it is important to not let interest in technology flows overshadow other aspects of low-carbon development. There is a risk that the relatively narrow and static framing of the challenges into a question of re-distributing low-carbon technology actually fails to address how communities can develop greater control over their own low-carbon pathways. We see this in the case of the CDM, which epitomises the technology and finance framing.

5. Technology-finance pathways: the Clean Development Mechanism

The Clean Development Mechanism (CDM) allows signatories to the UN Framework Convention on Climate Change to trade in carbon emission reductions. An instrument of the Kyoto Protocol, the CDM began operation in 2005 as a way to combine the desire of industrialised countries for economically efficient emissions reductions with the need in developing countries for sustainable economic growth and development. The mechanism allows developers to finance projects in developing countries that are low-carbon and 'additional' (meaning that they would not have been financed without the CDM). The CO2e emissions[4] saved are then converted into Certified Emissions Reductions (CERs) that can be traded on the international market such as in the European Emissions Trading Scheme (EU ETS). Kyoto Protocol Annex I countries (the industrialised world) can use the CERs to help them meet their Kyoto targets while, in principle, non-Annex I countries (the developing world) receive investments that support their sustainable development. Although the CDM does not explicitly mandate 'technology transfer', it has become an important mechanism for investments in technological hardware in (some) developing countries.

Our argument in this section is that, in its effect, the technology and finance framing underpinning the CDM privileges certain pathways over others. Those privileged pathways are located in places with sufficient absorptive capacity to host low-carbon energy projects, and the projects themselves are limited to technologies that are already sufficiently developed for the profitable generation of certificates of emission reduction. These pathways do not do much for the development of low-carbon innovative capabilities in other settings, nor for the improvement of a wider portfolio of appropriate technologies. Those exceptional CDM projects that do manage to seed local innovative benefits underscore the weaknesses inherent in the more general pattern.

CDM-related pathways suffer from two interrelated difficulties. First, similarly to the technology and finance framing more generally, the CDM exploits static comparative advantages rather than building dynamic capabilities capable of transforming local contexts for development. Second, there remains a simplistic understanding of technology that has two effects: one, the focus turns to finance and hardware flows; and, two, learning and capabilities are under-supported in the mechanism. The two main arguments combine when we see that the participation of a few countries and use of just a few technologies means there is a lack of diversity from which to generate rich learning opportunities. Without such

[4] CO2e emissions (carbon dioxide equivalent emissions) include all greenhouse gases under one measure by referring to the equivalent carbon dioxide impact each gas has on the climate.

learning, it is likely that the co-benefits claimed of the CDM will not materialise. To increase the chances of realising co-benefits (environmental and social), it seems that national policy plays an important role (Disch 2010).

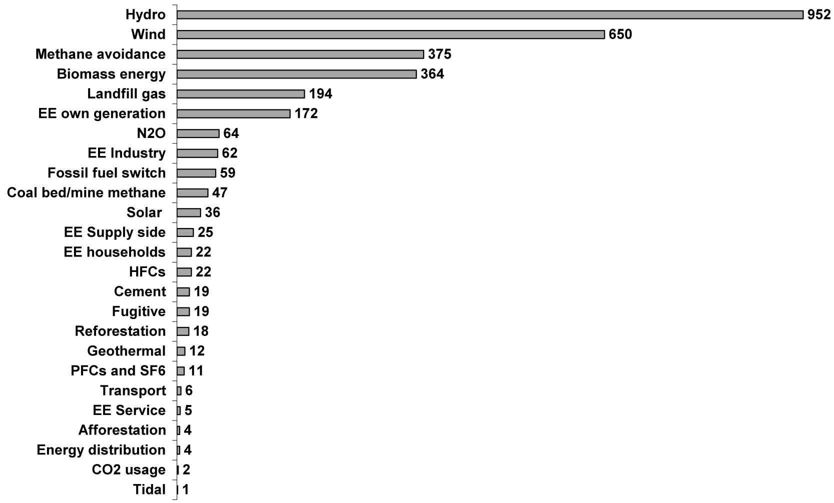


Figure 4: Number of registered CDM projects as of the end of May 2011, disaggregated by projects type (3145 total registed projects).
Source: UNEP Risø (2011)

As a market mechanism, the CDM creates incentives for firms to invest in low-carbon projects that are least-cost and/or will produce the highest returns through the sale of emissions credits. As such, ‘mature’ technologies, large-scale projects and low-risk investment environments tend to be the most attractive. Looking at the state of investments to date, we have already seen the bias towards a few countries – mainly China – but there is also a bias towards a small range of technologies. Figure 4 shows the number of registered projects by type, demonstrating clearly that the majority of projects are implemented using a small number of different technologies.

When examined in percentage terms, we can see that over 80% of the registered CDM projects are implemented using just five types of technology, only one of which could be considered a new renewable energy technology – wind – although mature relative to other new renewables. Apart from these technologies being mature – and therefore less risky – another explanation for the preponderance of them in the CDM portfolio could be that the methodologies needed for other technologies were not available until later and so prevented investments in them. However, Figure 5 and Figure 6 show the numbers of projects at validation since 2004 (Figure 5 shows the top nine project types and Figure 6 the rest). No obvious pattern suggesting any methodology bottleneck is apparent in these figures. So, although we might expect some of the explanation for the clear bias in chosen technology types to be due to unavailable methodologies, the main reason is likely to be one of technology-maturity.

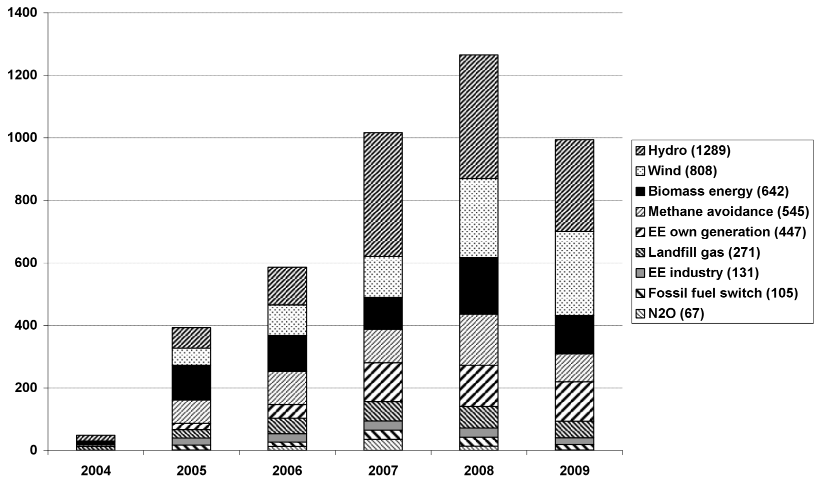


Figure 5: CDM projects at validation over time, disaggregated by project type (top nine types).
Source: UNEP Risø (2010)

In general, this preference for just a few project types is reflected in the total capacity that might be installed through the CDM. Figure 7 shows the potential installed capacity of all projects (for which power is a meaningful measure) disaggregated by type. These are not only registered projects but include those at validation and those awaiting registration. Finally, there is a dominance of large projects in the CDM portfolio. Figure 8 shows average project size by type, and average size of all projects.

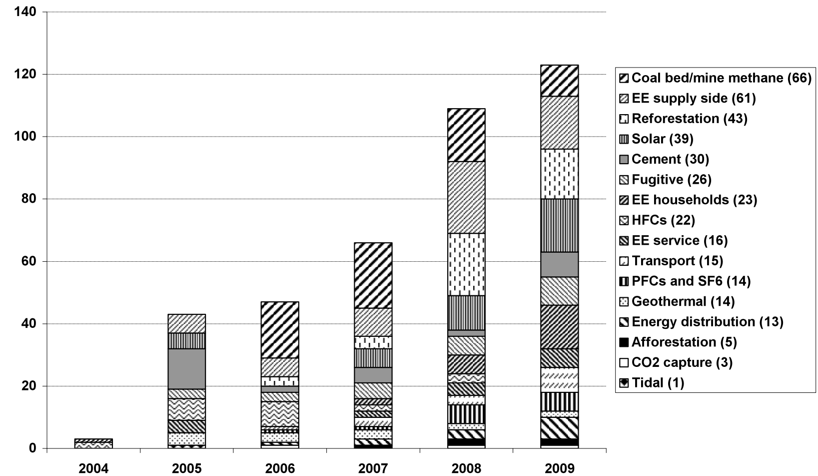


Figure 6: CDM projects at validation over time, disaggregated by project type (other 16 types).
Source: UNEP Risø (2010)

It should be clear from this brief description of the CDM portfolio that, while we need to be careful not to over-interpret project distributions, there are strong biases that result directly from the desire among the industrialised nations for economically efficient carbon reductions – the main determinant for the form the mechanism has taken. The significance of these biases is that diversity is being constrained – in terms of contexts where low-carbon technologies are being deployed, and in terms of the kinds of technologies being developed. In the short-term, there are benefits of both a public and private nature. Global public goods benefits derive from (cheaper) climate change mitigation, but the private gains are likely to be skewed in favour of industrialised-country firms. In other words, the CDM reinforces static comparative advantages. It is not transforming local contexts in a way that makes a broadening geography of locations attractive for low-carbon investment.

Consequently, the least-developed countries risk being marginalised. At worse, they may even be left with little option but to establish carbon-intensive development pathways. In the long-term, there may be little absorptive capacity for low-carbon technologies in these countries. As the need to mitigate climate change becomes increasingly urgent, low-carbon technologies may be imposed on the least-developed countries, undermining the hard-won development gains, and good development practice, of recent years. Moreover, with low absorptive capacity, there is a high likelihood that low-carbon technologies will fail in the least-developed countries, undermining climate change mitigation also. This is where the first critique is interrelated with our second critique of the CDM, an argument to which we now turn.

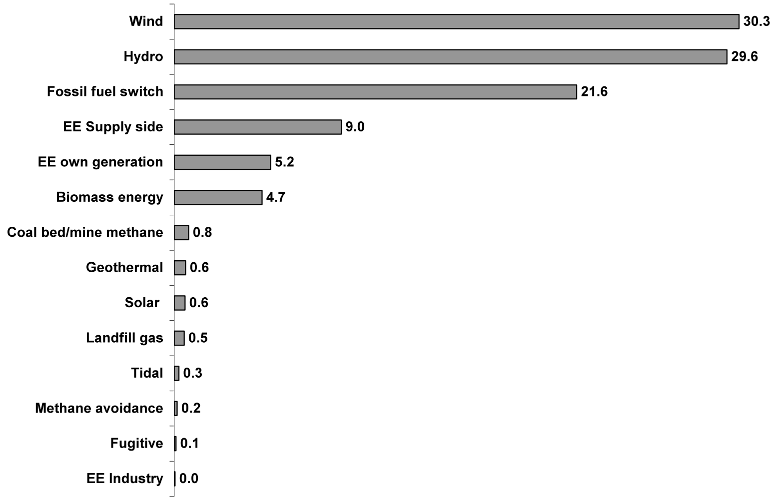


Figure 7: Total CDM project capacity by type (GW).
Source: UNEP Risø (2011)

Note a: Total capacity refers to all CDM projects for which power capacity is meaningful. These include projects at validation, those awaiting registration and those already registered. Ten project types are not classifiable using power as the measure: N20, HFCs, Cement, Forests, EE households, PFCs and SF6, EE service, Transport, Energy distribution, and CO2 capture.

A second critique of the CDM concerns the extent to which it fosters learning and the accumulation of technological capabilities, from which development can be enhanced. The critique stems from the observation that the current form of the CDM is fundamentally influenced by the narrow understanding of technology as hardware, although it accepts the need for some supporting 'software' (mainly, operation and maintenance skills). However, that supporting software, it is assumed, can be transferred with relative ease along with the hardware. This narrow view of technology partially explains the dominance of finance in international negotiations although, as Young (2002) discusses in relation to the GEF, it is also about maximising aid flows. Of course, finance is important, as without it there would be no acquisition of hardware. But, just buying equipment is not necessarily enough to realise 'technology transfer' in any deep sense of the term, and is far from our notion of low-carbon innovation l*et al*one socio-technical transformation. As we discuss below, the literature on technological capabilities shows that the degree to which absorptive capacity exists in the ‘recipient’ country (or sector) is an important determinant of the success of ‘transfer’. If absorptive capacity is low then it is difficult to adopt (and adapt, develop, design) new technological hardware; and to create the skills, knowledge, organisational changes, and institutional arrangements and linkages necessary to facilitate its sustainability. Even if absorptive capacity is high, it takes effort to adopt a new technology: that is, processes of learning must take place. In a context of low absorptive capacity, learning is much more difficult and so requires additional support (for example, longer-term training, subsidies to lower risk, complementary policies, and so on). None of this is included in the present form of the CDM, and few studies of the mechanism appear even to recognise the problem. Indeed, many studies of the CDM seem to be exclusively concerned with how much ‘technology’ is being ‘transferred’ from industrialised (or foreign) to developing countries, paying little or no attention to what this really means. An examination of the methodologies of a handful of studies reveals this preoccupation with technology transactions from which questionable inferences are made about ‘technology transfer’ (e.g. De Coninck *et al*. 2007; Seres *et al*. 2007; Dechezleprêtre *et al*. 2008; Schneider *et al*. 2008; Seres and Haites 2008).

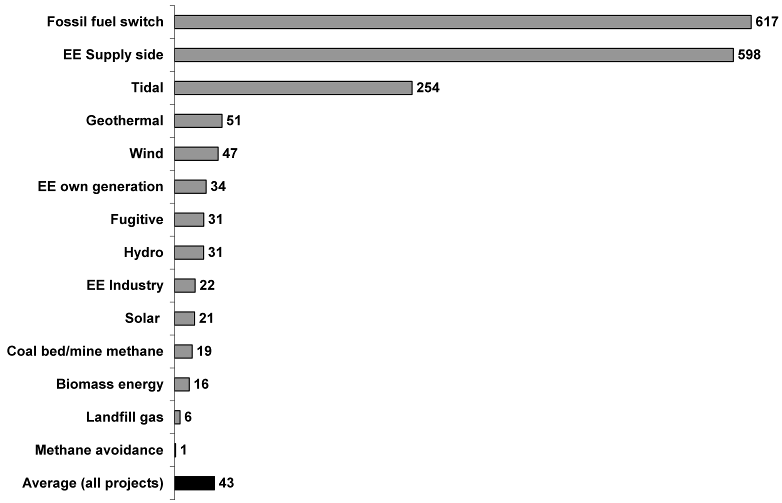


Figure 8: Average CDM project size (MW). All projects are included, where power is used as a measure of size those at validation, awaiting registration and those already registered.
Source: UNEP Risø (2011)

Two recent studies, however, use methodologies that are more sensitive to actual development outcomes. Doranova (2009) extends well beyond a review of Project Design Documents (PDDs) in the CDM to include a survey of project-implementing companies, and makes use of science and technology indicators of host countries to incorporate absorptive capacity into the analysis. The research analyses projects registered by the end of January 2007 (497 projects in 41 countries). The survey, which attempts to capture progress on technological capability building, is focused on companies in four countries[5] giving a final sample size of 104 companies. Findings of the study include: 52% of projects use locally-sourced technology and expertise, 19% use foreign sources and 22% use a combination; and foreign participation tends to be in larger projects (perhaps because of higher returns in terms of carbon credits). It also finds that, where technological hardware is sourced from elsewhere, local capabilities are important for its absorption. Once technological hardware has been acquired, there are processes of learning-by-doing that depend for their success on this absorptive capacity. Learning, however, is highest in operational capabilities, is lower for process improvement capabilities and lower still for the more advanced design and development capabilities (Doranova 2009: 40, 142). One other finding concerns the role of national policy in relation to technological learning. Across all three types of technological capability (operational, process improvement, and innovative) the analysis finds that national policy has some positive statistical significance in determining technological capability building (Doranova 2009: 130).

