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INTERNATIONAL SUPPORT FOR DOMESTIC CLIMATE POLICIES

International Cooperation for Innovation and Use of Low-Carbon Energy Technology

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Convened by: Climate Strategies

Climate Strategies aims to assist governments in solving the collective action problem of climate change. Sponsors include departments from European governments and other stakeholders.

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About Climate Strategies

Climate Strategies aims to assist governments in solving the collective action problem of climate change. It connects leading applied research on international climate change issues to the policy process and to public debate, raising the quality and coherence of advice provided on policy formation. Its programmes convene international groups of experts to provide rigorous, fact-based and independent assessment on international climate change policy.

To effectively communicate insights into climate change policy, Climate Strategies works with decision-makers in governments and business, particularly, but not restricted to, the countries of the European Union and EU institutions.

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1. Introduction

The projected annualised costs for combating climate change run into figures of hundreds of billions of dollars (Newell, 2008). Encouraging innovation and use of low-carbon technologies aims to reduce these costs and increase the positive spill-overs into other sectors of the economy. The UNFCCC dialogue on long-term cooperative action to address climate change emphasizes the role for international cooperation to support technology R&D and deployment, with the intention of reducing the cost of technology and ensuring its widespread application (UNFCCC 2007). The necessary technologies for carbon abatement range across energy transformation, renewable power, energy efficiency and carbon capture. Global efforts to develop and deploy these technologies on the scale required for stabilised GHG concentrations depend on the pursuit of two dimensions:

- Continued **innovation** in existing and emerging low-carbon technologies to improve their performance and manufacturing processes, and to adapt it to national circumstances
- Ensuring widespread **use** of low-carbon technologies, including developing the regulatory framework and complementary infrastructure for manufacturing, operation, maintenance, project management and financing.

The paper combines academic frameworks, illustrative examples, and a novel patent dataset to explore the possible trade-offs between these objectives and identify complementarities arising globally between innovation, adoption and use of energy technologies. Four objectives (illustrated in Figure 1) for policy design to support low-carbon technologies are emerging:

First, any new technology has to be sold on national markets, and is therefore dependent on the capacity of these markets to manufacture, install, operate and use the technology. This absorptive capacity grows with the production and use of low-carbon technologies. Robust domestic policies are required to support growing use of low-carbon technology in conjunction with the evolution of regulatory and pricing structures that open the opportunities for economy-wide application of new technologies. International support can augment this process, address barriers, provide resources, and create confidence to encourage domestic and international investment. Complementing policies and technical cooperation can enhance the necessary skills, provide training, develop the institutional setting and grow the domestic supply chain to deal with complex technologies.

Second, innovation is required to adapt the technology to domestic needs, thus ensuring that technologies are viable in national and local conditions. Resources and capacities in the manufacturing sector are required for local adoption and adaptation of internationally available technologies. An international network of innovation centres can support these domestic innovative activities. These networks can provide an initial stimulus to increase domestic market demand and further domestic policies, to create the necessary regulatory, institutional and financial background for new technologies and concepts.

Third, experiences from different national applications of a technology enrich the technology choices available internationally. International cooperation can accelerate the accumulation of experience, with opportunities for cost-sharing, knowledge-sharing, coordination on standards to facilitate compatibility of technology components, and frameworks that facilitate licensing. Thus access to multiple national schemes can give technology companies the confidence to invest in innovation, as a larger market is less exposed to the policy and regulatory uncertainty of individual governments.

Fourth, investors and innovators are assured by credible technology policies with shared visible low-carbon and social objectives. Increased experience with technology policy, international cross-fertilisation, and changing governments will result in a continued evolution of national policies and frameworks. If there is a commitment to the overall policy objectives, successful low-carbon and energy efficiency technologies and projects will continue to find market opportunities, irrespective of the specific policy choice. International processes can enhance this commitment by providing support and allowing national governments to make public commitments.

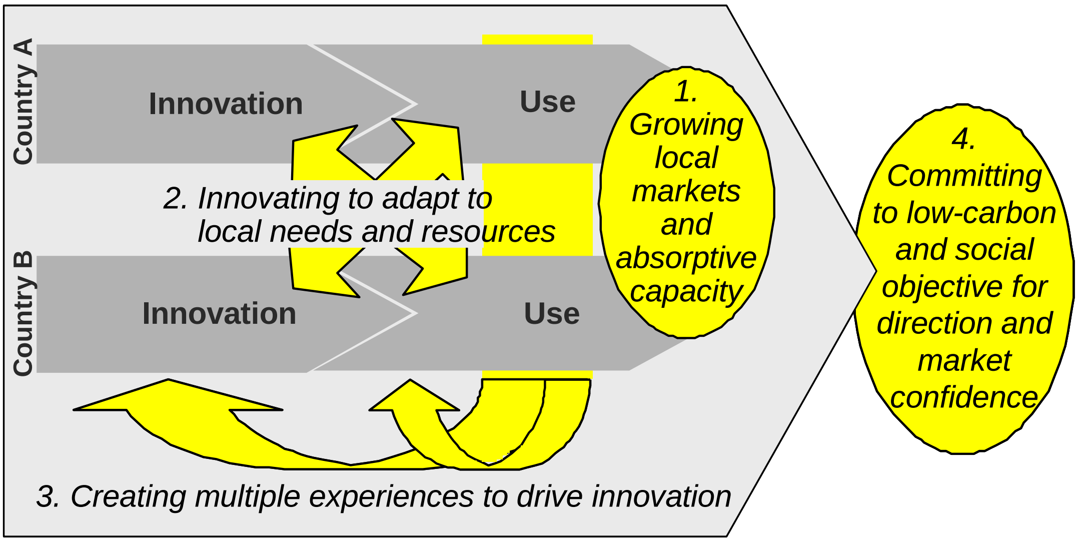

Figure 1. Innovation Chain: International Synergies and Use

This paper builds on the broader framework of the innovation chain that traces the development path of a technology, or technological component, from conception to widespread diffusion. Grubb (2004) suggests that the innovation process can be usefully thought of in terms of several key development stages. Research and development is typically followed by some gradual move into demonstration projects or prototypes. The subsequent commercialisation phase provides market experience to tailor the product to consumer demand, explore smart ways of manufacturing the product and accumulate experience and production scale to reduce costs. This can ultimately generate the right conditions for widespread deployment and diffusion of the product.

Figure 2 Figure 2 illustrates that movement along the innovation chain is determined by synergies between different stages of the process. Experience during demonstration, commercialisation and diffusion guides research and development, which can trigger new demonstration and subsequent commercialisation of the improved process or technology in a virtuous circle.