Disch (2010) concentrates on the so-called “development dividend” claimed for the CDM, using PDDs supplemented with primary data from the websites of Designated National Authorities (DNAs) administering the CDM process. These data are then analysed using 15 indicators that are intended to describe the environmental, economic and social dimensions of sustainable development. As a consequence, and considering the large number of criteria, the study is focused on just six countries[6] (although it investigates 122 PDDs). Perhaps the most important conclusion it draws is that the main co-benefit of the CDM is job-creation. In general, other benefits are usually weak or non-existent. The exceptional country in this regard is Peru, which has an unusual project assessment procedure that is highly pro-active. That is, the Peruvian DNA engages local stakeholders at the design stage of a project and makes on-site visits during the assessment phase rather than confine itself to a desk-based study only. The result appears to be a much higher quality CDM project portfolio than in other countries, with more co-benefits than those found elsewhere.

[5] The countries selected are Brazil, China, India and Mexico, accounting for over 70% of projects implemented and generating an initial sample size of 361 companies. The response rate of 28.8% results in a final sample size of 104 (Doranova 2009: 23).
[6] These are China, India, Brazil, Peru, Malaysia and South Africa (Disch 2010: 53).

The upshot of all this is that we know very little about the development outcomes from technology transfer in the CDM, although there is an indication that some does occur and a little is relatively deep. What is clear is that, for many, ‘technology transfer’ still means the acquisition of hardware and how much it costs. In the case of the CDM, the priority is on economically efficient emissions reductions, with an assumption – or simply a hope – that transfer of technology will take place. As a result, we have many studies that measure variables such as number and type of projects, country of origin of technological hardware, and CERs issued. Very few studies assess the more qualitative aspects of the CDM, despite claims that such co-benefits will materialise. As with a lot of the international debates, the CDM takes a very narrow framing of the transfer of technology, and as a result has no system that encourages or fosters technological capability building and self-reinforcing low-carbon development processes. Consequently, any low-carbon development that does occur is more the result of good fortune than of framing or strategy.

This disappointing picture is, to an extent, an overstatement on our part. The interest in co-benefits clearly indicates hope for the importance of CDM projects beyond carbon emissions trading and revenues. There are projects and discussions where a deeper and broader framing of technology transfer linked to local development is in play. The technology and finance framing of the energy challenges can be enriched here by insights from decades of research and debate about technology transfer and industrialisation, and from which some of the above evaluative concerns about technological capabilities arise.

However, when we begin to consider processes beyond the narrow (and static) framing of technology and finance, it becomes apparent that the transformation of contexts for low-carbon innovation is important. In other words, incorporating capability-building processes into a technology and finance frame is possible in principle, but it changes the understanding of energy systems in low-carbon development so much that ‘technology transfer’ no longer does justice to the goals. A socio-technical transitions approach provides an alternative framing capable of incorporating broader processes, and with a transformation of contexts in mind. This is the focus of our discussion in the following sections. However, we first need to consider some of the processes beyond the technology and finance frame.

6. What the technology-finance framing underplays: capabilities, contexts and political economies

Alongside, interwoven with and, at times, underpinning the international negotiations over technology and finance has been a growing academic literature on technical change in developing countries. We can identify, for our current purposes, two important streams in this literature: one concerned with industrialisation and the cultivation of indigenous innovative capabilities; the other often concerned with the adoption of energy technologies in the household but linking to industrialisation more generally. We will review these two streams here in order to argue that they provide us with many useful insights regarding how the building of technological capabilities can be achieved in developing countries. Relatedly, we unpack the framing of the idea of 'technology needs' within international policy. This facilitates insights into why certain conceptions of low carbon development, which are less oriented around the needs of indigenous firms and households in developing countries, are sustained by the dominant hardware financing policy approach.

One of the guiding assumptions of this paper is that developing countries need to be accumulating their own low-carbon innovation capabilities if we are to see both sustainable development succeed and to avoid dangerous climate change. Our reviews will reveal the complexities of the challenge of building technological capabilities, in stark contrast to the often simplistic understanding reflected in international negotiations (and mechanisms). However, we will also argue that this literature has yet to synthesise these insights into a broader framework that can incorporate the political economy of technology together with the micro-details of capability-building in firms and among other actors, and their integration into sustainable innovation systems.

6.1 Technical change and industrialisation

From the 1960s to the mid 1970s, technology transfer from industrialised-country firms to industrialising-country firms was assumed to be largely an event rather than a process. Even understood in this way, the term 'transfer' is something of a misnomer, considering that it was about buying technology and so would be more accurately described as 'transaction' (Bell 1997). In any case, as a result of this 'event' view of 'technology transfer', the primary focus of concern from the perspective of developing countries was on cost and contractual terms (Bell 1997; Radošević 1999). This concern was not unreasonable in itself, particularly as studies of the purchase of technology revealed that the costs to developing countries were often high and contractual terms severely restrictive. In response to these revelations, many developing countries were pre-occupied with establishing or strengthening institutions that could negotiate better prices and terms on behalf of domestic firms, the results of which have been judged to be mostly successful (Bell 1997; Radošević 1999).

Notwithstanding these few successes, during this early period, it was increasingly clear that the returns to 'technology transfer' were highly uneven across the developing-country economies (Bell and Pavitt 1993). It had been assumed that technologies purchased from the industrialised economies would automatically, and un-problematically, enable industrialising-country firms to perform to the same level of productive efficiency as firms in the developed economies (Bell and Pavitt 1993; Bell 1997). This assumption had some validity during the early period, as initial productivity gains were indeed experienced by developing-country firms following the acquisition of technology from the developed-country suppliers. But the assumption became increasingly questionable over time, with two sets of reasons given to explain uneven outcomes. First, the nature of technology was changing (see below), and changing at accelerating rates (Bell and Pavitt 1993). Second, the gains were primarily the result of efficiency improvements in sectors for which any particular developing-country economy happened to enjoy an initial comparative advantage (Bastos and Cooper 1995; Bell 1997; Radošević 1999).

With regard to the changing nature of technology, the understanding during the period to the mid 1970s had, in effect, been blind to the processes by which artefacts had been 'transferred', diffused, adopted and adapted. This blindness was, at least in part, the result of a narrow conceptualisation of technology (as hardware) and a misconception of the use of technology as a 'plug and play' phenomenon by an essentially passive recipient. The concept of technology simply as hardware prevents recognition that knowledge is embedded within its design and functionality, as well as deeper cultural assumptions that underlie that embedded knowledge (Pacey 1983; Bell and Pavitt 1993; Wynne 1995). The increasing intensity of this knowledge-embeddedness is an important explanatory factor of the highly uneven record of technical change, as we discuss below. Overlaying this was a growing recognition that the domestication of any given technology also involved a considerable amount of 'tacit' knowledge that accumulated through use and experimentation, and could not be codified in user manuals (Bell and Pavitt, 1993). The 'plug and play' misconception neglects the importance of subsequent processes of technological adaptation by those using the technology. As Barnett (1990: 543) states, with respect to the developed countries:

> "… much of the increase in productivity in industrialized countries is achieved through the aggregation of myriads of minor changes to existing production processes (rather than from individual massive jumps in productivity achieved through investment in new vintages of technology)."

The two misconceptions are, of course, related. If knowledge is embedded in technological hardware (and processes), as well as tacit knowledge requirements to get the technology to work effectively, then the ability to change hardware (or processes) depends significantly on understanding the processes of knowledge accumulation and related capability building. In short, the absorptive capacity[7] (of a firm, sector, country) is important to be able to adopt and adapt technological hardware. Bell and Pavitt (1993) argue that the early period of technology diffusion-adoption was characterised by hardware that was sufficiently 'light' on knowledge-intensity that operating such equipment provided opportunities to understand the embedded knowledge and so be able to make successful modifications to the hardware or processes. Over time, the knowledge-intensity of technology has been increasing, as has the degree of specialisation and the extent of differentiation of industrial production equipment, knowledge and services, along with an increasing optimum scale of production. The effect has been a "widening gap between … technology-using and technology-changing skills [which] has reduced the possibilities of acquiring the latter largely by experience in the former" (Bell and Pavitt 1993: 164). Box 2 gives a simple illustration of the increasing knowledge intensity of technology in the case of boilers for coal-fired power generators.

While gains may have been realised through improving and adapting technologies purchased elsewhere, they were nevertheless along existing technological trajectories. The gains may well have been valuable – we do not wish to argue that efficiency improvements are not worth pursuing – but they were associated more with growth than development, where 'development' in this sense is understood to mean movement along new technological trajectories and/or the process of enhancing capabilities to create new trajectories. Moreover, there are limits to the gains available through efficiency improvements – or at least diminishing returns – and there are potential 'rebound effects' that could raise the aggregate demand for resources and increase the production of pollution (Sorrell 2007). Many scholars have argued, and continue to do so, that the conflation of growth with development means that we miss the distinction between the ability to make progress along an existing trajectory (growth) and the ability to create a new trajectory (development). Both abilities are important for economic activity, but the creative ability is a necessary condition for a country to realise its own low-carbon pathways. Without these dynamic technological capabilities, it is difficult to see how developing countries could do better than exploit existing static comparative advantages, as seems to be the case for the CDM, and from which they run the risk of becoming 'stuck' on low-technology – low value-added – development trajectories (Bastos and Cooper 1995; Radošević 1999; Khan and Blankenburg 2009).

[7] The concept of absorptive capacity captures the degree to which the knowledge and skills necessary to adopt a technology, or understand and make use of new technical information, are present in the adopting firm, sector, country, etc. The idea is that the higher the absorptive capacity, the more readily a technology or new information can be adopted (Cohen and Levinthal 1990).

Box 2: Increasing knowledge intensity of technology

A simple example of the increasing knowledge-embeddedness of technologies can be seen in the boilers for coal-fired power plants. Learning to manufacture boilers was relatively easy to do on the basis of learning-by-using. Drawings and explicit design processes were available, and the skills for manufacture could be developed to a large extent through operation, repair and maintenance. Indeed, many firms in developing countries such as China are now able to manufacture boilers competently. However, the most efficient boilers are now designed using computer-modelling. The knowledge and skills necessary for this kind of design are no longer easily imitated or accumulated through learning-by-using. Instead, such knowledge and skills are embedded in boiler hardware through opaque (to the user) design processes hidden in computer software. This design 'edge' has been closely guarded by some industrialised-country firms, active in China through 'technology transfer', as a way to maintain their market power while exploiting lower manufacturing costs (Watson *et al*. 2000). No amount of operating, repairing and maintaining such boilers will afford opportunities to understand the computer models used to design them. That would require training and experience in the design processes themselves, working particularly with those who are skilled and knowledgeable in using those processes.

The discussion so far has been confined to the technical characteristics of technologies and technical change. But, as Bell and Pavitt's (1993) observation of the knowledge-intensity of technologies implies, the infrastructural dimensions of technical change also need to be considered if we are to see the successful development of technological capabilities. Indeed, this is already incorporated into the Bell and Pavitt definition of technological capabilities, which includes "institutional structures and linkages" (Bell and Pavitt 1993: 163). This need to consider infrastructure is underlined if Bell and Pavitt's observation of increasing specialisation and differentiation is an accurate one. That is, if the various 'functions' of technical change – "e.g. … design, production engineering, quality control, R&D, and … basic research" (Bell and Pavitt 1993: 201) – are being located increasingly in specialised firms and organisations then the form and quality of the linkages between them are becoming increasingly critical to the functioning of each, and to the functioning of the 'whole'. Not only this, but the increasingly specialised knowledge required for creating technical change suggests that developing-country training and education systems need to receive sustained investment and strategic development. Box 3 attempts to show how concerted effort in India led to the building of an indigenous photovoltaic (PV) industry that now exports to industrialised countries. While there could be many improvements to the capabilities of Indian PV firms, and to the capabilities of the local industry and its 'innovation system' in general, it is clear that links between the various actors relevant to a particular sector are important, both locally and internationally.

Whether we conceptualise the group of firms and organisations, together with their linkages, as supply or value chains, clusters, networks, or systems, we cannot assume that functional relationships will emerge spontaneously. Moreover, experience demonstrates that even deliberate fostering of these linkages needs to be realised carefully and with some understanding of sequencing. Bell (1997) argues this with reference to a number of studies, from as early as the 1970s, focused on a range of countries in Latin America and East and South East Asia. Citing the work of Katz and colleagues (Katz 1987), and research conducted by Hobday (1995a, b) and Kim *et al*. (1989), Bell discusses two different sets of approaches to establishing inter-firm and organisation linkages; one based on centralised R&D services and the other more sequenced along a ‘simple’ to ‘complex’ trajectory. The centralised approach, in which R&D organisations were expected to conduct research on behalf of private firms, was unsuccessful, largely because the R&D organisations and private firms were unable to communicate with each other. That is, private firms, without sufficient existing technological capabilities, were unable to articulate their technical needs in a form that the R&D organisations could use to focus their research, and R&D organisations were not necessarily interested in the technologies that the firms were using. So, while the ‘pieces’ of an ‘innovation system’ were in place, from the perspective of technological capability-building, the system was disarticulated and dysfunctional. In the sequencing strategy, there was considerably more success. As Bell (1997: 75) puts it:

> “… dynamic technological capabilities are cumulatively built ‘upwards’ from simpler to more complex design, engineering and managerial competences, not ‘downwards’ from R & D.”

The building of technological capabilities, then, is an increasingly complex process that involves micro-learning experiences within firms, supported by articulate interactions with other firms and organisations, each drawing on the human resources available from training institutions at all levels, highly cognisant of user-needs, and is resource-intensive and long-term. But this complex picture is not ‘complete’ without recognition and understanding of the role of policy and the implications of such for the dynamics of what we could call political economy.

The simple argument supporting this assertion lies in the observation that any state looking to create and exploit technological trajectories, which do not begin from static comparative advantages, cannot rely on market forces to produce the desired outcomes (Bastos and Cooper 1995; Bell 1997; Khan and Blankenburg 2009). Following from this observation, the state must therefore intervene in some form to encourage the creation of those trajectories. That will mean a variety of actions that could include new policies, legal and regulatory measures, and the commitment of resources. Any one of these actions will require political choices, with consequent challenges to existing economic and political interests as well as raising opportunities for new interests (Barnett 1990). In the context of developing countries, we should not forget that donors, and the multilateral development institutions, will also play significant roles in these dynamics. We could, therefore, conceptualise interacting and interdependent levels of political economy from the village to the international arena. And, if we accept this line of argument, crucial issues of framing, legitimacy and governance immediately come into view (see section 3 on pathways): How are technological trajectories (and associated pathways) to be identified? Who decides which pathways to encourage, who benefits, who loses, and so on? Whose voices are most influential in the interactions from which pathways emerge? Box 4 provides an example of interacting levels of political economy in the context of biofuels in Brazil and beyond.

Box 3: The development of an Indian PV (photovoltaic) industry

Drawing on Mallett *et al*. (2009) and Haum (2010), who analyse the development of PV production capacity in India, we can see an example of the importance for inter-linkages between firms and other actors, and the deliberate fostering of these links and supporting infrastructure.

In the mid 1970s, the Government of India (GOI) began supporting the development of an indigenous PV industry. Under the Solar Photovoltaic Programme (SPP), state-owned enterprises were assisted to build R&D, test and production facilities, including the indigenous construction of PV manufacturing equipment rather than its purchase from abroad. In the 1980s, one of the state-owned enterprises sent operations staff for training and experience with a US PV manufacturer. Private firms were allowed to enter PV cell and module production at the end of the 1980s, and the GOI began to use incentives for PV production such as tax exemptions and procurement of systems for various communications applications. From the mid 1990s, the GOI began to reduce its procurement for communications but instead supported PV through its rural electrification programme. The rural electrification programme only partially exploited the production capacity now available and so private firms began to export PV hardware. Over time, these export markets have become more important to the private sector than the rural electrification programme, and the GOI continues to support the PV industry through industrial policy.