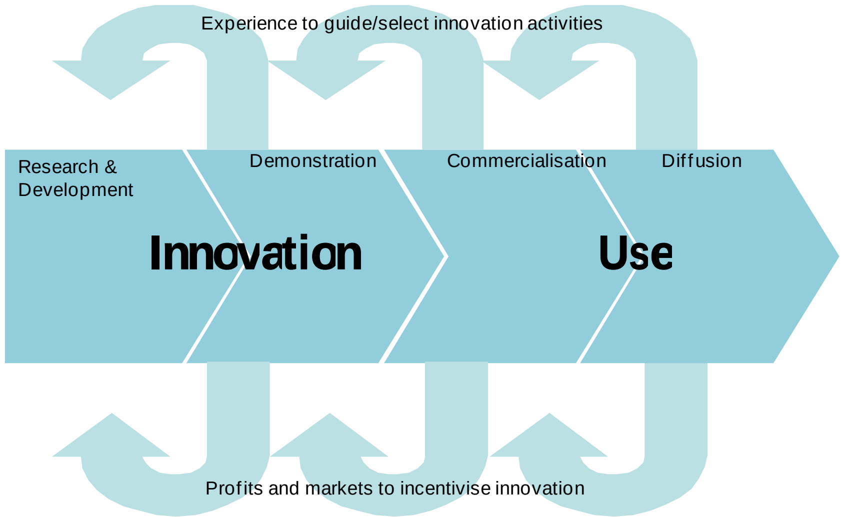

Figure 2. A simplified model of the innovation chain for a given technology

This paper focuses on the role of domestic policies for technology development, adoption and diffusion. It also explores the wider discussion about the role of IP rights in stimulating innovation and promoting - or hindering - technology diffusion. Section 2 focuses on domestic policies to support innovation and use of low-carbon technologies. Multiple, local innovation streams generate diverse innovation contributions, create locally adapted solutions and build local absorptive capacity for subsequent large-scale use of technologies. Section 3 explores the opportunities to increase the interaction between local innovation streams. Section 4 focuses on the international interactions and support needed for commercialisation and wider use of technologies. Finally section 5, synthesises international innovation and use, and concludes with a discussion on the implications of national and international technology innovation and use for policy design.

2. Domestic Policies to Support Innovation and Use

Historically, the adoption of superior technologies and improved efficiency of existing technology platforms have been shown as critical drivers for increased productivity and economic development (Nelson & Winter, 1982). Similarly, improving the efficiency of current energy technology and the adoption of novel and superior technological solutions are expected to play a crucial role in climate mitigation strategies and our transition to a low-carbon energy economy. The energy technology innovation process generates new employment opportunities, expands markets and strengthens local skills as well as creating the potential for realising environmental benefits (Foxon et al, 2004).

Government policy to support innovation may have a variety of motivations. For instance, where technology spillovers reduce private agents' ability to internalise the returns from innovative activity, government policies may aim to increase the incentives through R&D support schemes or strengthening of IPRs. On a broader level, inherent market failures in demand for future goods and services, in the context of new technology risk or market size, may lead to sub-optimal investment in innovation; governments may address this by purchasing pre-commitments for specific technologies, and other tools. Studies have highlighted the importance of domestic policy support for adequate investment in clean energy research and development (e.g. Garibaldi (2007)). Interventions such as public funding for R&D, carbon pricing, removal of regulatory barriers and strategic deployment of new technologies can help redress these issues.

In this section innovation is analysed from the perspective of one market, typically at the national level. The next sub-section discusses policies in the context of the first two innovation stages R&D and demonstration. Then the commercialisation and diffusion of technologies is addressed. Finally, possible synergies that a comprehensive policy can leverage across the innovation chain are explored.

Innovation Policies: Research, Development and Demonstration

Figure 3. Innovation in the national context

Research, development and demonstration lies at the heart of innovation and innovation systems. Public and private R&D spending represents the critical driver behind experimental and emerging technologies. It bridges the divides between concept, prototype and demonstration of production processes, technology components or emerging technologies. Applied R&D, especially in the private sector, is driven by market demand, or potential market demand, and thus focuses more heavily on development. Public R&D activity tends to focus on more basic and applied research, although strong overlaps and synergies exist between these dimensions. Collaboration across the public and private sectors is important for sharing experience and driving innovation (Ockwell et al 2006)

According to the OECD, member countries account for 85% of total R&D spending globally, amounting to over $800 billion annually (OECD 2007). Of this, the public sector of IEA members spend around $11bn on public sector energy technology R&D, whilst the private sector accounts for another estimated $40-60 billion annually (IEA, 2008a). Estimates suggest that overall power sector R&D spending has declined in both the public and private sectors since its peak around 1980 (See Figure 3)[1].

[1] It should be noted that public R&D expenditures are only a partial proxy for overall energy R&D activity. For several emerging low-carbon technologies such as Solar PV and biomass, many of the important technological steps have occurred outside the energy sector and beyond conventional energy research funding- e.g. in the biotech and electronics industries.

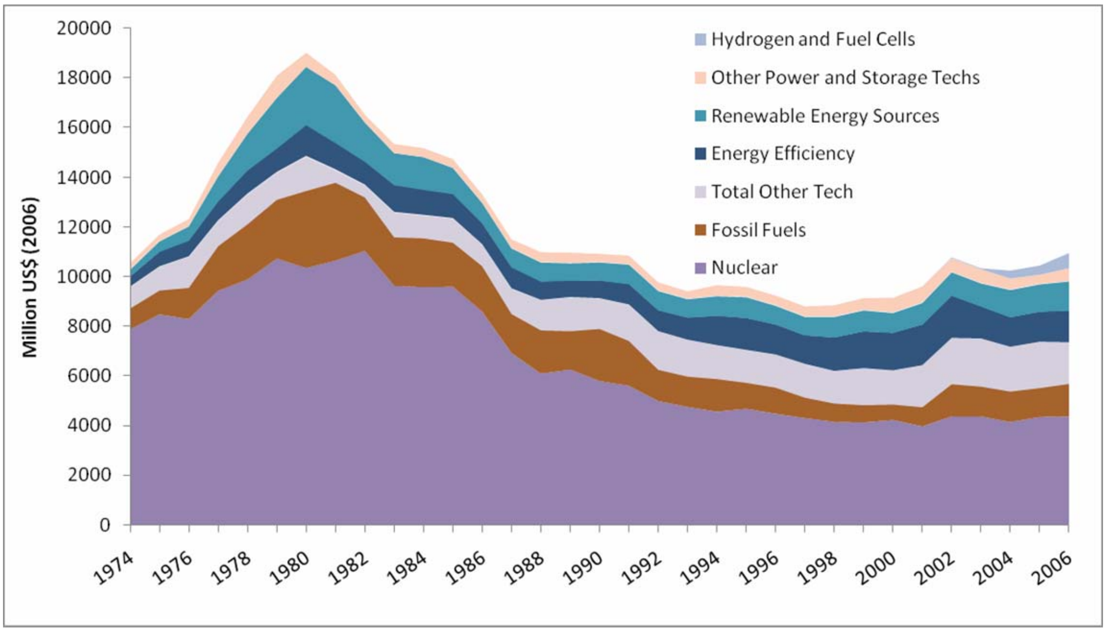

Figure 4. Technology Share of IEA Public Expenditure on RD&D

Historically, **research and development in the energy sector** has been lower than that in product driven sectors (Grubb et al, 2008). In the private sector R&D could be limited because it is very difficult for firms to fully appropriate their investments in R&D (Margolis and Kammen, 1999). Technology spill-over in the energy sector is large (Neuhoff, 2006) making it harder for private sector agents to recover the full benefits of innovation and breakthrough. This, along with markets often failing to fully internalise environmental externalities, undermines the incentive to achieve optimal amounts of innovative activity. Various policy instruments create support for innovation in the energy sector:

- **Publicly funded research and development programmes**
  In many OECD economies the public sector has directly funded research into novel renewable technologies. In the US such funding has been channelled through the Department of Energy (US DOE, 2005), while in the UK such direct funding for R&D has been provided by the Research Councils. In the US in particular, there has been a significant increase in funding for Clean Coal technologies, which might explain the sharp increase in patent activity in clean coal technology after 2005 (see Figure 5).

- **Direct capital grants and subsidies**
  Innovation in the Danish wind sector was not only encouraged by direct grants for R&D programs but also by the market demand that resulted from a subsidy for installation of turbines to the value of 30% of the investment (Karnøe, 1989). These solutions are directed at both ends of the innovation chain; supporting R&D and providing the enabling environment for commercial application. Similarly, innovation in the Japanese PV sector was supported by capital grants and direct investment aid. In 2007 Japan had the second biggest country share of production (23.8%) with Germany holding the largest at 35% (IEA, 2008b).

Technology demonstration is used to establish whether emerging technologies are capable of working on a commercial scale (Garibaldi, 2007). It requires sustained investment and improved risk/reward ratios (Foxon et al, 2004). Public financial support can assist with the demonstration phase: A key factor in the development of clean coal technologies in USA was government supported demonstration plants, which led to private sector participation in developing advanced designs (Bañales-López & Norberg-Bohm, 2002).

Policies for Technology Use: Commercialisation and Diffusion

The gap between demonstration and the commercialisation and diffusion of a technology is the stage at which many technologies fail to survive (Grubb, 2004). Many infant technologies are not yet cost-competitive and are therefore not widely adopted by industry. This is pertinent in the energy sector where a majority of technology has benefited from many years of government support and incremental learning. Various enabling activities can be used to bridge the gap between demonstration and commercialisation:

Growing initial markets
An important factor that determines whether firms will invest in production capacity and pursue ongoing product improvement is their confidence in a growing market for the product (Bañales-López & Norberg-Bohm, 2002). Costs of newly commercialised technologies can decline with increased deployment through incremental process learning and innovation from production, installation and economies of scale.

For some technologies, removal of energy subsidies suffices to create a commercially viable environment; others might require the full internalisation of environmental externalities to be cost competitive (Garibaldi, 2007). In particular, the homogeneous nature of energy provision limits the role of natural niche markets for new technologies, and points to the importance of government policies for strategic deployment of a technology during its commercialisation phase. This could involve tenders, feed-in schemes or subsidies for low-carbon generation sources. For example, in South Africa, the electricity utility Eskom, accelerated the diffusion of PV panels in rural settlements by subsidising the cost of installation. Such support mechanisms can ensure the increased scale of a market for a new technology (Nemet 2008).

A growing market is not only important for a narrowly defined technology, but also for the broader industry included in the supply chain. It allows for the transition from small operations to mass-production of the technology, including training and development of other facilities such as after-sale service, insurance, maintenance and quality checks. Thus the building of local markets and local absorptive capacity facilitates subsequent technology use.

Non-financial support during commercialisation
The risks associated with new technologies could be mitigated through the establishment of stringent quality standards and regulations. This can build confidence in local technologies (Siikavirta, 2006). In 1978 a test station for wind-turbines was established at the Risø Centre in Denmark. This not only provided resources for demonstrating technologies but also allowed quality standards to be set for the technology. All Danish designs had to undergo a demonstration phase at the Risø Centre before they could be authorised for commercial use (Karnøe, 1989). This ensured that sub-optimal technologies did not proceed to market.

Improving the regulatory environment
Diffusion of a technology at the domestic level is generally driven by the development goals of a country. Technology choices will be made relating to the local needs of the country. Lu et al (2007) suggest that the success of China's clean coal technology industry was driven by

the introduction of technical policies with tangible goals and penalties. Thus environmental policies have enhanced the incentives created by technology policies through the implementation of stringent emission standards (Lu et al, 2007). In 1997 the Chinese government distributed their 9th Five-Year Plan on Clean Coal and Development until the year 2010. It is believed that this document became the driving force in the CCT industry (Yu & Yu, 2001). Discussions on the appropriate policy framework to support carbon capture and sequestration are moving in a similar direction – with increasing emphasis on mandatory standards for capture ready plants or emission standards for plants built after a certain year that can only be satisfied by using carbon capture and sequestration.
Non-market barriers for implementing generating technologies, such as difficulties in accessing the electricity grid and power market may also need to be removed.

Creating Synergies between Stages in the Innovation Chain

Johnson and Jacobsson (2002) suggest that in the early stages of research and development, technology uncertainty is high and firms need to be encouraged to explore a variety of options. Alic et al. (2003) support this view and recommend that funds should be made available for a wide range of programmes to encourage competition and support diversity. This highlights the need to maximise the benefits of feedback loops and synergies between stages in the innovation chain to ensure that strategic innovation and technology deployment takes place.

Encouraging a variety of innovation streams
It is important not to take a myopic view of innovation support. For example, R&D-led attempts in Germany, the US and other countries in the early 1980s, that exclusively focussed on building multi-megawatt wind turbines failed both on engineering and cost grounds (Norberg-Bohm, 2000; see also Bergek and Jacobsson, 2003). However private and subsequently public initiatives in Denmark supported a wide range of R&D in small and large wind turbines (Jensen, 2004). Through application experience, the turbine manufacturers learned how to address design challenges, and turbine sizes gradually increased (Grubb and Vigotti, 1997). Strategic investment in R&D for wind energy cost Denmark an estimated US$1.4bn in subsidies between 1993-2001; meanwhile, annual revenues of Danish wind companies by 2001 were $2.7bn, the vast majority of which came from its dominant position in export markets (Carbon Trust, 2003).

Building Confidence in future market opportunities
By outlining industry requirements and capacity targets, governments can assist in guaranteeing a future market for technology. In Denmark, the adoption of an energy plan in 1981, which outlined a target 10% wind contribution by 2000, created confidence amongst the private sector for the future of the industry (Karnøe, 1989).

Policies that remove 'old technology' energy subsidies and internalise carbon costs create future market opportunities for low-carbon technologies that succeed in the commercialisation phase. Thus these policies are important for innovation and investment decisions in low-carbon technologies, even at times where technologies still require additional support from government sponsored commercialisation programs.

In summary, the experience from national technology policy illustrates that public support for RD&D is necessary to assist innovation in the energy industry. Commercialisation of a technology is encouraged through the generation of market demand or by guaranteeing the existence of a future market. Strategic deployment programs, improving the regulatory environment and ensuring that quality standards are adopted, accelerates the use of technology. Foxon et al (2005) highlight the crucial role of a stable and consistent policy framework to support this iterative process. Therefore, policy instruments need to be developed in response and as a complement to the environmental and development objectives of the country.

3. International Innovation

Cost reductions in renewable technologies or their production processes occur when innovation is encouraged on an international scale (Bottazzi and Peri, 2004). Innovation tends to be geographically dispersed, at least in part due to high knowledge spill-over effects and globalization of the production value chain of energy equipment manufacturers. To illustrate international differences and collaborations in innovation activity a novel patent dataset[2] for clean coal innovation was developed. Figure 5 illustrates the diverse national origins of patent filings. It also displays the emergence of new players, such as the Republic of Korea and India, in the coal innovation system. Strong innovation activity can be observed across major developed and developing economies, with China accounting for 12% of all patents in the past five years[3]. Clean coal patenting activity, has kept pace with rapid growth in global patents.