The international links that PV firms have been able to develop, through various means, have enabled them to continue to enhance their technological capabilities. Indian firms have used the networks developed through training staff overseas to keep up to date with technological developments; and they have used a number of ways to get access to technologies where IPRs remain a potential ‘barrier’, including the use of licensing, collaboration and acquisition, and in-house R&D. While these international links have been important to the development of the Indian PV industry, there are some firms who believe that the GOI could do more to help them by supporting the local infrastructure. In particular, this support could be in the form of more R&D facilities that could make use of the engineering skills available in India and at lower cost than those in industrialised countries.

We can see from the example in Box 4 not only the importance of political-economic analyses for understanding how power and politics shape the direction of technological capability building, but also some of the potential benefits and dangers of policy interventions that seek to create or strengthen particular technological trajectories or pathways. That is, we can see that incentives of various kinds generate, in effect, 'rents' that attract rent-seekers who may become powerful constituencies that are difficult to manage when attempts are made to remove those rents. However, we should not necessarily see this as an argument against rent creation per se. Khan and Blankenburg (2009), for example, argue that a more useful approach would be to consider the compatibility of such policies with their internal and external political-economic contexts, and that any state making use of rent-creating incentives needs to develop rent-management capabilities.

Box 4: Biofuels and interacting levels of political economy

An illustration of the interacting levels of political economy is provided in two papers on biofuels; one concentrated on Brazil (Lehtonen 2009), and the other at the international level but with particular attention to Brazil (Dauvergne and Neville 2009). Lehtonen (2009) analyses a complex set of political-economic relationships and dynamics within Brazil's bioethanol sector, which started in the 1960s when sugarcane received increasing state support as part of the drive for economic development. Bioethanol was initially a by-product of sugarcane production sold into a niche market but became increasingly important during the 1970s, as Brazil attempted to reduce its oil consumption but maintain its car manufacturing industry, while cane producers looked for new markets in response to the steep decline in world prices for sugar. In the process, two centres of ethanol production grew in the country: one in the northeast, where there was a long-standing dependence on sugarcane production and where little modernisation of production was realised; and one in the southeast, around São Paulo, where a more modern bioethanol sector was developed. The sector benefited from a number of state-supported measures, including investment subsidies, price controls, import protection, R&D programmes, and others, resulting in increasingly powerful economic interests with political influence, and further concentration of land-ownership in both the northeast and São Paulo. However, from the mid 1980s, with the rise of democratic values and market liberalism, and amid falling oil prices and a deepening debt crisis, disillusionment with the military government and power struggles within the bioethanol sector resulted in severe cuts to subsidies and the closure of many production units (130 in the period 1987 to 1997). The balance of power within the sector shifted in favour of the producers around São Paulo where some policy-help continued (the share of ethanol in petrol was maintained), because of the employment and environmental benefits associated with ethanol-powered vehicles.

The sector enjoyed a resurgence around the beginning of this decade as "energy security … record-high oil prices, increasing concern for climate change, and the introduction of the flex-fuel car" have driven local and international policy agendas (Lehtonen 2009: 7). However, this resurgence faces a new challenge as the initial international enthusiasm for biofuels in general has turned to fears that their expansion will "drive up food and land prices, and increase pressure for land conversion and deforestation" (Dauvergne and Neville 2009: 1088). These doubts have contributed to political and economic struggles internationally. Dauvergne and Neville (2009: 1091) point in particular to the discussions within the EU over biofuel policy and how these can be broadly classified into producer and consumer camps: those countries who stand to gain from biofuel expansion and those who stand to lose. In response to the uncertainties for the sector caused by such struggles, Brazil has been seeking partnerships with other biofuel leaders (notably the US) and new markets in developing countries where, it is suspected, the concerns over land, food and other environmental impacts will be overshadowed by increasing energy demands to power economic growth.

This brief review of the industrialisation stream of the literature on technical change in developing countries demonstrates that 'technology' is more than hardware. However, its expanded understanding has not reached further beyond processes of knowledge and capability accumulation between firms. But, as sections 2 and 3 emphasise, one needs to broaden the analysis further in order to understand how firm-derived energy technologies go out and induce or become domesticated within broader development processes (also Smith *et al*. 2010). This becomes more apparent when we turn to household energy practices in the next sub-section.

Recognition that technology can be dimensioned in a more sophisticated socio-technical way than hardware yields important insights into the challenges of building innovation capabilities in general, and not just in narrow, firm-based innovation systems. This is so even when there are static comparative advantages that can be exploited. Technological artefacts are embedded with knowledge and cultural assumptions, require skills for their use, and are situated in systems of interconnected and interdependent actors, including users of the technologies and people reproducing energy service practices, as well as civil associations and others in the broader social milieu.

Furthermore, the direction of technical change is significantly influenced by an institutional environment (rules, regulations, laws, policies) that co-evolves with political and economic interests at all levels from the local to the international. This environment is even more critical in cases where no static comparative advantages exist; where new development pathways are to be created, with particular technological trajectories at their heart. These are generally the conditions that apply in the case of low-carbon development or innovation. That is, where there is only weak or no logic of simple economic efficiency, the building of innovation capabilities needs careful nurturing. Low-carbon technologies are usually in this category and, moreover, are still perceived to be radical and therefore risky. The literature reviewed above tells us that this is a long-term endeavour requiring interventions on multiple dimensions while facing powerful interests. It seems to us that a technology and finance framing that is expanded to try and incorporate all these other processes actually becomes a very different framing of energy challenges altogether. It becomes a framing concerned with the manifold, and multi-levelled processes of socio-technical transformation, that includes the development of distributed capabilities, supportive infrastructures, and political economies all favourable to the pursuit of low-carbon development pathways.

These insights are from the perspective of industrialisation. The other end of the development spectrum, so to speak, is at the household level and focuses on the adoption of small-scale technologies that convert energy into useful household services. The next section reviews this literature briefly and finds that there are similar 'pathways-relevant' insights to those emerging from the industrialisation literature. From here, we will be able to argue in section 7 that we can begin to synthesise these insights into an integrating socio-technical transitions framework. Once we have presented these ideas, we will be able to identify the issues that emerge from all our discussions to point to an ambitious research agenda.

6.2 Rural household energy services and development

The energy-development relationship in the context of the household has also received a great deal of attention in the literature, focused primarily on technology fixes that could avoid or reduce the use of oil. That concern grew out of responses to the oil crises of the 1970s, which led to an increasing awareness of the energy needs of households in developing countries and the understanding that these were being met largely through the unsustainable exploitation of biomass (Goodman 1984: i; Gill 1987: 135). Consequently, more efficient or renewable energy conversion technologies were thought to be necessary to tackle this problem. Within the household context, therefore, technical change has been discussed in terms of technology adoption and the economics for users of particular technological choices. Nevertheless, alongside these concerns for economic efficiency, there is a significant discussion of the prospects for local manufacture of various technologies and the implications of such for industrial development[8] (Barnett 1990). However, for the purposes of this discussion, we shall concentrate on the adoption aspects of this literature, leaving aside the concerns for industrialisation, notwithstanding the note already made of the linkages between household energy needs and demands, and the possibilities these afford for local commercial growth and development.

According to Barnett (1990: 542), the early research on adoption of technologies was mainly "focused on the social-psychological aspects of the diffusion process and … the personality traits of the adopters", a useful approach but "flawed by neglect of the characteristics of the technology being diffused". However, this was not an appeal to shift to a purely technocratic understanding of adoption. Discussions in the literature were beginning to acknowledge that technological artefacts include embedded knowledge and cultural assumptions (Pacey 1983, cited in Green 1999: 1134; Bell and Pavitt 1993); one implication being that differences between the 'content' of a dimension – the embedded content of the artefact versus the embodied content of the user – were sources of tension and potential failure in technology-adoption processes. Whatever the merits of this multi-dimensional view of technology, empirical studies of technology adoption suggest that the technical characteristics of an artefact are not necessarily the primary determinant of success or failure, assuming the artefact at least performs reasonably well.

For example, improved stoves have been introduced through many projects around the world with the intention to reduce the amount of wood consumed and the amount of smoke produced in kitchens or homes[9] (Gill 1987). While there have been notable successes of the dissemination of improved stoves, such as the Kenya Ceramic Jiko (Jones 1986), other interventions have failed. Gill (1987: 138) describes how stove programmes in villages in a number of countries emphasised fuel economy whereas the villagers, among other needs[10], "were more concerned about being able to cook quickly than about fuel efficiency".

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[8] The latter point highlights how it is somewhat artificial to completely separate the energy-development relationships of the household sector from those of industrialisation.

[9] The perceived benefits being reduced deforestation and wood-collection, as well as less smoke produced in the home or kitchen leading to health gains. Gill (1987) questions some of the assumptions behind these efforts, suggesting that traditional cooking techniques are often more efficient than believed and the main cause of deforestation is land-clearance for agriculture rather than wood-collection for fuel. Moreover, many of the 'improved' stoves did not result in efficiency gains and could produce more smoke than open fires, if used incorrectly. This is not to denigrate the aims of these projects; it is to illustrate that technological artefacts are embedded with assumptions that may not be robust across different contexts.

[10] Some of these other concerns include: versatility, where the stove needs to be able to accept a wide variety of combustible materials; multi-functionality, where the stove may be used for space heating and light (and, indeed, smoke may be useful as it deters insects and can cure food); and social and symbolic values that outweigh improved cooking efficiency (Gill 1987: 138-139).

If the energy source for lighting is kerosene or some form of biomass then there can be serious impacts on health. Not only do health problems detract from the quality of life directly but they also have implications on productivity and income: visits to doctors who may be far away will reduce time available for productive activity and so reduce personal income (and labour-productivity in the commercial sector); and there may be fees for seeing doctors and the costs of medicines.

Furthermore, many researchers and practitioners were already pointing to broader issues in technology transfer-adoption processes that have important influences on success or failure outcomes, as well as less instrumental concerns such as equity and legitimacy[11]. In terms of the more overtly instrumental, Green (1999: 1134, following Aasen *et al*. 1990) describes these broader issues as constituting "the larger web of technical infrastructure", particularly the organisational framework of "transfer", and the organisational and technological infrastructure of the "receiver country". The organisational framework refers to whether a technology is introduced through a project or firm (or some combination); the technological infrastructure refers to systems that support the functioning of a technology such as the general level of technical education, maintenance skills, and so on; while the organisational infrastructure refers to systems that support planning, coordination and management of technical change processes (Aasen *et al*. 1990: 31-33). The infrastructure cannot be taken for granted and can often be missing or weak in rural areas of developing countries, requiring the prolonged and purposive training of managers, technicians and others in supply and support services if technical change is to be somehow sustainable (Hankins 1995: 119-120; Green 1999: 1134).

But, so far, we have only considered the literature in terms of the supply-side of the technology adoption process. On the side of demand, the literature also has important insights to convey. As much as technology includes a broader infrastructure of supply – managerial, design, installation, maintenance, and repair skills and systems – so the demand side involves supportive skills, knowledge and the capabilities to articulate the needs of users. In the rural areas of developing countries where there can often be little experience of anything but the simplest technologies, such skills, knowledge and capabilities tend to be lacking. In such circumstances, it is unrealistic to expect a user to be able to know how to choose, operate or maintain a solar home system (for example) without some degree of training (indeed, much the same could be said for wealthier countries where technologies such as solar home systems are also unfamiliar). Such training can be given – by an installer, perhaps – but this is a 'shallow' form of the articulation

[11] Our use of the phrase "less instrumental" is deliberate: the issues of equity and legitimacy, while clearly rooted in a moral concern, are linked in a substantive sense to the instrumental. An argument for this includes the idea that users will not willingly adopt, in the long term, artefacts that worsen their equity or for which they cannot identify any legitimacy. They may adopt such artefacts in the short term, or under coercion, but the tensions generated will lead to failure in the long term.

of user needs. A deeper form would involve users early in the adoption process – and ideally in design – increasing the chances that an artefact would be suited to a user's needs. In this sense, the literature talks of participation (Barnett 1982, 1990; Agarwal 1986; Heidenreich 1993; Green 1999).

Box 5: Two approaches to the design and diffusion of wood-burning stoves

Two approaches to wood-burning stove dissemination projects, cited in Agarwal (1986), illustrate the difference that user-participation can make. The first concerns an attempt in the late 1960s in Ghana to replace open fires in household kitchens with more efficient (and cleaner) wood stoves. There had been no interactions with users prior to design of the stoves, a weakness in the project that only became apparent much later when it was found by the mid 1970s that many of the stoves originally installed were no longer in use. Agarwal (1986: 77) quotes a vivid description, given by Hoskins (1979: 37), of the effect that the lack of understanding amongst the project implementers of cultural and cooking practices had on the stove design:

"If they had tried cooking in 1½ ft tall kettles, constantly stirring mush for ten people with a large wooden paddle, they would not suggest waist-high wood stoves (unless they also added step-stools), flat bottomed pans (which burn around the edges) and lids (for pots requiring constant stirring)."

There were other problems too. The stove used larger pieces of wood than open fires for which the women had to search further afield, increasing rather than reducing their burdens. And, if the stove was used 'incorrectly' – that is, using loosely fitting pots or not covering all the holes of the stove – it would burn more wood and cause more smoke than an open fire.

By contrast, Agarwal (1986: 83) reports on a more intensively interactive stove design-diffusion approach in north-west India undertaken by Madhu Sarin and described in Sarin (1981). Quoting Agarwal (1986: 83):

"Each stove, built from local clay, was made user-specific in terms of its location within the kitchen, its size, the cooking routine of the family, the number of pot holes, the size of the pots and the overall aesthetics of design. The stove was usually built jointly by Sarin and the female members of the household, with other village women sometimes helping in or observing the process. Modifications were made after the user had utilized the stove for some time and found some aspects unsatisfactory."

A number of benefits apparently followed this method of 'diffusion'. These included: high acceptance and satisfaction among users, with subsequent informal dissemination among family, friends and neighbours; the development of capabilities to build stoves without the assistance of Sarin; and technical success in terms of less wood burned, as well as increased ability of users to modify and repair stoves themselves.

In addition, much of this presumes a willingness or even enthusiasm for adopting new energy technologies. A socio-technical perspective considers these technical changes in the light of prevailing energy practices, in which often invisible routines of daily life nevertheless contain significant ideas and norms about certain energy services, like thermal comfort, and the normal ways for fulfilling them. As well as requiring skills to perform those services with the given technologies, this is as much about the socio-technical evolution of social norms. Low-carbon practices are about unsettling and re-configuring the tightly coupled links between skills/capabilities in relation to meanings/ideas in relation to technologies/things (Shove 2003).

Finally, the energy-development relationship in the rural household context does not escape the influences of political economy. Once again, many researchers and practitioners point to the importance of this aspect (Barnett 1982, 1990; Agarwal 1986; Heidenreich 1993; Green 1999; Smits and Bush 2010). These influences can operate at different levels – from local to international – and interact across those levels. For example, Agarwal (1986: 91) discusses the impact on information flow of extension work biases towards “the economically and socially privileged households” who tend to be targeted with innovations while poorer households are ignored or treated condescendingly. Barnett (1990: 549) notes that “the government of the Philippines took no action to subsidize the diffusion of wood stoves, because it was felt that such action would inevitably undermine the already thriving stove production industry”.

An illustration of the interplay of domestic and international political economies is given in Smits and Bush (2010), where they argue that the Lao government have been neglecting the potential for rural electrification of pico-hydropower[12] because of a combination of interests of national and international actors. The government’s focus on the development of large hydropower has enabled the centralisation of control of water resources, provided opportunities to claim equity shares between 20-25% of the projects, plan to supply electricity to neighbouring countries, secure large-scale funding opportunities from development banks, and maintain a “command and control” policy environment. Where the government is concerned with off-grid provision of electricity, it appears that the focus is on Solar Home Systems (SHSs). The implication in the Smits and Bush paper is that this focus on SHSs results from the dominance of “a small group of actors led by the

[12] Smits and Bush (2010: 116, note 1) use the term “pico-hydropower” to refer to electricity generated from the flow of water, and to a maximum of 1 kW for use at the household level.