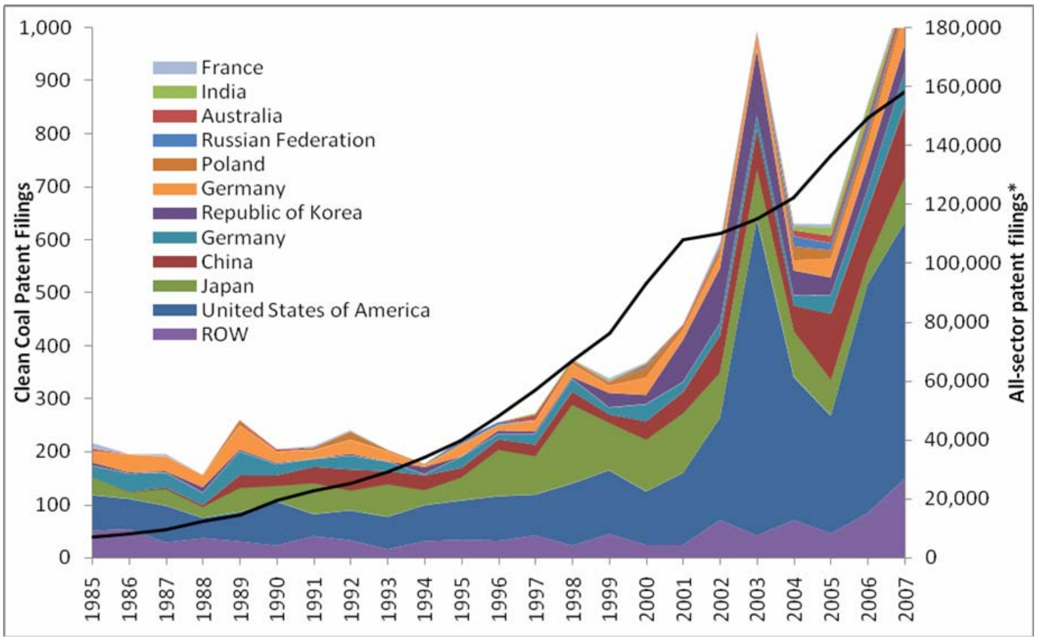

Figure 5. Clean Coal Countries by Inventor Origin (Top 10 countries in terms of total patents in past 5 years)[4]

[2] The Clean Coal patent dataset was developed by using a combination of industry expert interviews and in-house research. The 'technology descriptors' gathered were used to create patent search algorithms for four technology sub-fields, which collectively are believed to represent the bulk of Clean Coal related innovation. The resulting dataset of 7,752 patents and patent applications was used in generating the analyses in later parts of this paper.

[3] This is defined by country of origin of patent inventor

[4] All-sector patent filings under WIPO only. Clean Coal patents drawn from all available patent databases including USPTO, EPTO, WIPO and SIPO.

Figure 5 also illustrates the changes in patent activity between countries and points towards the potential for sharing experiences from bursts of innovative activities in individual countries. At each stage of the innovation process, access to international experience and markets provides the knowledge and resources required for the development of a diverse range of technologies. International collaboration allows for cooperative specialisation and mutual learning (Grubb, 2004). Multiple feedback loops from accumulated learning-by-doing assists in accelerating the incremental improvements in innovation.

The optimal policy instrument or suite of instruments to encourage international collaboration may be country and/or technology specific. Therefore they need to be tailored to suit the national capacities for learning (OECD, 2002). A convergence of domestic policies from different countries may not be required as national innovation policy generally only impacts local actors (Neuhoff, 2006).

Research Development and Demonstration Collaboration

The OECD report on *Dynamising National Innovation Systems* noted that it is becoming increasingly necessary for firms to enter global alliances to effectively access distributed knowledge and to provide support for the growing costs and risks of R&D and innovation (OECD, 2002). The report indicates that innovation clusters are a powerful mechanism for encouraging knowledge flows and complementary interactions. A cluster is defined as “networks of interdependent firms, knowledge-producing institutions and customers, linked in a value-added production chain” (OECD, 2002).

Past collaboration trends
Data on clean coal patents gives an indication of the extent of international collaborations in innovative activity in the past. Figure 6 shows a dynamic picture of the changing collaboration between countries by using the recording, on a single patent, of multiple inventors from different countries of origin, as a proxy. This illustrates growing international networks and also the increasing globalisation of energy companies and research activities. Both intra-continental (shown by circular arrows) and intercontinental (shown by straight connecting arrows) collaboration grows between the periods 1998-2002 and 2003-2007.

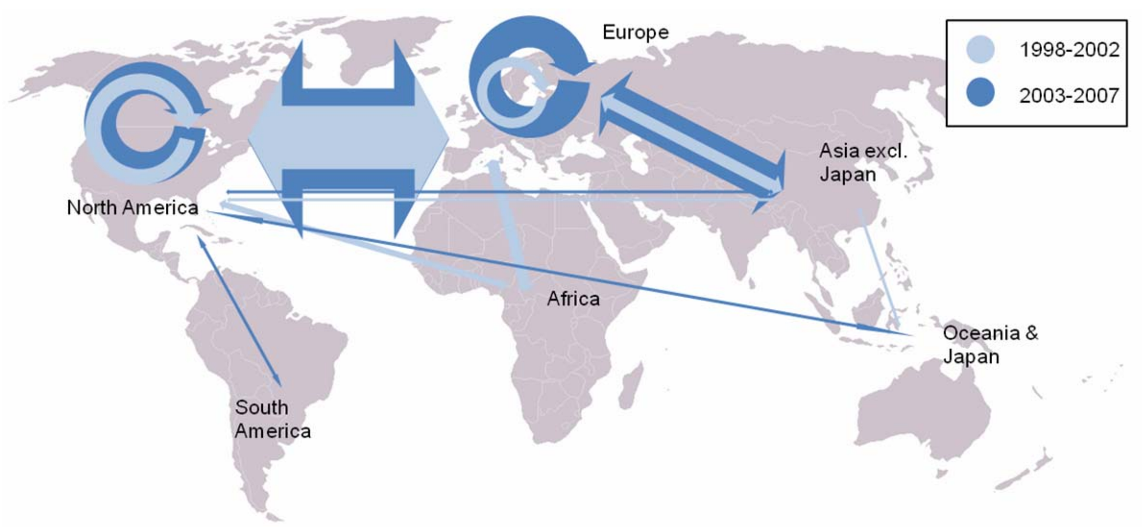

Figure 6. International Inventor Collaboration on Clean Coal Patents

The Figure indicates that collaboration activities are concentrated within and between North America and Europe, with some limited activity between Europe and Asia. Collaboration between developed and developing countries is less evident. These findings are supported by a recent study by the World Bank that indicates that the majority of innovation and invention activities are carried out in high-income countries (World Bank 2008). While technology cooperation is increasing internationally, the extent of cooperation between developed and developing countries is still limited. It would be extremely beneficial for developing countries to establish research collaborations so that innovation can spread. Added to this, by getting involved in the earlier stages of the innovation process, developing countries can have some input into the adaptation of technologies to their local contexts.

Clean coal patent data (Figure 7) illustrates the changing pattern of clean coal innovation. This is most noticeably indicated by the spikes of proportionate clean coal patent filings first in Germany, then in India and Poland. This could be as a result of changing national priorities resulting in different use of technology and expectations of future technology use by market participants. It could also be as a consequence of the gradual integration of international markets. Our observations are consistent with the gradual migration of 'old technology' manufacturers in South economies from a low-tech/non-patentable type of production to more high-value added/patentable work. This change may be the result of modernisation through FDI, sub-contracting arrangement to a 'North' multinational, or other modes of engagement with 'carriers' of North technology.