[Government of Lao] and the World Bank" (Smits and Bush 2010: 120), the funding of the subsidised SHSs coming from the GEF. Meanwhile, there is estimated to be about 60,000 pico-hydropower installations in the country (in contrast to about 6,000 SHSs) but development and promotion of the technology, the authors argue, is being neglected because of the desire of multilateral development actors for a single rural electrification model, and the government's interests of centralisation, and "maximising foreign investment and export revenues" (Smits and Bush 2010: 126).

6.3 Technology 'needs'

A final issue that warrants consideration in relation to current framings of technology transfer and low-carbon development is the idea of 'technology needs'. Aside from the hardware financing policy mechanisms implemented under the UNFCCC, activities under the Convention have also included the introduction of a process encouraging developing nations to produce Technology Needs Assessments (TNAs). These are supposed to form a basis against which policy actions to facilitate technology transfer under the Convention can be focused, although there is little clarity as to how this integration of TNAs with delivery mechanisms is expected to occur. In reality, as demonstrated above, the production of TNAs has very little to do with what technologies are transferred to which developing countries – this is more an artefact of the hardware financing architecture of international climate change policy which has led to an uneven geographical distribution of a limited number of technologies. Nevertheless, within a pathways perspective of low-carbon development, the idea of technology needs – how they are framed, and by who – forms a useful focus for analysis and raises important questions regarding the nature of policy mechanisms and whose interests, or 'needs', they serve.

The discussion in the previous two sections constructs two different levels at which technology needs might be considered – at the level of industrial development or at the level of household technology uptake. At both these levels an implied desire to increase the general use of low-carbon technologies is evident. Importantly, at both levels (industry and households), the analysis above demonstrates a tension between different framings of the nature of technology needs and, relatedly, how they might be met. On the one hand, needs might be framed around a need to finance the uptake of foreign produced technologies, either industrially or among households. At the industry level this framing justifies the kind of hardware financing approach that characterises international mechanisms such as the CDM. It also justifies a similar external hardware financing approach at the level of households: e.g. the dissemination of externally manufactured cook stoves in

Ghana that burn less wood (see Box 5 above). The alternative framing of these issues discussed above centres around a need to develop indigenous capabilities in developing countries, whether at the level of innovation capabilities among developing country firms, or the capabilities of households to participate in the development and implementation of new technologies (e.g. the capabilities to build more efficient cook stoves from locally available materials that fit the social practices of their families and facilitate knowledge transfer to others in their communities).

In line with the pathways approach, it is clear from the different framings of technology needs above, and the different policy approaches they imply, that these framings have important implications for the concentration of power and benefits stemming from alternative policy options. For example, efforts aimed at increasing capabilities amongst developing country firms or households imply more networked, participatory, user engaged policy approaches. These in turn imply (although cannot guarantee) that power is likely to be more diffuse with perhaps more power for developing country firms or technology users and communities to play a role in constructing their own visions of appropriate technologies and related development pathways. From a political economy perspective, this also implies an important shift in the balance of power away from advanced technology owning firms who were previously based predominantly in industrialised countries (and in the main continue to be, aside from exceptions amongst the BRICS countries).

The idea of a North/South power balance and the way in which different framings of technology needs serve different parties' interests also speaks to a broader tension within international negotiations on technology transfer that relates to different conceptions of what low-carbon development is, and the role of technology within it. If, for example, the key concern of low-carbon development is to meet the needs of the global community to reduce greenhouse gases as fast as possible, then technology needs might be framed as a need to achieve the widest possible diffusion of low-carbon technologies across developing countries, regardless of in which developing country or where and by whom within these different countries technologies are adopted, or whether or not firms and households in developing countries, as opposed to international technology leading firms, have any ownership over these technologies. If, on the other hand, low-carbon development is seen more as a way to increase the aggregate economic wealth of developing countries (often seen as synonymous with development) then technology needs might be framed as a requirement for developing country firms to own, operate and produce low-carbon technologies as part of an economic development pathway underpinned by the increased international competitiveness of indigenous companies. Indeed, these broad diffusion vs. development framings are good characterisations of the discourses that continue to play out within international policy negotiations on climate change and technology transfer (Ockwell *et al*. 2010). However, both framings are ignorant of a multitude of context specific issues, raising further critical questions relating to framings of technology needs.

For example, the geographical insensitivity of the 'rapid diffusion' framing ignores the possibility discussed further above of LDCs becoming locked-in to high carbon pathways. And both framings (rapid diffusion and increasing aggregate national wealth) ignore the issue of whose needs low-carbon technologies might meet. In poor rural areas, for example, low maintenance configurations of solar energy and LED (light emitting diode) technologies might better serve the needs of households than low-carbon grid-based electricity generation which might better suit the interests of urban industries situated closer to sites where power is generated. Both framings (rapid diffusion and increasing aggregate national wealth) also risk a fixation on hardware, and ignore the role that knowledge flows can play, both in underpinning sustained low-carbon industrial development by building indigenous innovation capabilities, or by improving the resilience of poor and marginalised people's livelihoods, such as by the transfer of knowledge of less energy intensive farming practices. As these examples imply, this hardware fixation also ignores the socio-technical nature of technology use and innovation.

A final aspect of the framing of technology needs that warrants attention here is the extent to which international policy approaches recognise the role that technology transfer oriented initiatives might play in meeting broader development goals than simply 'low-carbon' development. Within the UNFCCC's guidelines for the production of TNAs, a definition is employed that alludes to low-carbon technology needs as relating to more than simple greenhouse gas mitigation or climate change adaptation. Technology needs are also seen as relating to the role low-carbon technologies can play in "contributing to sustainable development goals" (Gross *et al*. 2004). Indeed, the UNFCCC and Kyoto Protocol are both more broadly framed around a commitment to sustainable development alongside the achievement of climate change mitigation and adaptation. A key way that broader development goals might be considered in relation to technology needs is via engagement with stakeholders when producing national TNAs, thus providing an opportunity for the reflexive appraisal of alternative technology options. By reflexive appraisal we mean providing space for consideration of different opinions on technology needs and exposing the values, interests and subjective assumptions that underpin the construction of these different opinions to critical reflection. The UNFCCC's guidance for the production of TNAs seems to recognise the need to engage with stakeholders. However, it fails to integrate this with any meaningful attempt to elicit a reflexive appraisal of technology options. The TNA manual lists the following stakeholder groups as being worthwhile engaging with when producing a TNA (Gross *et al*. 2004: 15):

- Government Departments with responsibility for policy formulation and regulation in energy management (e.g. power supply, industrial processes, waste management) and vulnerable sectors (e.g. agriculture, forestry, fisheries, human health, parks/wildlife)

- Private and public sector industries, associations, and distributors that are involved in the provision of utility services (i.e. responsible for GHG emissions) or are sensitive to climate change impacts (e.g. tourism, agriculture, water resources, forestry, fisheries)

- Organisations involved in the manufacture, import, and sale of environmentally sound technologies or other hard or soft technologies (e.g. software) appropriate for mitigation or adaptation

- Households, small businesses, and farmers using the technologies and practices in question, and/or who are or could experience some of the effects of climate change

- NGOs involved with the promotion of environmental and social objectivs

- Institutions that provide technical and scientific support to both government and industry, e.g. academic organisations, industry R&D, think tanks, consultants, etc.

- Labour unions, consumer groups, and media

- Country divisions of international companies responsible for investments of critical importance to climate policy, e.g. the energy sector, agriculture, forestry

- International organisations and donors

In practice, however, the personal experience of one of the authors (of this STEPS paper) as an expert reviewer of the production of one developing country's TNA is that the stakeholders consulted were far more limited in scope – they did not include any representation outside of government departments, did not consult with the private sector and certainly did not stretch to engaging with households and communities. This experience is echoed in the informally expressed views of several other observers of the process and outcomes of TNAs under the UNFCCC. The only real reference to any more socially oriented concerns within the UNFCCC's TNA production manual is under a section relating to the role of stakeholders in conducting a "barriers analysis" where one potential barrier is labelled "social and cultural acceptability" with a subsequent elaboration stating that "[a] range of cultural practices and beliefs could lead to opposition to certain [technology] options" (Gross *et al*. 2004: 16-17).

As a result, the TNAs produced to date[13] resemble more of a wish list of low-carbon hardware that countries might like to access, as opposed to any reflexive consideration of a country's needs, including whose needs within that country this might relate to, not least with consideration of the needs of poor and socially marginalised people within these countries. This is an important observation as it again emphasises the fact that technology needs at the level of international

[13] See http://unfccc.int/ttclear/jsp/CountryReports.jsp.

negotiations are framed very much around both a hardware oriented understanding of low-carbon technology needs, and also around an understanding that gives little weight either to broader sustainable development goals or to the needs of different stakeholders, not least the needs of firms and households, particularly poor and socially marginalised households, in developing countries.

So we begin to see the importance of how and by whom different framings of technology needs are constructed, and which framings dominate policy discussions. On a more pragmatic level, if the arguments we make in the previous two sections in favour of an emphasis on capacity building hold true, then these different framings also have important implications for the likely success of implied policy approaches in underpinning successful long term socio-technical transitions to low-carbon energy practices. Indeed, the capacity building oriented policy approaches advocated above in and of themselves are framed around a broader socio-technical understanding which speaks more directly to the needs of end users and producers of technologies in developing countries, whether at the level of firms or households. We now reflect on the implications of the technological change literatures reviewed above before moving on to demonstrate how a socio-technical transitions framing might offer a more productive way forward for research and policy approaches to low-carbon development.

6.4 Reflections on the technology transfer literature

This brief review of the literature on what is commonly called ‘technology transfer’ has attempted to identify some of the useful insights that we might apply to reframing energy challenges in low-carbon development; especially when the latter is perceived as an issue of drawing in innovation capabilities from other places. The most general insight that the literature provides is that the building of technological capabilities is a systemic phenomenon, emerging from long-term resource-intensive processes that interact interdependently with political priorities and economic interests. An enormous amount of empirical research and evidence analyses the dynamics of technological capability-building in developing countries at firm and sectoral levels; research that tries to understand, enhance and hasten the process of industrialisation. There is also a large body of work concerned with the adoption of technologies at the level of the household and, helpfully for our purposes, does so with respect to energy technologies, although this research tends not to characterise the adoption process as technological capability-building but rather as user participation. Still, both strands of literature share similar insights.

In particular, it is clear from the discussions above that the view of technology as hardware is not only simplistic but also unhelpful when we are trying to understand how technological capabilities can be built and accumulated; whether for industrialisation, for improving energy services in the household, or whatever the development objectives might be. Taking a more multi-dimensional socio-technical view allows us to see that technological artefacts (hardware and processes) are embedded with knowledge and cultural assumptions, with important implications for how those artefacts can be used and changed. Moreover, the very use of an artefact is itself an element of the technology: that is, the 'technology' is a combination of the hardware, the practice of its use, the knowledge relevant to this practice – embedded in the artefact and embodied in the user – and the institutions that enable its use (norms, regulations, laws, etc.). Understood in this way, we can see why the processes of technical change and the building and accumulating of technological capabilities are complex, long-term and resource-intensive. Furthermore, these interactions operate across multiple scales from the village to international arenas.

The discussion above also highlighted how the dominant framings of technology and its role in development sustain certain constructions of technology needs which do not necessarily attend to the needs of firms and households in developing countries. This has important political economy implications and is central to determining which vision of low-carbon development technology oriented policy fulfils, and whose needs and interests this serves.

Many of these insights are available in the literature on technical change in developing countries. However, we would argue that they have yet to be brought together into an integrative and coherent framing of the energy challenge in low-carbon development. We have, instead, the elements of 'socio-technical' configurations: the multi-dimensionality of energy practices, supportive infrastructures, and political economies of technology. All are recognised as important and interdependent parts of a 'system'. But the 'system' is not well defined and the interdependence of the elements is either partially understood or weakly theorised, creating difficulties for each of the perspectives to communicate – l*et al*one integrate – with each other.

We suggest that theoretical and empirical work coming from the 'socio-technical transitions' literature could be helpful in this regard. This literature takes a multi-dimensional view of (technological) innovations oriented towards the transformation of systems, and provides a framework that enables analysis of the dynamics of agency and capability-building over time whilst attending to the structural features of the systems one wishes to change. Furthermore, the framework lends itself to the study of purposive technological change: how incumbent systems remain dominant or resistant to change from promising alternatives; and how promising alternatives can influence the dynamics of change in systems.

The next section outlines these ideas, in whose development members of the

STEPS Centre and the Sussex Energy Group in SPRU (also at the University of Sussex) have had a hand, but whose major innovations were pioneered by Dutch researchers working at the interface of evolutionary economics and science and technology studies. This includes René Kemp, Arie Rip, Johan Schot, Frank Geels, John Grin, Rob Raven, Jan Rotmans, Derk Loorbach, and others (see Smith *et al*. 2010 for a review). A growing network of international researchers are bringing their own perspectives and interpretations to bear, such as Jochen Markard and Bernhard Truffer (2008; bringing in innovation systems), Elizabeth Shove and Gordon Walker (2007; bringing in constructivist and practice-theory sensibilities), Audley Genus and Anne-Marie Coles (2008; bringing in actor network theory), Adrian Smith, Andy Stirling and Frans Berkhout (2005; bringing in constructivist and political science issues). Here we connect these 'transitions' ideas with insights from the pathways approach discussed earlier.

7. Broadening the goals and the analysis: a socio-technical transitions framing

- Given the argument above, we believe a reframing of energy challenges is required that is able to:

- Focus on the build up of indigenous energy innovation capabilities for low-carbon development

- Recognise that low-carbon development requires the transformation of incumbent systems (cf. the insertion of low-carbon technologies in those systems)

- Attend to the normative values inherent in energy practices

- Be open towards the political economy of energy, including the exercise of power through dominant framings of issues such as technology needs

- Recognise that novel, sustainable energy solutions arise amidst existing energy practices that are deeply institutionalised

- Cover the multiple socio-technical dimensions of an energy practice

- Bring multiple framings into a dialogue about the development of energy pathways

- Consider a plurality of pathways, and understand each in interaction or co-existence with the other

- Facilitate debate about the kinds of low-carbon pathways to pursue, and the prospects and requirements for each.

Conceiving energy and development as a challenge for re-configuring energy socio-technical systems (Rip and Kemp 1998) emphasises the considerable technical, economic, sociological and political work that has to be done to align narratives, actors, artefacts and institutions into the working ensemble that constitutes an energy service. This much should be clear from the discussions above.

By way of further example, consider all the material, discursive and institutional elements and changes needed to make small-scale bio-gasification power stations succeed: specialised knowledge, reliable technologies, skilled workers, investment capital, local grid infrastructures, maintenance services, willing customers, profitable markets, acceptable environmental impacts, and so on, and so on (Verbong *et al*. 2010). Considerable social agency is required. Technological hardware, supported by public-private R&D, and the financing of its transfer and diffusion, supported by international carbon markets, are unlikely to generate all these path-building alignments. Each is an important factor in the overall governance of low-carbon development, but that governance is not reducible to a core factor.

A socio-technical systems perspective allows us to appreciate these recursive relationships. For instance, institutions are required to train engineers and provide facilities for developing particular styles of technology. These must in turn be linked to market incentives, marketing possibilities and the needs of prospective consumers. Beyond this, broader social, demographic and ideological processes are at work. These include the cultural milieu in which the technology operates, where social movements, lifestyle expectations, environmental stresses, behavioural patterns and resource endowments all exercise their influence upon patterns of technology development and use.

At the same time, researchers note that developing highly novel, path-breaking socio-technical practices takes place in a context of deeply embedded, substantially institutionalised and widely reproduced 'socio-technical regimes' (Unruh 2000; Geels 2002). The accumulation over time of capabilities and skills, business models and markets, capital and other interests, infrastructures and technologies, institutions and user routines, political commitments and social values, constitute powerful path dependencies driving incremental innovations within the socio-technical regimes that these processes constitute (Geels 2002). Box 6 elaborates these path-dependent processes.

At times, it can appear as though societies are 'locked-in' to certain energy regimes, such as the centralised generation and distribution of energy from fossil-fuels underpinning high energy consumption lifestyles in wealthy and emerging economies; or, for completely different reasons, wood fuel economies in poor countries. The transitions literature has developed through an interest in the way society has been transformed by changes to some underpinning socio-technical systems, such as the move from societies with gas/candle light to societies with electric light. Prospective interest in moving to sustainable low-carbon societies has a broadly analogous problem framing (Rip and Kemp 1998).

Note here how the regime concept has predominantly been informed by industrialised and wealthy country contexts. Its relevance for other development contexts still needs to be explored. The central point, regarding the structural impediments and opportunities that historical socio-technical alignments present for transforming local energy practices nevertheless remains. Even if the regime concept requires revising or replacing for certain development situations, a need to account for the influence that incumbent energy practices have over alternative sustainable energy initiatives will endure.

In some cases the path-dependency processes may derive more from a lack of something towards which there is a strong commitment, but they are nevertheless in play. The processes that lock people into wood-fuel regimes include dimensions of capabilities and skills regarding its gathering and use, institutions regulating wood access, the economics of wood-fuel, cultural associations with any or all of these practices, cooking and heating practices developed through reliance upon wood fuel, and the embedding of these practices in daily routines that all have to be considered when trying to insert alternative energy practices for cooking and warmth.

Box 6: Mutually reinforcing path dependencies across different socio-technical dimensions

Actors vital to the reproduction of energy systems generally tend to favour incremental innovation and systems improvement over radical innovation and systems transformation. This arises from a host of mechanisms that promote stability and resistance to change in socio-technical regimes and which informs incremental governance strategies that perpetuate the regime pathway (Walker 2000; Unruh 2000). These mechanisms include:

Capabilities: The innovation activities of incumbents are constrained by existing capabilities and knowledge (Dosi 1982; Nelson and Winter 1982), which channel technical developments into restricted subsets of the possible directions (Kemp *et al*. 1998; Elzen *et al*. 2005). Innovative activities and investments are also constrained by existing beliefs and perceptions, routines and habits.

Economics: Existing technologies tend to be cheaper in the short run because they have benefited from long periods of dynamic increasing returns (e.g. learning-by-doing and using, scale economies and positive network externalities). This puts them in advantageous positions compared with novel practices (Arthur 1989; Dosi 1982).

Vested interests: Incumbents have sunk investments (in capital, competencies and social networks, for example) that they will try to protect. They therefore resist radical change that threatens them. Large, established industries may contain divisions and individuals with more radical ideas, but they are less often empowered to implement these if core business interests are thereby challenged.

Politics and power: Incumbent businesses, regulators and others enjoy important positions in the current system. Economic power bestows considerable influence; they have voices that will be listened to by innovation policy processes (Smith *et al*. 2005). Innovators outside this nexus rely on future expectations to make their case. 'Outsiders' need not be small players. For example, large information technology companies are outsider innovators in energy systems but have a potentially transformative role to play in a move to 'smart grid' technologies. However, 'outsider' innovators are often relatively weakly organised compared to incumbents. Whilst today's shareholders, workers and customers can invest, vote and exert influence in numerous ways, tomorrow's stakeholders in more sustainable systems are a constituency less essential to the immediate reproduction of current energy systems.

Infrastructure: Existing technological devices may be embedded in dedicated infrastructures that make their substitution with alternatives difficult (Jacobsson and Johnson 2000).

Institutions: Government regulations and subsidies, professional associations, and market rules have co-evolved as part of existing systems and tend to reinforce existing trajectories of development (Hughes 1983; Walker 2000).

Market and consumer cultures: Prevailing market and social attitudes influence the kinds of technical performance deemed acceptable; whilst the business models, lifestyle norms and routines that are created around them can resist novel practices (Shove 2003; Yearley 1988).

In sum, there is a range of mechanisms through which societies collectively commit to certain socio-technical pathways rather than others (Geels 2002). Systems that have become 'locked-in' to these trajectories are difficult to unsettle and re-direct.

In other instances, the socio-technical regimes are more 'virtual' but nevertheless structuring due to the powerful hold they have in framings for energy system aspirations. We can see this in the hold that rural-electrification-as-grid-extension has had in many international programmes and national energy policies for rural electrification. Familiarity with centralised electricity grids and their apparently self-evident desirability amongst consultants, engineers, politicians, energy businesses, and others, has worked to frame energy development thinking, especially in national energy plans, even when resources and capabilities to realise this vision have been lacking. This has meant that support for alternative, decentralised approaches to providing electricity has had to make its case in the shadow of the grid-extension framing even in contexts where there are no grids as yet.

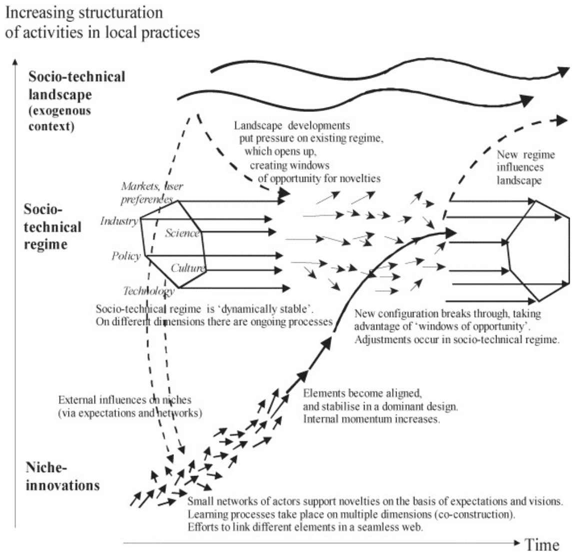
However, inflexible path-dependent alignments can, under shifting circumstances, become a source of fragility. Moreover, internal misalignments, brought about by technical changes or shifts in ownership or reframings of the energy-development challenge, can combine with external processes, such as rising environmental awareness, demographic change, and resource shifts. Such processes can unsettle regimes and open windows of opportunity for alternatives to develop, and perhaps seed transitions towards radically different configurations and pathways.

Clearly, we are talking about a very complex and heterogeneous collection of system processes here. There are various ways of simplifying and thinking about that complexity. The multi-level perspective (MLP) on socio-technical transitions is one way (Rip and Kemp 1998; Geels 2002). We believe it provides analytical purchase by providing a framework for situating and relating dynamically the structurally-inclined processes of path dependency with the agency-oriented processes of path-building. The framework is presented schematically in Figure 9.

The innovative configuration of novel socio-technical energy practices (e.g. passive cooling in urban housing) is considered to take place in 'niches'. These spaces of socio-technical agency afford some protections for the alternative practice, which cannot compete directly with the incumbent, more structured and structuring socio-technical regime (e.g. globally-standardised apartment block designs that rely upon mechanical air conditioning). An example could be to consider distributed micro-renewables in new urban developments as currently constituting a niche, in the context of expanding a centralised, fossil-fuelled regime into that development, and in which prevailing energy infrastructures and institutions are disadvantageous towards micro-renewables.

In their different ways, both the niche(s) and regime(s) define and relate to a specific 'societal function', such as certain energy services, classified and problematised as 'technology needs' in an earlier section. The (reflective) realisation[14] of these societal functions is the starting point for the analysis and the reconstruction of the niche and regime socio-technical configurations. At the same time, niches and regimes are situated in similar 'landscape' contexts, though they experience them and identify with them differently. For instance, processes articulating social pressure for carbon emissions reduction or energy access (e.g. social movements, policy measures, green business strategies) means different things for actors and processes configuring, say, the micro-renewables niche (e.g. low-carbon is a potential opportunity) compared to the fossil-fuel electricity grid regime (e.g. low-carbon is a threat).

[14] We use 'realise' to denote the dual, iterative processes of a) figuring out needs and b) satisfying those needs.



Source: Geels (2002)

Figure 9: The mutli-level perspective on socio-technical transitions.

Transitions are consequently theorised as arising through interactions between these three analytical levels: it is the way niches, regimes and landscape processes interact that determines the specific transition (Smith *et al*. 2005; Geels and Schot 2007). The MLP has been used to orientate the analysis of various kinds of energy transitions:

1. Historical analyses explaining successful energy transitions at varying scales (e.g. the move from sail shipping to steam shipping, the move from coal/town gas to natural gas)

2. Analyses of sustainable energy niches and explanations of the difficulties they face in becoming more widespread (e.g. ultra low energy housing compared to volume housing)

3. Both 1. and 2. inform prescriptive and prospective uses of the framework, and develop policy recommendations for strategic niche management and transition policies that might improve the chances of sustainable, low carbon energy transitions.

Analytically, socio-technical systems of varying scales have been studied (e.g. international steam shipping, bio-gasification systems, eco-housing practices).

Prospectively, policy jurisdictions of varying scales have undertaken transition policies (e.g. cities, regions, nations) (Loorbach 2007; (Smith and Kern 2009). The ‘niche’ and ‘regime’ is a matter of empirical definition; in terms of the scale of practice in which one is interested, be it transitions in energy practice in the household, dominant wind turbine designs in the industry, entire electricity systems, or other units of analysis. The point is that one has to remain aware and open to activities going on beyond the unit of analysis, and interpret them in terms of what it means for one’s core research concerns. Contexts and pathways for change will vary from case to case for complex socio-technical systems (Smith *et al*. 2005; Geels and Schot 2007). In the context of sustainability, it is the possibility of accelerating transitions away from unsustainable regimes and along more sustainable pathways deriving from niches that preoccupies analysts and policy-makers. Here a particular mode of ‘purposive transition’ or ‘transition management’ is debated (Kemp *et al*. 1998; Rotmans *et al*. 2001; Smith *et al*. 2005; Loorbach 2007). Socially negotiated visions for future low-carbon energy systems form a point of departure for policy processes that back-cast to the deliberate creation of experimental niches (Rotmans *et al*. 2001).

Niches are constituted across networks of experimental sites for reflexive learning, expectation development, network building and, in cases where niches are promising, the institutionalisation of these practices through the development of further experiments. On rare occasions a niche develops and grows, and it displaces more and more of the incumbent regime provision. Hybrid versions emerge as niche ideas are appropriated into an adapting regime (Smith 2007). Further destabilisations and growth opportunities arise, but eventually, on those rare occasions, a new energy regime may be discernable.

It has been suggested that rapid development in South and South-East Asia provides one such situation (Berkhout *et al*. 2010). The challenge of low-carbon sustainability is such that catching-up with the ‘technological frontier’ in developed countries will be insufficient. Frans Berkhout and colleagues argue that the dynamism in Asia and other late-industrialising regions provides space for socio-technical experimentation, and which could seed the creation of entirely new regimes that leap-frog the historical industrialisation model. That is the hope. There are other pathway dynamics in this region and others that suggest unsustainable regimes in the future, and that repeat problematic lock-ins in the developed countries, such as car-based urban-transport systems. The challenge is to analyse the experimentation with sustainable alternatives in Asia, and other regions, in the context of these broader, contending processes of development. This may then uncover strategies for promoting more sustainable pathways on the basis of niche experimentation (see special issues in Environmental Science & Policy (13, 4) and Technological Forecasting & Social Change (76, 2)).

It should be noted, by way of concluding this section, that the MLP framework is neutral as to which niches should be promoted and whose momentum should be encouraged towards becoming influential pathways for energy and development.

Rather, the MLP provides a framework for analysing a plurality of niches and explaining their relative success in building momentum in the context of historical regime trajectories of development. These niches can be in interaction (and competition) with one another as much as with the regime they seek to transform or displace. Symmetry in the analysis of niches, regimes and pathways is warranted. In each case, however, it is important that the problem framing be kept broad – the ambitious transformation of energy systems into low-carbon forms – and that the analytical framework is also wide enough to consider the complex factors relevant to such a framing. The MLP is alluring because it meets these criteria, and provides an account for how pathways may variously build, fizzle out, or decline over time; but it is also challenged, precisely because it tries to bring the details of innovative agency into play with long-term societal change (Smith *et al*. 2010).

8. A pathways research agenda for energy sustainability in development

Of course, socio-technical experimentation in development is not new. What is promising, however, is the way the MLP situates this within a mid-range analytical framework that seeks to identify, contextualise and thereby understand wider developmental promise. It is noteworthy how development practice and the development literature are rich in exemplary local sustainability initiatives for energy. These path-breaking projects suggest alternative ways of powering more sustainable livelihoods. The local consequences of these initiatives are evaluated, praised or criticised; as are the processes by which the specific initiatives came about. Such contextually rich studies provide some helpful tips for others wishing to emulate the initiative elsewhere. However, broader institutional (political and economic) processes that influence the diffusion of path-breaking sustainability initiatives are beyond the full grasp of these micro-level studies. At the same time, macro-level analysis tends to abstract narrow technical and economic performance characteristics from the initiatives, for use elsewhere, much as we see in international technology transfer negotiations. As such, they imply a straight-forward and universal calculus for deciding whether to adopt that presupposes an economic rationale or hurdle blind to diverse contexts. Macro-level studies tend also to presume a single, rational decision-maker when the reality is of initiatives emerging and diffusing through networks of social and technological activity by differently situated and perceiving actors. Socio-technical transitions theory may well provide a link between innovative agency in local initiatives and incumbent structures of technological practice in their broader socio-economic contexts, and analyse their respective, interacting transformations over time.

8.1 Niche based research

Local projects can be conceived as contributing to networks of alternative practice (i.e. niches), and which can then draw upon hypotheses for how path-breaking 'niches' contribute to transitions to new structures. In this case, we are interested in how niche sustainability socio-technical practices in energy, such as solar PV, or low energy housing, attain momentum through diffusion from one development initiative to another, and how this constitutes alternative pathways to incumbent regimes of energy production. Whilst transitions theory has developed over the last decade in a North-west-European context, projects elsewhere are already interrogating its relevance in South- and East-Asian contexts. Berkhout and colleagues consider the experience of 'sustainability experiments' in these regions and their contribution to niches and alternative development pathways. Sustainability experiments are understood as “planned initiatives that embody a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains” (Berkhout *et al*. 2010: 262). These initiatives are where the earliest stages of a process of socio-technical learning take place. For example, in a Kenyan context, Byrne (2011) describes how the solar home system (SHS) niche began in the mid 1980s following the installation of a small PV system in a school. Soon after, some of the school’s staff wanted PV systems for their homes. Guided by the expectation this initial socio-technical learning created, the PV installers began to develop SHSs and to market them in the local area, creating further socio-technical learning about user-preferences, supply chains, PV system technicalities, and so on.

Transition theory might help analyse the processes by which similar sustainability initiatives do or do not **replicate** in different localities; opportunities for **scaling-up** so that follow-on initiatives benefit more people and communities; and the possibilities that path-breaking sustainable innovations may provide adaptable and appropriable solutions that can be **translated** into mainstream development settings, thereby building momentum for the novel pathways. Byrne (2011), again, illustrates how initial attempts to replicate the success of the Kenyan SHS niche failed in Tanzania; the failure attributable to an expectation that was not sufficiently cognisant of the Tanzanian context. Nevertheless, expectations that SHSs could provide solutions to rural electrification needs in Tanzania persisted and, driven in part by donor agendas for low-carbon development and in part by a local constituency of support for PV that included private sector actors, a number of initiatives were realised in parallel during the 2000s. Within a short time frame, donors, private sector actors, local NGOs and energy ministry actors were implementing a range of projects and communicating extensively with each other as their activities unfolded on the ground across a large area of Tanzania. As a result, a great deal of context-specific socio-technical learning was both generated and shared (in similar ways to the Kenyan case) and the market for SHSs began to grow rapidly.