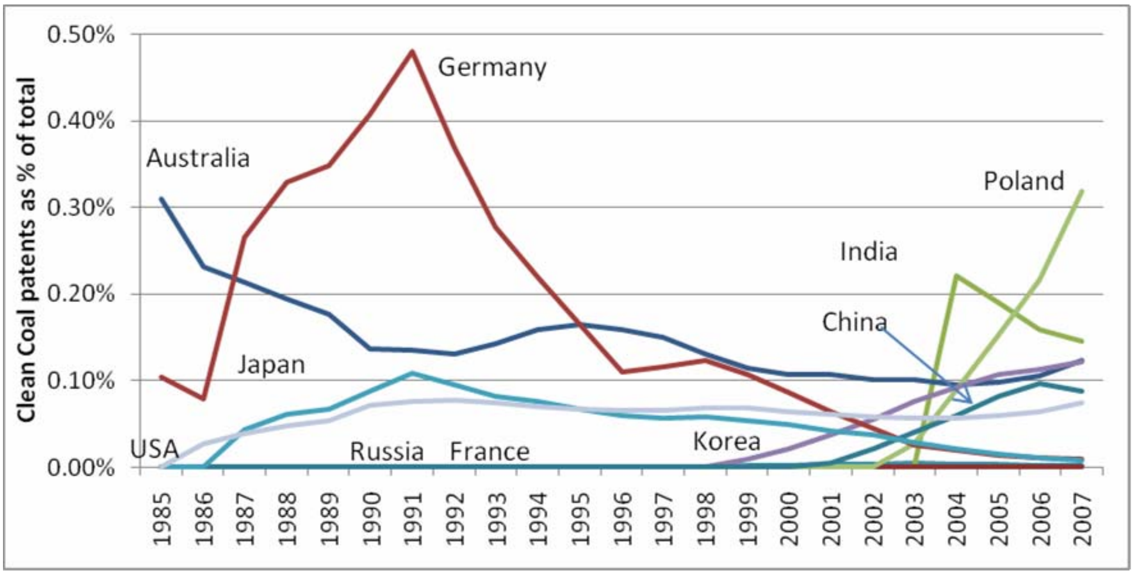

Figure 7. Clean Coal patents as proportion of total WIPO filings by Priority Country of first filing (5-year moving average for top 10 Clean Coal filing countries).

Innovation appears to be driven by emerging markets that create commercial incentives to adapt a technology to a new environment or context. The benefits of nurturing improved international innovation systems are discussed below.

Facilitating knowledge transfer: the role of Intellectual Property rights (IPRs)

Article 4.5 of the UNFCCC calls on developed countries to "promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how." The distribution of knowledge is paramount in international partnerships and various forums have been set up to support this process:

- The International Energy Agency (IEA) set up the 'Implementing Agreements' framework to promote collaboration in technology research and development. This system is a step in the right direction, however renewable technologies only get a small share of the $120-$150million that is annually spent under this programme (Neuhoff, 2006).
- The Expert Group on Technology Transfer was established within the UNFCCC process to promote the development and transfer of technologies. The TT:CLEAR information portal was launched to provide a publicly accessible web-based resource on technology and transfer information (UNFCCC 2007).

Any detailed examination of the question of technology and knowledge transfer would have to take into consideration the question of patents and intellectual property rights (IPRs). Many of the key actors in the energy sectoral innovation system make heavy use of patent protection as a way of capturing returns on their R&D investments, as well using it as a strategic positioning tool. Hence increased international cooperation in energy technology transfer may result in increased prominence of negotiation, with the owners, for access to IPRs for underlying technologies. Continued liberalisation of trade in services and international diffusion of legal code has led to a remarkable synchronisation of patent law and best practice across economies. While implementation questions persist in some developing economies, overall we are witness to the most integrated marketplace of IPRs historically. Yet considerable controversy remains as to the impact, of strengthening IPRs, on economic development and international technology transfer. Research has consistently indicated that the impact and role of IPRs on trade systems is different from the idealised view expressed in the economic literature. Enhancing IPRs has been seen as a barrier to diffusion of innovation (Alic et al., 2003): Monopoly rights to production and monopoly pricing of licences associated with patents may limit the affordability of low-carbon technologies in developing countries. International rivalries may cause complications when allocating IPRs or the biased promotion of local technologies (Grubb, 2004). RETs can also be quite disaggregated and as such depend on a 'cluster' of industries to provide the different components. Therefore collaboration is required across many companies to improve the overall operation of the system (Neuhoff, 2006). The spill-over of such partnerships can be difficult to recover as much of the learning experience is intangible and it is not always possible to predict the contribution of the innovation to future profits. Experience also shows (Ockwell, 2006) that even when partnerships are established between developed and developing countries, firms believe that it is not within their commercial interest to fully divulge their knowledge and they may wish to retain control over certain key technologies.
Even where 'North' companies have shared technologies fully through licensing-out, they may use their IPRs to block access to their core domestic markets of 'South' manufacturers. Hence incumbent players may use their IPRs to diminish the rate of technology transfer or extract disproportionate rents. Controversies surrounding the manufacturing of generics and anti-retroviral drugs in the 1990s and early 2000s are examples frequently cited.

However, it has also been argued that patents allow firms to licence innovation, making the information available in the public domain and allowing incremental improvements. IPR concerns begin to escalate in a highly concentrated industry and/or where the complexity of a technology develops significantly: such as was the case in the semi-conductor industry in the 1980s. Barton et al. (2007) suggests that for some renewable energy technologies (solar PV, biofuels and wind) there exists a significant amount of competition (in the industry and with existing technology) such that licensing and IPRs are unlikely to present financial barriers for too long. IISD (2008) suggests that patents are necessary because they allow firms to recover the costs of innovation and thereby create an incentive to invest in R&D. It goes on to propose that robust patent laws in a country may assist with technology transfer because technology firms may be averse to transferring products to countries with uncertain laws, for fear of imitation. In addition, an ability to register and prosecute a patent is a strong signal, by a new entrant, of organisational and innovative capability: assisting with strategic entry in new industries.

While the pharmaceutical industry has frequently been criticised about its IPR practices, other industries have been remarkably successful at using IPRs to promote an IP governance regime that has encouraged sharing and exchange of technology under non-discriminatory licensing practices. Since the 1980s the semi-conductor industry has been characterised by a remarkably low rate of litigation, while new entrants from the 'South' (initially South Korea and now China) have been able to participate in these frameworks and gain access to US and EU markets. Similarly the mobile telephone industry has seen remarkable rates of innovation and growth on the back of cross-licensing and patent pooling agreements around the GSM, 2G, 3G and other standards[5].

The debate continues regarding the extent to which patents might impede diffusion to developing countries or whether alternative patent paradigms might undermine incentives to innovate.

Smoothing out volatility of R&D expenditure

An additional benefit of international innovation is that with global networks, the impacts of shifting priorities in national government R&D budgets could be minimised. This point is illustrated by Figure 8, which shows the change in priorities in government R&D expenditure on energy technologies.