Networks of similar initiatives, such as those just mentioned in the Tanzanian case, can be conceived as niches that provide a protective space in which local-scale sustainable solutions can be nurtured, and from which they can be diffused into new localities and contexts. Existing transition studies suggest that niches grow and contribute to pathway momentum through three inter-linked processes:

a) expectations contribute to successful niche building when they are robust (shared by many actors), specific, and of high quality (substantiated by on-going initiatives);

b) social networks contribute when their membership is broad (plural perspectives) and deep (substantial resource commitments by members); and

c) learning processes not only accumulate facts, data and first-order lessons, but also generate second-order learning about alternative ways of valuing and supporting the niche.

Niche practices become influential to the extent that processes ‘a’ to ‘c’ above become robust enough not only to facilitate diffusion, but also exert influence over wider institutional changes, such as policy support.

Future research needs to test the **hypothesis** that niches grow through replication of initiatives in different locations; that strategic learning across replicated initiatives facilitates scaled-up adaptations; and that elements of these translate into new business models and markets. Self-replicating diffusion is challenging for local sustainability initiatives; support is needed for both niche development and initiative-to-initiative networking. This suggests niches do not provide blueprints, but rather reservoirs of ideas and practices; and that dedicated work is needed to transfer and adapt from across locations, scales and contexts (e.g. into commercial prospects), such as observed in the Kenyan and Tanzanian solar home system niches referred to above. Of course, given historic difficulties in scaling-up and diffusing exemplars, it is likely that future, niche-oriented research will also end up studying the difficulties experienced by our hypothetical path-building processes: when is social learning ignored; when do expectations deflate; and why do networks fragment?

A weakness in the transitions approach is the under-theorised relations between located socio-technical initiatives and the emergence of an influential, abstracted, niche-level identity and interest, based around stylised socio-technical practices. How do strategic niches influence institutional reform? This includes evidence that experience with, say, skills or infrastructure issues, gathered from earlier initiatives is mobilised into demands for reforms to policy and industrial strategy. Whilst the literature argues successful niches prompt facilitating institutional reforms within the wider energy regimes, it is unclear why this would happen given path-dependencies in those regimes. So what political roles do path-breaking sustainability niches need to play in order to influence these reform processes? This is where social movement theory might inform transitions theory and reveal the political roles niches must adopt in sustainability transitions. How do niches develop collective **identities** and **interests**; what repertoires of niche activism press for reforms? Where are the ‘opportunity structures’ for pursuing demands? The social technologies movement in Latin America, and the appropriate technology movement of an earlier generation, are and were mobilising a set of political and institutional demands around alternative technological styles (Willoughby 1990). It is striking how many of the ‘soft energy’ options characteristic of appropriate technology are now part of the hardware and finance discourse, but with the awareness of important local contexts stripped away. Social technology advocates are aware of the broader social changes required for socially just and environmentally sustainable transformations, whilst seeing practical experimentation as furnishing a material base for such wider changes (see Saber Cómo 92, September 2010 [15]).

On this latter point, we have to look at sustainability niches the other way around, from the external perspective of actors committed to the incumbent energy regimes. Sustainability transitions theory argues that niche performance is interpreted by actors situated in a wider context. Tensions emerging in mainstream energy regimes, such as security and environmental crises, cast niche solutions in more positive light, and thereby attract interest from policy-makers and businesses worried about the regime. What innovations do sustainability niches offer concerned businesses and policy-makers in the regime? How do these solutions perform in terms of interest for, say, accelerating development, or delivering carbon reductions, and at what cost? This speaks to the translation mode of diffusion: what niche innovations can be adapted into reforming conventional development institutions relevant under different contexts in future? The structural influence of the political economy of energy regimes on niches is important here. This also speaks to issues raised above in relation to technology needs; how are these framed? Whose interests do current framings serve? We unpack this in more detail further below.

Empirically, future research will have to develop a protocol for identifying classes of socio-technical energy practice as path-breaking sustainability niches. Research will then identify initiatives where these practices are developed (this could be within a country or regionally). A mixture of survey work (e.g. web-based where practicable) and in-depth case study can interrogate networking between initiatives, the roles of intermediaries, and the political/social movement performance of the niche. Our core analytical concerns are for niche building processes, evidence of niche influence on institutions, and thus the momentum building behind these alternative sustainability pathways under different contexts.

Our recent research on low-carbon innovation in India and China shows how important these contexts are – with respect to particular low-carbon technologies as well as national circumstances (Ockwell *et al*. 2008; Watson *et al*. 2011). A future priority is therefore to understand how these processes of innovation and the barriers to innovation differ in other developing countries, particularly in countries that are less developed than China or India.

Of course, it is important to remember that the MLP framework is also interested in the way incumbent regimes become unsettled, and thus more susceptible to transformations and transitions. This too has to be part of a future research agenda for sustainable energy and low-carbon development pathways. Strong policy and business commitments to grid-extension pathways for energy have already been mentioned, and research in this vein would look to the kinds of regime this is constituting, and the possibilities this opens up for larger-scale low-carbon energy practices, as well as any difficulties this might present for the co-existence of decentralised solutions.

[15] http://www.inti.gob.ar/sc92/inti7.php

8.2 Regime-level research

The research agenda proposed above tends to dwell on niche-building since it is interested in alternative low-carbon development pathways. However, care needs to be taken that this is not to the neglect of regime processes. Bearing in mind the extent of high-carbon regimes, we can expect – indeed we already experience – enormous strategic and tactical efforts to resist serious moves towards low-carbon infrastructure and socio-technical practices, underlining the need to incorporate a better understanding of the political economy of transitions and where and how powerful support for low-carbon pathways might be mobilised.

Included in regime process considerations have to be wider developments that underpin energy developments, such as industrialisation, urbanisation and the development of new livelihoods and lifestyles. How these unfold is intimately related to energy demands and forms of provision.

A focus at the regime level also draws attention back to issues of political economy. In line with a pathways approach, analysis is required to deconstruct existing policy narratives around low-carbon development and unpick whose interests these narratives serve. With the attention given to the idea of technology needs under the UNFCCC process, analysis of how these needs are framed and whose needs existing policy approaches serve could make an important contribution to understanding how policy might be reframed to better serve the needs of different communities in different developing countries. As noted above, there are likely to be important differences between less developed countries and emerging economies such as China and India with respect to these issues.

Particular emphasis needs to be given to understanding the context-specificities that define these needs, and to appraisal processes which facilitate reflexive expression of their subjective constructions in different places, by different people at different times. Such reflexive appraisal holds greater promise of facilitating policy approaches that are sensitive to the characteristics of existing socio-technical regimes and therefore to introduce new technologies and practices that have maximum chance of being accepted into, and therefore ultimately transform, existing everyday practices.

At a broader level, attention needs to be given to how existing policy discourses construct the idea of ‘low-carbon development’ and the extent to which this attends to multiple different constructions of development. Again, attending to alternative possible framings of technology needs, together with a broader understanding of the socio-technical nature of technology related practices provides a useful point of departure. It points research towards questioning dominant policy discourses, such as the hegemonic technology financing discourse, and examining concrete case studies of technology transfer and provision of energy services more broadly, in order to unpick which conceptions of development these currently serve, which aspects are not served, whose interests this benefits, what narratives serve these interests and how these narratives might be reframed to meet different, or broader development needs in future. Questions such as to what extent technology transfer policies serve the needs of poor and marginalised communities, least developed countries or emerging economies, need to be asked and approached in a more disaggregated, context-specific way than existing policy discussions and mechanisms facilitate. The broader question of what exactly a construction of technology transfer and development as pro-poor actually looks like also needs to be unpacked in more detail (see Urban and Sumner 2009 for a useful starting point).

Such critical analysis and more detailed deconstruction of current framings and narratives on technology transfer and low-carbon development may also identify areas of complementarity, providing purchase for reframing existing narratives to better serve a broader range of interests and technology needs. These synergies might be usefully brokered via a promotion of a better understanding of the role of indigenous innovation capabilities in both underpinning industrial development in developing countries at the same time as facilitating faster diffusion of low-carbon technologies, thus dissolving entrenched tensions between industrialised and developing countries within international climate change negotiations.

Furthermore, this analysis can take into account the interactions between the low-carbon agenda and other related issues that remain important for developing countries. These include the challenge of improving energy access (particularly in rural areas), and on-going debates about the extent to which energy sector reforms are desirable or required to meet this and other challenges.

8.3 Mapping and building indigenous innovation capabilities

Work is also necessary to better map the level of existing indigenous innovation capabilities across a range of different technological areas. Effective transfer of existing technologies requires detailed understanding of what capabilities already exist, where they exist and why. Understanding the nature and location of existing absorptive capacities would enable focussed targeting both of new capacity building activities that address areas of need, and focussed targeting of flows of technologies in areas of relevant existing capacities making adoption more likely within these new contexts. Particular attention also needs to be given to whether, where and how projects funded by existing policy mechanisms have contributed to broader capacity building and what can be learnt in order to reorient policy to more explicitly foster new capacities in future. Additional empirical work exploring barriers to, and successful examples of, technology transfer and capacity building across a range of different contexts is also essential to inform the architecture and emphasis of future policy approaches. At a theoretical level, it would also be useful to articulate a more coherent, empirically informed theory of the role of innovation capabilities specifically in relation to low-carbon technological transitions within different developing country contexts, and to articulate such a theoretical framework in terms that can be easily understood and applied in policy and practice. This work is particularly timely given on-going discussions on new policy approaches to low-carbon technology transfer and development within a post-2012 international climate policy framework – and the need for this framework to learn from previous and existing international initiatives designed to foster low-carbon innovation.

9 Conclusions – ways forward

This paper has covered considerable ground. It began by noting how relationships between energy and development operate across increasingly diverse settings. What many share in common, either now or in the future, is interest in drastically reducing the carbon emissions of powering development, and improving access to energy services amongst the poor. At the international level, we noted how this has often been reduced to the challenge of financing and facilitating the transfer of appropriate technologies. This largely remains the case in UNFCCC climate regime negotiations.

But this is only one way of 'framing' energy pathways in low-carbon development. This paper has gone to considerable lengths, and drawn upon a long tradition of research, in order to indicate how the long-term process of accumulating innovation capabilities in poorer countries and communities differs from financing 'technology transfer' projects. Another useful insight from the literature on technical change in developing countries is the significance political economies have for learning processes, the mobilisation of resources and the institutionalisation of new development pathways. The whole notion of technology being transferred and embedded as a package into a conforming recipient context begins to look problematic. Instead, we have to begin to think of local socio-technical experimentation contributing to the development of niches, and which in turn offer alternative development pathways compared to those underpinned by existing energy socio-technical regimes.

If we are to make progress in achieving pro-poor low-carbon development, we need to develop robust analysis that can understand and explain the kinds of complex interactions we have discussed. We have suggested that a broad framing of the issues, that sees the challenge as one of wide-scale, path-breaking socio-technical transformation, needs to be accompanied by a variety of concepts. Transition and niche theories suggest that policy interventions need to be long-standing, but also that there needs to be learning from experimentation and that learning should contribute to the widespread cultivation of relevant knowledge. Broad networks of actors engage in such experiments and carry such knowledge, helping to institutionalise new socio-technical practices and provide constituencies that challenge incumbents. Resources are needed to create protected spaces in which new practices can develop and learning can take place. Coordinating actors – system-builders – are needed to manage the networks and facilitate exchange of information and learning. The participation of users is important to realise the legitimacy and enrich the knowledge informing any favoured niches and trajectories in particular contexts.

Drawing on the research agenda set out in section 8 of this paper, the following priority areas are proposed for future STEPS research. The three priorities outlined here are not designed to be exhaustive, but are particularly important areas in which STEPS can make a distinctive contribution to the literature, and to policy and practice. Amongst the important drivers for these particular priorities are the opportunities STEPS has to bring its perspective to international processes (e.g. the UNFCCC climate change talks and the Rio + 20 conference in 2012) and to national and local policies and strategies within developing countries.

1. There is a clear need for more systematic evaluation and learning of multilateral funds and mechanisms that are designed to foster low-carbon innovation in developing countries. Examples include the Global Environment Facility, the Clean Development Mechanism and the more recent World Bank Climate Investment Funds. Given the establishment of the new Technology Mechanism and Green Climate Fund under the UNFCCC, and the large number of other public and private sector initiatives that exist, learning from current and past mechanisms is important. It is not only important to understand 'what works' in delivering low-carbon development (and particularly innovation capabilities). It is also essential from a STEPS perspective to gain a better understanding of which low-carbon development pathways are favoured by these mechanisms, and which interests benefit (or not) from them.

2. This paper's broad framing of low-carbon development suggests that this particular issue needs to be connected to other 'regime level' agendas that continue to be important for the provision of energy services in developing countries. The improvement of energy access for citizens of developing countries has been the subject of considerable policy and practitioner attention for several decades. Related to this, there has been a controversial debate about the extent to which the reform of utility sectors (e.g. through privatisation and/or liberalisation) is an appropriate way to improve the financial performance of these sectors and their ability to improve energy access. There are also links to other policy domains such as industrial and trade policies. The analysis of low-carbon development sometimes takes too little account of these pre-existing challenges. It is therefore important that such links are made, and new research focuses on how the low-carbon agenda interacts with them.

3. This paper's analysis of the development of low-carbon technological capabilities has emphasised the importance of context. Whilst recent work by the Sussex Energy Group has added much needed empirical evidence from India and China to policy debates, it is hazardous to draw significant conclusions from this evidence for other developing countries. This is particularly the case with respect to less developed countries, where the challenges of building relevant capabilities are different and arguably greater. Future research therefore needs to gather new evidence in less developed country contexts to better understand how different their challenges are – and the extent to which the evidence leads to different implications for national and international policy.

Annex A: Energy access and carbon emissions in the developing world

In terms of energy issues in development, increasing access is the overriding concern of many developing countries. We can consider their current energy situation in a number of ways. There is the absolute level of energy-use and the level of access to different energy carriers. Figure 10 shows a map of the world with electricity consumption by region or continent. It is clear that there are considerable differences in the consumption of electricity between industrialised countries and the developing world. But there are also differences between developing countries. If we were to examine each of the continents more closely, we would also see large disparities within them, and within each country between rural and urban areas. Africa stands out most starkly as the lowest consumer of electricity and when we contrast this with biomass consumption (see Figure 11) the picture is almost completely reversed.

Table 1 and Table 2 give absolute numbers to these basic pictures.

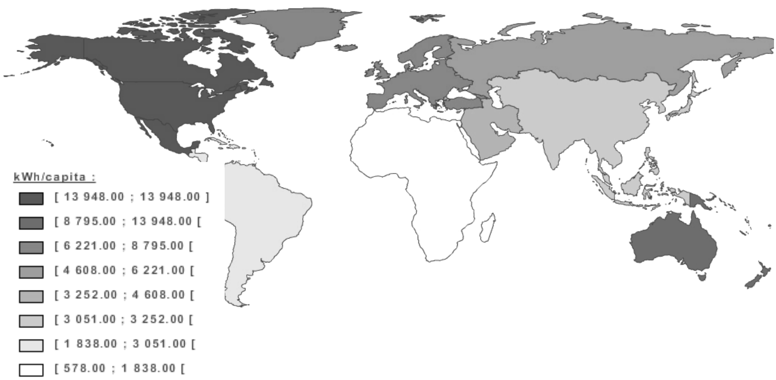


Figure 10: Electricity consumption by continent or region (kWh/capita).
Source: IEA (2010)

These figures and tables give a snapshot of the energy situation in developing countries. We can also examine the situation over time to see what trends, if any, are discernable. Figure 12 shows developed and developing countries divided into four income groups and their average energy-use per capita. As we might expect, the ranking of the groups by income and by energy-use per capita is the same. The disparity between the high-income group and the others is clear and is about ten times higher compared with the low-income group in particular.