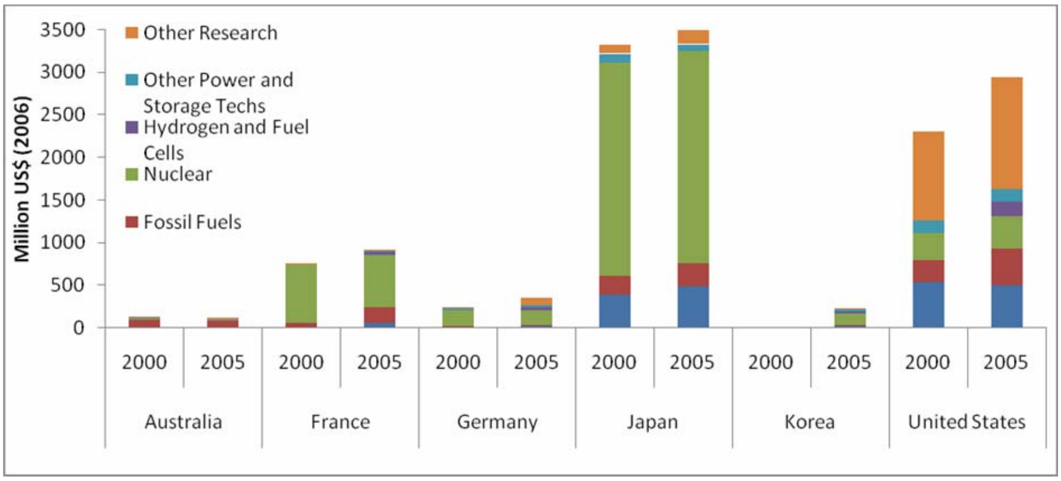

Figure 8. Technology shares of Public R&D expenditure for years 2000 and 2005

[5] See the website of the European Telecommunications Standards Institute (www.etsi.org) for a history of the emergence of the GSM and other mobile telephony standards, and an example of how IPR conflict can be successfully intermediated through an industry organisation.

The changing support level for individual technologies limits the ability of research institutions and departments to hire staff and retain expertise. Global cooperation on RD&D could smooth out the volatility of national support programs. International innovation cooperation can help ensure that research and demonstration takes place irrespective of changes, volatilities or political uncertainties at the national level. This further emphasises the overall value of supporting multiple innovation streams across different countries.

Increased access to financial support

Collaboration in innovation actions and resources has the further benefit of enabling working groups to tap into a much larger pool of financial resources which are currently concentrated in only a handful of IEA members. Significant differences exist across countries in terms of size of public expenditure, with Japan and USA accounting for the majority of the R&D spending (Also illustrated in Figure 8). Multinational funds could assist in balancing this inequality.

Shifting R&D activities from public to private sector

Effective collaboration in R&D increases linkages between public and private research institutions. Patent data indicates that with the maturity of innovation streams there is a shift from public to private sector supported R&D. This is illustrated in Figure 9, which shows the differences in origin and ownership (in terms of patent assignee) of Clean Coal patents. In Annex I countries the largest portion of patents are filed by companies i.e. the private sector. In contrast, in Non-Annex I countries, a significant share are filed by publicly supported research institutions. The findings suggest that universities and research institutes are relatively more important sources of innovation in emerging markets than is the case in developed economies. A secondary consideration may be the greater awareness and capability, of universities and research institutes than of local private sector actors in developing countries, of using the patenting system. These illustrations indicate the importance of accelerating the maturity of innovation streams in developing countries because as private R&D becomes more self sufficient, developing governments will have less strain on their national budgets and will be able to dedicate funds to other development priorities.

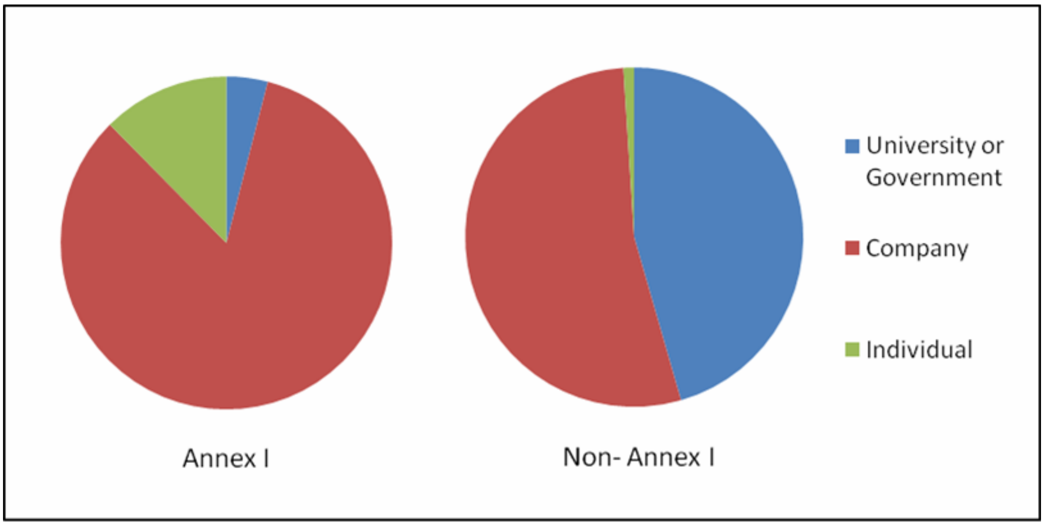

Figure 9. Organisational Breakdown by number of Clean Coal Patents for Annex I and Non-Annex I countries, for period 1971-2007.

In summary, this section reviewed the benefits of promoting international collaboration in innovation. The positive impacts of domestic innovation discussed in section 2 are amplified when projected to an international scale. Not only through access to increased financial and technical resources but also through the smoothing of changing national budget priorities. The need to increase collaboration between developed and developing countries was highlighted, whilst also recognising the value of multiple complimentary innovation streams.

4. International Use of Technology

Widespread deployment of low-carbon technologies across both developed and developing countries is critical for successful climate policies. It allows for improved energy services, lower carbon emissions, and the accumulation of experience in a growing market can reduce costs globally. Research shows that a growing frequency of international relationships is correlated with the strengthening of domestic networks (OECD, 2002). This illustrates the importance of parallel support for domestic and international activities.

As indicated in Figure 10, international cooperation can enhance technology choice and scale of implementation through supportive regulation, financial transfers, or policies for technology access. The increased global use of a technology also offers incentives for local industries to innovate and exploit the potential of a larger market.

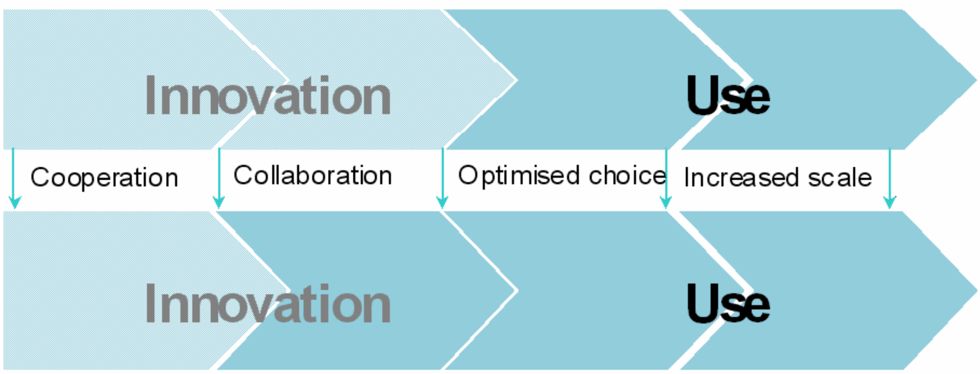

Figure 10. Innovation Chain for diffusion in international context

The previous section pointed to the role of innovation clusters in sharing knowledge during the innovation process. This idea could be expanded to facilitate the accelerated deployment of a technology by establishing networks that support the selection and use of optimal technology components and sharing of the knowledge that has been gained during implementation. By increasing access to the international market for technology buyers and sellers, the increased level of information helps to reduce the costs of acquiring existing technologies (Hoekman et al, 2005). The discussion of national technology policy in section 2 has shown that countries will seek to encourage innovation and use of technologies that promote their own development goals. However the goodwill of a government alone may not be sufficient for the effective diffusion of a technology.

Policy success is also contingent on domestic markets, the affordability of technology, and the absorptive capacity of the various local industries. In the global context, technology use depends on the ease of access to optimal technology, the penetration of new innovations, and the opening up of new financing channels. This section explores some of the drivers that encourage technology use across international boundaries and where international cooperation may have a supportive role to play in accelerating this process.

Building local capacity

The presence of global markets or the accessibility of technologies is not sufficient to promote the adoption of a technology. The capacity of a country to adopt and operate technologies in local industry is also a deciding factor. Whilst adoption of more efficient technologies offers large development co-benefits, weak internal diffusion persists across most developing countries. Recent research indicates a positive trend in the technological progress of low and middle-income countries. However, the ability of countries to absorb and deploy these technologies is often impeded by a lack of local skill and expertise (World Bank, 2008).

Encouraging firms to source a certain percentage of components and skills locally could accelerate the process of skill creation. China has encouraged joint ventures, more than pure foreign direct investment, to facilitate knowledge transfer, whereas Japan and Korea have used instruments such as import barriers and export incentives to nurture local industries (Hoekman et al, 2005). However, Moran (2004) suggests that there is a difference in the level of technology transfer between multinational enterprises and their local subsidiaries depending on local Trade-Related Investment Measures (TRIMs). Those that are restricted by mandatory joint ventures and domestic content requirements are not able to make use of the MNE’s existing resource network and therefore they may be averse to investing when they are required to procure locally at a higher cost.

Alternatively a combination of a policy to stimulate the demand for low-carbon and energy efficiency technologies can be paired with technical cooperation and assistance to support the development of local manufacturing. With public commitment to the diffusion of a technology, local industry will be encouraged to build up expertise in this area. Barton (2007) suggests that foreign direct investment in an industry develops local capability and facilitates independent research. However, it has been emphasised that it is essential for the necessary infrastructure and policies to be in place to provide an attractive climate for foreign investors (Ockwell, 2006).

Tailoring for country specific technology needs

Countries are characterised by a variety of different power generation structures and industry concentrations. International technology diffusion allows countries to tailor technology choices to their specific needs. For low-income countries, process learning and adaptation to local conditions is of central importance, typically building upon existing technology developed elsewhere (World Bank, 2008). One of the recommendations of the COP decision on development and transfer of technologies under the subsidiary body for Scientific and Technological advice, is that Non-Annex I parties compile a Technology Needs Assessment (TNA). TNAs detail the technology industries that countries hope to develop. These reports could highlight synchronicities and similar interests between countries where collaboration could occur and experience could be shared.

The lack of incentives is one reason for deficiency in local initiatives to adapt a technology to the country specific circumstances of a developing country. Private parties that contribute to the adaptation of a technology cannot retain ownership of the technology, with e.g. patents (World Bank, 2008). This undermines the very incentives to pursue such adaptation. Recommendations include a move towards applied R&D agencies focussing on outreach, testing, marketing, commercialization and dissemination activities (Sagar et al, 2008). Hoekman et al (2005), suggest that technology transfer could be facilitated through local R&D programs, a strong foundation of technical skill and human capital and the ability to apply technologies to local industry processes.

Case Study: Pre-Paid metering in South Africa - growing a local industry
Eskom is South Africa's government-owned electricity utility. In the 1990s Eskom sought to push electrification to non-connected rural and semi-urban areas using a secure pre-paid metering solution. After determining that there existed no appropriate solution globally, Eskom led a domestic alliance of electronics manufacturers to develop a locally bred technology and standard for pre-paid metering. The outcome was a globally adopted standard for pre-paid metering, which is now used by a majority of smart pre-paid electricity meters.

Eskom's approach was characterised by the mixture and sequencing of several strategic technology and innovation management techniques. Throughout the initiative Eskom committed itself to a growing volume of meters it would purchase. In the early stages of technology development, technology diversity was stimulated by the guarantee that purchases would be split across technology types. At this time, initiative participants were given access to complementary capabilities (such as R&D facilities and equipment testing results), while the broad outcomes of rounds of technology development were diffused among the participants. When Eskom narrowed its search on features, it switched to a push towards a common standard. In order to ensure transparent and neutral management, Eskom transferred its IPRs to a standards management body, the STS Association, of which it retained founders' rights. Simultaneously Eskom encouraged the internationalisation of the manufacturers' markets, and eventually began overseas purchasing of components. The STS standard underpinning the Pre-paid metering technology is now adopted by the IEC as the preferred pre-paid metering communications standard, and is used by manufacturers globally (Iliev, 2005).

Harnessing country resource strengths
A global value chain will harness the resource strengths of different countries. Many multi-national enterprises already make use of this advantage through the sourcing of their components, labour or technology expertise. For example Siemens' gas turbines are manufactured in Germany, whereas their combustion chambers are manufactured in Hungary. In China there is a big domestic market for coal technologies, there is also a sufficient amount of technical capacity to adapt new technologies. As a result of these resource strengths, China is now exporting supercritical coal power stations. They are still less efficient than supercritical build in OECD countries, but significantly cheaper.

Increasing market scale
A global value chain allows countries to focus on manufacturing components that best harness their resource strengths. It increases the incentive for domestic innovation, as the returns are less dependent on the volatility of the local market.

An international drive towards encouraging use of low-carbon technologies will increase the scale of the market. This has several benefits both for suppliers and consumers. For suppliers, the potential of growing markets creates confidence and incentives to scale up production, to gain economies of scale and to explore new production processes to benefit from cost reductions. Particularly in smaller countries, only the joint market of several neighbouring countries might have sufficient size to justify investment into a plant, e.g. the manufacturing of mirrors (heliostats) for a concentrated solar power plant. The teaming up of several countries can thus create the market size and offer the opportunity to build on existing capacities of all participating countries.

For the consumer, increased deployment of a technology results in incremental improvements and cost reductions. Policies can help drive local production or demand through the creation of appropriate market conditions that ensure a need for low-carbon technologies and indicate a commitment to reduced emissions targets. The target to provide 20% of final energy in Europe from renewable energy sources by 2020, that has been agreed upon by European heads of state, creates an attractive market and helps foster and accelerate domestic production and use of low-carbon technology across the EU.

For many countries, providing the initial financial support for more expensive technologies so as to contribute to their improved global performance or better local adoption can be a strain on the national budget. International support could contribute initially towards the incremental costs between new and entrenched technologies and thus trigger a shift towards a lower-carbon technology. This would result in increasing the market scale within developing countries.

Smoothing policy volatility for investor confidence

Market needs and government priorities with respect to energy policy can vary across countries and across time. Such variation can have adverse implications for domestic investment in low-carbon technology (innovation and use), particularly when investment takes place over longer time horizons. Public R&D expenditure can be particularly affected by government's priorities of the day as discussed earlier in the paper.