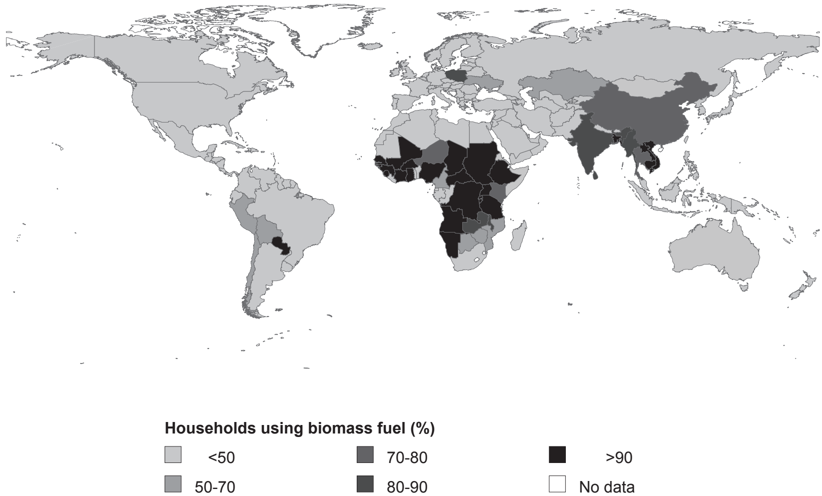


Figure 11: Percentage of households using traditional biomass fuel by country. *Adapted from:* Gordon *et al*. (2004) cited in Modi *et al*. (2005:12)

Table 1: Electricity access in 2008 by region

Country or region	**Population without electricity** millions	**Electrification rate** %	**Urban electrification rate** %	**Rural electrification rate** %
Africa	*589*	*40.0*	*66.8*	*22.7*
North Africa	*2*	*98.9*	*99.6*	*98.2*
Sub-Saharan Africa	*587*	*28.5*	*57.5*	*11.9*
Developing Asia	*809*	*77.2*	*93.5*	*67.2*
China & East Asia	*195*	*90.2*	*96.2*	*85.5*
South Asia	*614*	*60.2*	*88.4*	*48.4*
Latin America	*34*	*92.7*	*98.7*	*70.2*
Middle East	*21*	*89.1*	*98.5*	*70.6*
Developing countries	**1,453**	**72.0**	**90.0**	**58.4**
Transition economies & OECD	**3**	**99.8**	**100.0**	**99.5**
World	**1,456**	**78.2**	**93.4**	**63.2**

Source: WEO (2008)

Table 2: Number of people relying on traditional biomass for cooking and heating in developing countries in 2000

Country or region	**Million**	**Percent of total population**
China	706	56
Indonesia	155	74
Rest of Asia	137	37
India	585	58
Rest of South Asia	128	41
Latin America	96	23
North Africa/Middle East	8	0.05
sub-Saharan Africa	575	89
Total, Developing Countries	**2390**	**52**

Source: IEA (2002) cited in Modi *et al*. (2005:13)

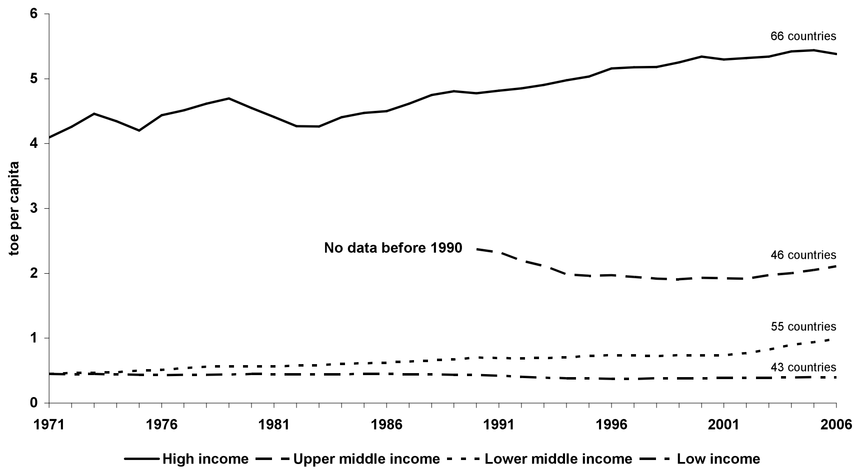


Figure 12: Energy use per capita by income group.
Source: WDI (2009)

Similarly to the energy-use per capita disparities, carbon dioxide emissions continue to be highest on average among people in the rich countries (see Figure 12). In fact, the disparity here is even larger at over twenty times the average CO2 emissions of those in the poorest countries. The aggregate emissions, however, show a closing of this difference, except in the poorest countries (see Figure 14). We can see that emissions from the richest countries have continued to grow but they are being approached rapidly by those countries in the lower middle-income group.

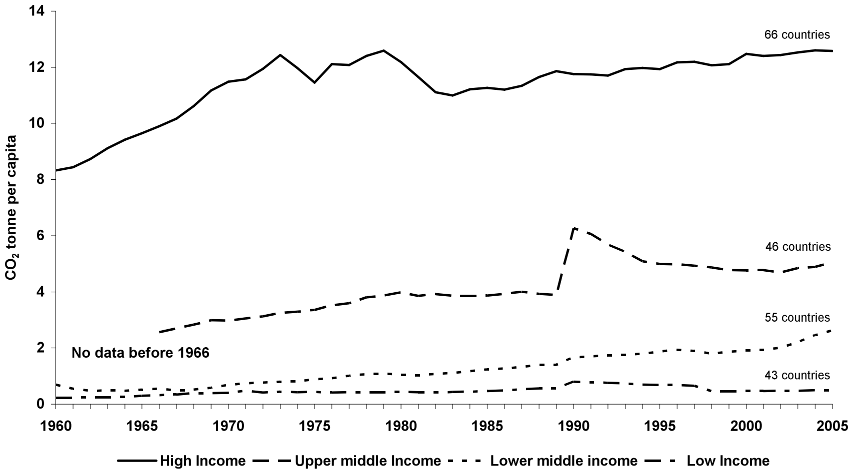


Figure 13: Carbon dioxide emissions per capita by income group.
Source: WDI (2009)

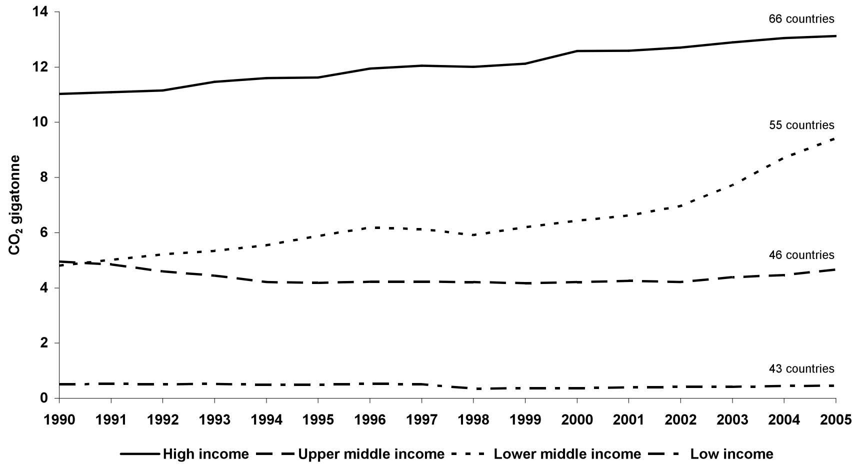


Figure 14: Total carbon dioxide emissions by income group.
Source: WDI (2009)

From the perspective of preventing dangerous climate change, of course, these trends are worrying. Indeed, they may be even more so when we consider the intensity of CO2 emissions. Despite general trends worldwide towards lower energy-intensity of GDP (see Figure 15), the carbon dioxide emissions of each unit of energy-use in the lower middle-income countries are increasing and are now the highest worldwide (see Figure 16).

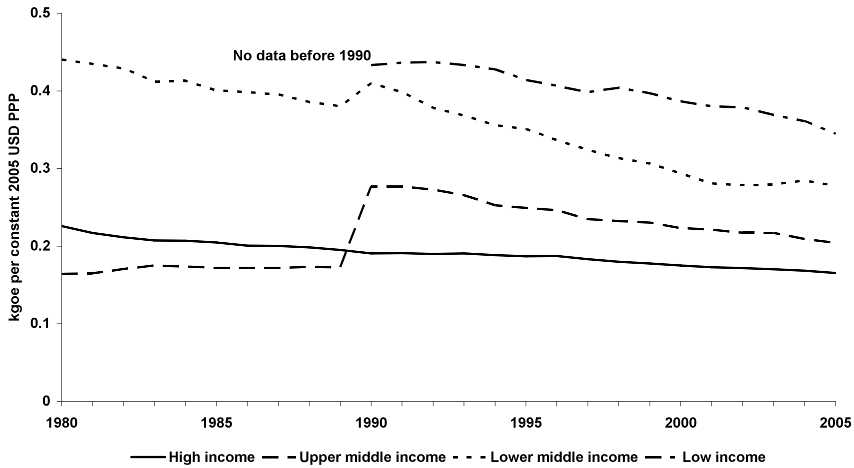


Figure 15: Energy intensity by income group
Source: WDI (2009)

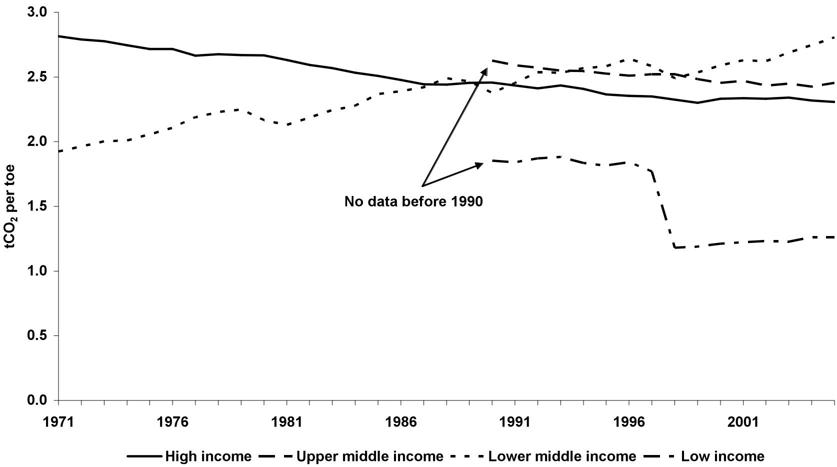


Figure 16: Carbon dioxide emissions per unit of energy-use by income group.
Source: WDI (2009)

It is clear that the levels of access to energy, and its consumption, are highly uneven across the world. Within this broad picture there are further disparities among developing countries, with the poorest countries at very low levels on both per-capita and aggregate measures. There is also an important issue of energy quality that is, again, most stark among the poorest countries where the vast majority of households continue to rely on traditional biomass. The most serious implications of this reliance are on human health, and the consequences for the local environment and global climate change. The burning of traditional biomass in the household is understood to cause severe eye and respiratory problems; the latter resulting in the "premature death" of 1.3 million people each year, more than half of which are children under five years old (OECD-IEA 2008). Depending on the particularities of the local environment, and practices of biomass collection, there can be serious deforestation that causes further degrading of the local environment, which in turn drives local people (usually women and children) to search longer and wider for biomass. If the burning of biomass is not part of a neutral carbon cycle then there will be net CO2 emissions that increase the risk of dangerous climate change globally, with impacts on the local environment as well.

In terms of the links between energy-use and carbon emissions worldwide, there are important trends emerging among the lower middle income countries. While their emissions are lower than the rich countries on per capita and aggregate levels, they are rising quickly on both counts. Indeed, as a group, they are on a trend of increasing CO2 emissions per unit of energy-use even if their energy intensity of GDP is falling. This suggests that the economies of the lower middle income group are actually carbonising rather than decarbonising.

Classification of countries as used in the figures in Annex A

Table 3: Low Income (43 countries)

Afghanistan	Guinea-Bissau	Rwanda
Bangladesh	Haiti	Senegal
Benin	Kenya	Sierra Leone
Burkina Faso	Korea, Dem. Rep.	Somalia
Burundi	Kyrgyz Republic	Tajikistan
Cambodia	Lao PDR	Tanzania
Central African Republic	Liberia	Togo
Chad	Madagascar	Uganda
Comoros	Malawi	Uzbekistan
Congo, Dem. Rep.	Mali	Vietnam
Eritrea	Mauritania	Yemen, Rep.
Ethiopia	Mozambique	Zambia
Gambia, The	Myanmar	Zimbabwe
Ghana	Nepal	
Guinea	Niger	

Table 4: Lower Middle Income (55 countries)

Albania	Honduras	Paraguay
Angola	India	Philippines
Armenia	Indonesia	Samoa
Azerbaijan	Iran, Islamic Rep	Sao Tome and Principe
Belize	Iraq	Solomon Islands
Bhutan	Jordan	Sri Lanka
Bolivia	Kiribati	Sudan
Cameroon	Kosovo	Swaziland
Cape Verde	Lesotho	Syrian Arab Republic
China	Maldives	Thailand
Congo, Rep	Marshall Islands	Timor-Leste
Cote d’Ivoire	Micronesia, Fed. Sts.	Tonga
Djibouti	Moldova	Tunisia
Ecuador	Mongolia	Turkmenistan
Egypt, Arab Rep	Morocco	Ukraine
El Salvador	Nicaragua	Vanuatu
Georgia	Nigeria	West Bank and Gaza
Guatemala	Pakistan	
Guyana	Papua New Guinea	

Table 5: Upper Middle Income (46 countries)

Algeria	Grenada	Peru
American Samoa	Jamaica	Poland
Argentina	Kazakhstan	Romania
Belarus	Latvia	Russian Federation
Bosnia and Herzegovina	Lebanon	Serbia
Botswana	Libya	Seychelles
Brazil	Lithuania	South Africa
Bulgaria	Macedonia, FYR	St. Kitts and Nevis
Chile	Malaysia	St. Lucia
Colombia	Mauritius	St. Vincent and the Grenadines
Costa Rica	Mayotte	Suriname
Cuba	Mexico	Turkey
Dominica	Montenegro	Uruguay
Dominican Republic	Namibia	Venezuela, RB
Fiji	Palau	
Gabon	Panama	

Table 6: High Income (66 countries)

Andorra	France	Netherlands Antilles
Antigua and Barbuda	French Polynesia	New Caledonia
Aruba	Germany	New Zealand
Australia	Greece	Northern Mariana Islands
Austria	Greenland	Norway
Bahamas, The	Guam	Oman
Bahrain	Hong Kong SAR, China	Portugal
Barbados	Hungary	Puerto Rico
Belgium	Iceland	Qatar
Bermuda	Ireland	San Marino
Brunei Darussalam	Isle of Man	Saudi Arabia
Canada	Israel	Singapore
Cayman Islands	Italy	Slovak Republic
Channel Islands	Japan	Slovenia
Croatia	Korea, Rep.	Spain
Cyprus	Kuwait	Sweden
Czech Republic	Liechtenstein	Switzerland
Denmark	Luxembourg	Trinidad and Tobago
Equatorial Guinea	Macao SAR, China	United Arab Emirates
Estonia	Malta	United Kingdom
Faeroe Islands	Monaco	United States
Finland	Netherlands	Virgin Islands (U.S.)

Annex B: A brief history of international policy towards energy and development

Technology has long been seen as an important factor of development. Early theorising identified industrialisation as essential to economic growth in developing countries and therefore saw access to technology as central to the success of the development process. Whether the overall development strategy was based on import substitution or industrialisation by invitation, the importance of using efficient production technologies was the same (Hunt 1989; Oman and Wignaraja 1991). Such technologies, it was assumed, were those designed and manufactured in the industrialised economies and so it was from here that technology needed to be ‘transferred’ to the developing economies. Furthermore, it was thought, developing countries could be ‘spared’ the cost of innovating to create these technologies, while enjoying the benefits (Bell and Pavitt 1993; Radošević 1999).

In line with this thinking, from 1948 the ILO and UNESCO began supporting teams of experts to provide technical assistance to developing countries (Shah 2009). However, mainstream economic theorising viewed technology as an exogenous factor – a given – and so understood ‘technology transfer’ as predominantly an event rather than a process. As such, technology could be purchased by a developing-country firm, which could be trained how to use it, and then be ready to compete with all other firms that also had the same equipment (Bell 2009). From this perspective, the only difficulty regarding technology was to finance its purchase. Therefore, as the development endeavour gathered pace during the post World War II period, the financing of technology became an important focus of attention, whether through the private sector or through the interventions of bilateral and multilateral donors. Developing countries needed technology and industrialised countries lent the money through ‘aid’ to finance that technology. As Robb (2004: 21) notes, this was clearly “a manifestation of inequality” and, moreover, with the Cold War as a motivator of interventions in many parts of the world, the offering or withholding of aid – both from the West and the East – became a tool of foreign policy.

It is not surprising then that ‘technology transfer’ became highly politicised; an object of power relations between the industrialised and developing worlds (Robb 2004; Shah 2009). Initially, however, there was a long period of optimism about the role of science and technology – particularly science – in development. This was rooted in what Standke (2006: 641) describes as a 20-year period after WWII of “euphoria for science in the developed countries”; the period culminating in the first specialised science and technology conference organised by UNESCO in Geneva in 1963. Out of that conference the Committee on Science and Technology for Development (CSTD), the Advisory Committee on the Application of Science and Technology for Development (ACAST), and the Office of Science and Technology (OST) within the UN Secretariat were created (UNCTAD 2003). But this "techno-optimism" began to turn more critical with the confluence of a number of factors (Shah 2009: 8-9). The G77 group of developing countries was formed in 1964, increasing their bargaining power within the UN system (G77 2010); various forms of dependency theory were being posited to explain the uneven record of development, or underdevelopment, (Hunt 1989: 67-68); there was a general questioning of the assumptions of 'standard' economic-growth models, particularly in the light of debates following publication of The Limits to Growth (1971); a wave of environmental awareness began to emerge that helped, among other factors, to stimulate organisation of the UN Conference on the Human Environment in Stockholm in 1972 (Najam and Cleveland 2003); and critiques of 'technology transfer' to developing countries were articulated in the 'Sussex Manifesto' (1970), as well as Small is Beautiful (1973) (which helped to inspire the growth of the Appropriate Technology movement) (Carr 1985; Smith 2005). Perhaps the most radical development was the attempt by the G77 to demand a New International Economic Order (NIEO) (which, among other things, sought better terms of technology transfer), spurred by a temporary rise in the group's power (and confidence – see Bhagwati 1986, particularly page 769) following the 1973 oil-price shocks and changes in other economic and political conditions (Geldart and Lyon 1980: 91-94).

So, by the time of the second conference on science and technology – the UN Conference on Science and Technology for Development (UNCSTD), held in Vienna in 1979 – the political landscape had changed significantly. Amid increased North-South tensions in regard to the NIEO – towards the establishment of which UNCSTD was intended to contribute (Standke 2006: 637) – the conference was "not about transferring technology but [about] asserting equitable access" to technology (Shah 2009: 13). Bearing in mind that the agreed plan of action was not supported by any serious financial commitments, and that attempts to manoeuvre science and technology expertise to the UN in New York were both unsuccessful and precipitated a weakening of UNESCO's position as the pre-eminent source of science and technology expertise within the UN system, Standke (2006: 637-639) judges the conference to have been a failure. Indeed, subsequent UN conferences that related either to science and technology or, more directly relevant to our interest in this paper, those concerned with energy, environment and development could be seen largely as failures. But this may be a simplistic interpretation. Certainly, there are some who argue that there is reason to be cautiously optimistic (see, for example, Najam and Cleveland 2003). Still, we will not assess here whether these were successes or failures. Instead, we believe they illustrate how enduring are the themes of discussion between industrialised and developing countries concerning 'technology transfer' since the Vienna conference: the 'rate' and financing of transfer, and the issue of property rights.

In 1981 the UN held a conference in Nairobi specifically on energy – the Conference on New and Renewable Sources of Energy – and the intended transition away from fossil-fuel energy carriers (El-Hinnawi *et al*. 1983). For many developing countries this was an urgent issue as they were suffering severe economic problems as a result of high oil prices (notwithstanding those countries that were benefiting from increased prices for commodities and/or were exporting oil). The conference took place in the context of a new administration in the US, under the presidency of Ronald Reagan, which began to vigorously pursue the neo-liberal economic agenda already guiding others elsewhere (Harvey 2005). But, according to Bhagwati (1986: 769), developing countries were still in general pursuing the broad NIEO agenda "that put them in a confrontational posture with the developed countries". Certainly, there was little agreement over the terms of 'technology transfer', even if there was agreement that it needed to happen. According to the summary provided by Biswas (1983: 125):

> "Most delegations stressed the importance of technology transfer and adaptation in harnessing the potential of new and renewable energy in developing countries.
>
> The representatives of the developed market economy countries emphasized the important role of the private sector in this process. However, most of the representatives of developing countries stressed their need to have access to technology on reasonable and equitable terms, and considered that developed countries, where most modern technology originated, had a special obligation and responsibility in respect of such transfers.
>
> Uruguay reminded the Conference that technological advances in energy conversion are the result of huge efforts. Therefore it is very difficult if not impossible that they be given away free to others. France questioned whether the industrialized countries were ready to break the near monopoly that they enjoy over advanced technologies in the energy field."

Two further quotes following the conference give a flavour of the disappointments felt by some regarding the outcome. Norman (1981: 1235) comments that the failure to agree on how to finance and implement the Nairobi Programme of Action (something that was agreed):

> "… was entirely predictable. The United States delegation, together with a few others from industrialized countries, went to Nairobi with instructions to oppose the creation of any new institution or international fund … Delegates from Third World countries generally argued that new arrangements are needed to channel funds into the development of renewable energy resources in the developing world."

And, an editorial in the Times (1981) comments:

> "The Nairobi Conference … reviewed a range of renewable energy sources which the Third World might be able to exploit. …
>
> However, the nations of the South remain sceptical, partly because the North continues to talk of technology 'appropriate' to the South, leaving the impression that sophisticated technology is not appropriate to peasant cultures based on the wood stove and the bullock cart, which is often true. But there is also the failure of the advanced nations to devise ways in which the development of energy resources in the Third World can be effectively financed. …
>
> The Reagan Administration, however, believes that the exploration and development of new energy sources in the Third World should be left to private enterprises and not taken over by bureaucratic international agencies. As a result, the energy affiliate [of the World Bank] is, for the time being, no longer under serious consideration. This is a pity because the big multinational companies may not feel it worth their while to explore for new energy sources in poorer countries where any additional energy discovered may add only marginally to the total resources at the command of the company."

So, no special fund or new institution was formed out of the 1981 conference to help developing countries increase access to 'new and renewable energy' technologies. Nevertheless, the World Bank and UNDP had already begun energy assessments for developing countries, starting in 1980 through the Energy Assessment Programme (EAP). In 1983 the Energy Sector Management Assistance Programme (ESMAP) was created by the same institutions, subsuming the EAP, in order to "move from studies to actions" (Thalwitz *et al*. 1990: 1-2, emphasis in original). Based within the World Bank, ESMAP was conceived as a technical unit that would go beyond the investment recommendations given in the EAP reports to "more detailed pre-investment studies leading eventually to investment opportunities which the donor community could support" (Thalwitz *et al*. 1990: 2). The activities of ESMAP during the 1990s began to include more pro-active engagements such as testing particular types of equipment, developing new products, and experimenting with finance models (see, for example, the work done in Kenya in the late 1990s, reported in: Ochieng *et al*. 1999; Hankins and van der Plas 2000; EAA 2001). More recently it has provided assistance to develop policy for rural electrification and renewable energy, and conduct energy-stakeholder workshops in developing countries (Wang 2004). But its expenditure is small: total disbursements for the financial year 2009 were just under USD 15 million (ESMAP 2009).

Other, more substantial, funds and institutions have been created since ESMAP. In 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer was ratified; a process that had been initiated ten years earlier in Vienna (MLF 2010). In 1990, the Multilateral Fund (MLF) was established as an "inducement to participation by developing countries" (UNEP 2002:13), intended to help them "cover the incremental costs of complying with the Protocol's provisions" (Luken and Grof 2006: 244). This followed recognition in the 1989 Helsinki Declaration that CFC-substitute technologies needed to be transferred to developing countries urgently. Developing countries, in similar vein to discussions at the 1981 Nairobi conference, "vehemently demanded that transfer of technology be conducted on a free or non-commercial basis" while industrialised countries were concerned for the protection of intellectual property rights so as not to "undermine the incentives for research and development in environmental technologies" (Ling 1992: 115-116). The compromise achieved was the acceptance of paying incremental costs. To date, the MLF has disbursed over USD 2.34 billion through more than 6000 projects in 147 developing countries (MLF 2010), and ozone-depleting chemical emissions have been reduced globally by 95% (Green 2009). Furthermore, the Montreal Protocol and subsequent amendments established the principle of 'common but differentiated responsibilities', as well as providing a successful example of the application of the 'precautionary principle' (Green 2009: 259), achievements that led Mostafa Tolba (Executive Director of UNEP) to describe it as "a precedent-setting bargain" (quoted in Ling 1992: 97-98).

The Montreal Protocol was, of course, focused on a particular issue – the protection of the ozone layer – and was able to discuss solutions concerning discontinued use and replacement of particular technologies. The UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, however, was concerned with the fundamental connections and tensions between the development process and the environment in general. Although considered a failure by some, it is credited with at least raising the profile to global recognition of the environment and development relationship and the concept of 'sustainable development' (Najam and Cleveland 2003; Shah 2009). In addition to the official output of the summit – Agenda 21, the Authoritative Statement on Forest Principles, and the Rio Declaration on Environment and Development – the Global Environment Facility (GEF) rules were 'agreed', and both the UN Framework Convention on Climate Change (UNFCCC) and Convention on Biological Diversity (UNCBD) were established (Najam and Cleveland 2003). The GEF was intended to provide the finance for implementing Agenda 21, estimated to be USD 625 billion per year at the time, of which the industrialised countries would supply USD 125 billion through the GEF (UNEP 2007).

But the GEF was a controversial idea from the outset, particularly over the governance of the fund (Porter and Brown 1996: 141; Young 2002: 64). In essence, the industrialised countries wanted the GEF housed and governed within the World Bank and its structures, while the developing countries wanted a new institution governed along the lines of the UN General Assembly. The difference between the two forms is clear: the donor countries would have significant control if the fund were structured similarly to the World Bank; the developing countries would have significant influence within a UN-like structure (Porter and Brown 1996). Eventually, developing countries were persuaded to agree to the

GEF under the World Bank, but only after donors promised a review of the first period of operation, and a realisation that it was the best outcome the developing countries were likely to get. As Young (2002: 67) observes, "the main priorities of most Southern governments at Rio were reduced to simply maximising aid flows and technology transfer as far as possible". However, in 1994, agreement was achieved to restructure the GEF, including a governing council of 32 states (14 industrialised-country, 16 developing-country, and 2 from the transition economies) and the secretariat made "functionally independent of the [World] Bank" (Porter and Brown 1996: 145). Nevertheless, it remains controversial (Young 2002), and the finance actually disbursed has been "extremely modest in relation to the environmental challenges it addresses" (Porter and Brown 1996: 141). There are different estimates of the level of finances, but the three-year pilot phase saw between USD 730 million and USD 1.2 billion allocated, rising to USD 2 billion over the next three-year phase and USD 2.75 billion for the next period (Osborn and Bigg 1998: 112; Porter and Brown 1996: 142; Young 2002: 133). In terms of finance associated directly with the climate change remit of the GEF, the estimate is USD 1.4 billion in total up to 2002 (Ellis *et al*. 2007: 18). Whatever the precise figures, and whatever the level of arrears from various donors (Young 2002), these amounts were considerably smaller than the USD 125 billion per year that the industrialised economies were to provide.

More successful in terms of mobilising finance has been the Clean Development Mechanism (CDM) of the Kyoto Protocol. Disch (2010: 51) cites estimates of the value of carbon emissions reductions for 2007 alone as USD 7.4 billion, and the number of new projects has continued to grow rapidly. The CDM was created late in the process of the Kyoto Protocol negotiations following suggestions from Brazil for a Green Development Fund (an idea supported by the G77 and China but rejected by the industrialised countries), and the US for a market mechanism of emissions trading (Matsuo 2003). Finally agreed within the Protocol was a combination/compromise between the two proposals that was expected to simultaneously promote sustainable development while assisting industrialised countries to meet their Kyoto commitments (Lecocq and Ambrosi 2007: 134-135). Hailed as a "win-win" agreement by both the industrialised and developing countries (Matsuo 2003), the CDM nevertheless continues to attract criticism over a number of aspects. Among others, these include the fear that it will result in carbon 'leakage', and that it (Clémençon 2008: 85):

> "… allows developed country investors to accumulate carbon reduction credits cheaply by "picking the low hanging fruits" in developing countries and selling emission credits for big profits."

Although the CDM appears to be a credible and acceptable solution to the long-standing argument between the industrialised countries and the developing world over technology and finance (and could even be claimed as something of a victory for the developing world, considering that it has not had to commit to GHG reductions), the issue has not gone away. As Ockwell *et al*. (2008: 4104) observe:

> "How to achieve low carbon technology transfer … continues to represent a contentious issue, which came close to derailing a major part of the negotiations at the 13th Convention of the Parties … in Bali 2007."

The incident referred to concerns an intervention on the final Saturday morning by India and China that successfully changed Article 1(b)(ii) so that the emphasis of "measurable, reportable and verifiable" was placed on "technology, financing and capacity-building" rather than "nationally appropriate mitigation actions by developing country Parties" (Clémençon 2008: 76). As Clémençon notes, the differences between the two forms of text are subtle, perhaps even irrelevant, but the fact that the intervention was made highlights the sensitivity of the issues of technology and finance in climate negotiations. Indeed, during the Copenhagen conference in December 2009, we saw the same issues raised again. Fears among developing countries about the Copenhagen Accord – the final Draft Decision[16] of the Climate Change Conference in Copenhagen – are substantially related to the possible weakening of industrialised-country obligations to finance technology transfer to the developing world (South Centre 2010). Notwithstanding these fears, the Accord does articulate a number of measures that had been in developing-country demands for many years: a separate fund (the Copenhagen Green Climate Fund); a "Technology Mechanism to accelerate technology development and transfer … guided by a country-driven approach"; and "goals" for mobilising significant finance (UNFCCC 2009: 3). The details are absent, and the language is generally weak, but it represents a shift of some significance in the historical positions of the industrialised countries.

What this history reveals is just how long-standing have been some of the themes that bedevil current international climate change negotiations around low-carbon development:

- conceiving (low-carbon) development as a matter of access to technology
- debating the terms of that access
- assuring returns on investment for technology developers
- trying to spread the benefits of those technologies
- the respective roles for the private sectors and public sector – states and markets
- the absence of a focus on learning and development over time.

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[16] Although the Accord is described as a "Draft Decision", there are questions as to its status within the UNFCCC process. The Conference merely "took note" of the Accord and countries have been invited to "associate" themselves with it (Bodansky 2010; South Centre 2010). By mid-2010, according to the US Climate Action Network (USCAN 2010), "119 countries, including the 27-member EU, are likely to or have engaged with the accord, representing 83.30% of global emissions", while "5 countries will not engage with the accord, representing 0.58% of global emissions". There are reports that accuse the US of using threats of withholding climate finance from countries if they do not associate themselves with the Accord (Goldenberg 2010).

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