Figure 11 illustrates the volatile nature of annual investment in wind turbine capacities across a range of countries. This may be related to the changing local development priorities of the countries or alternatively to the capacity of the country to support a given technology.

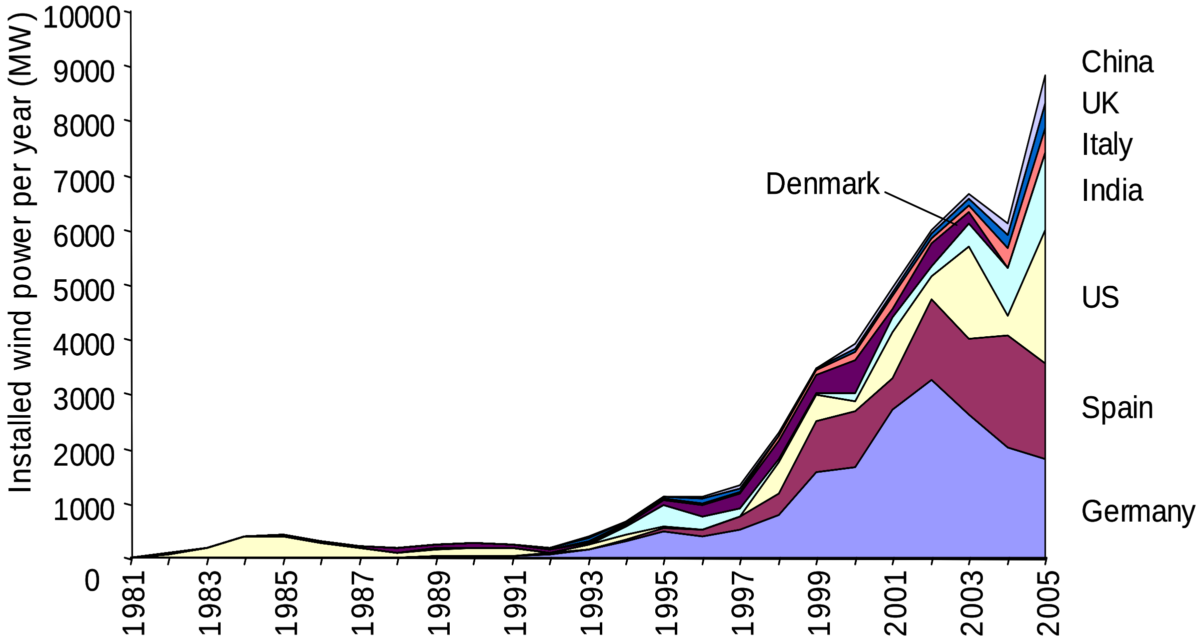

Figure 11. Growth of wind output compiled from data from the BTM Consult and GWEC (2006)

The Figure shows that although individual countries experience dynamic changes, the overall trend in wind turbine investment is positive. This emphasises the importance of international deployment and the smoothing of innovation priorities and actions across different countries. By facilitating access to international markets, local firms are no longer solely dependent on the national market, which could be volatile and vulnerable to policy uncertainties. They are empowered to take advantage of changing international trends as well.

Facilitating access to international markets
International trading channels allow suppliers to source the most suitable and cost effective components. It also provides a channel through which they can export their products. In the same way, consumers have a greater variety of technologies to choose from and can ensure that the technology best suits the local needs. The matching of global demand and supply in a dynamic market can contribute to efficient diffusion of technology. Added to this, the increased competition resulting from new market entrants contributes to improved quality of the products. The caveat to free trade flows is that developing countries may still be at a disadvantage to the early innovators in developed countries with years of government support.

In summary, this section discusses the benefits of the increased market scale inherent in international cooperation in the acceleration of technology use. It emphasises that promoting access to existing technology is not in itself sufficient to ensure widespread adoption of technologies in developing countries. Policies need to be tailored to country specific needs and should focus on building up local expertise and capacity to absorb the technology. The next section discusses the need and options to develop skills, expertise and manufacturing capacity for energy technologies.

5. Synthesising International Innovations and Technology Use

National policies to support domestic technology innovation and use can be supported and strengthened through international cooperation, coordination and transfers. Following the previous discussion on the international interactions of innovation and use, this section looks at the policy implications for international cooperation arising from these dimensions.

Growing Local Markets and Absorptive Capacity

Countries and markets can select a suitable technology portfolio to match the domestic absorptive capacity to adopt, produce and use the technology. For example, as illustrated in Figure 12, deployment of Concentrated Solar Power plants using the nascent linear Fresnel technology (linear CSP) could be a more attractive option for less developed countries, as it uses flat mirrors, which are much cheaper and easier to produce, than the parabolic ones used in CSP trough technologies (Ausra, 2008). The increased production and use of CSP will then also build additional local capacity and allow countries to use more complex technologies.

The Figure also illustrates that for some technologies, for example Photovoltaics, the complexity of the technology results in a global supply chain. Thus countries with less absorptive capacity might find themselves importing most of the technology. This could still be desirable where the quality of the technology, e.g. benefit of reduced energy import dependency, justifies the use of the technology. With increased use of the technology, and given a supportive policy environment, operation, maintenance, assembly, fitting and increasing shares of the supply can be provided locally.

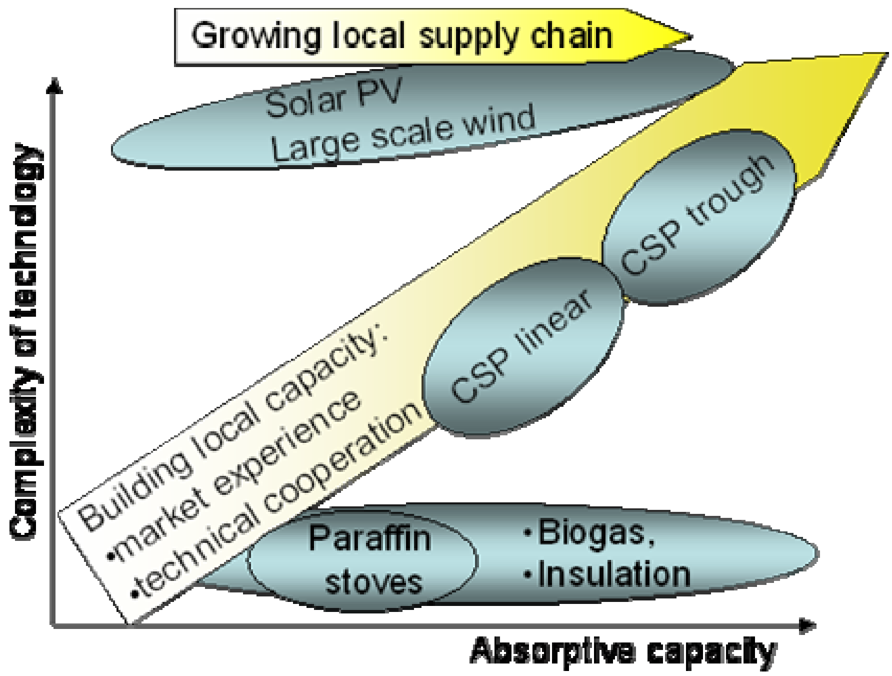

Figure 12. Technology policy, tailored for local absorptive capacity (technology achievement, institutional capacity, skills, training, local resources etc).

Strengthen absorptive capacity

Adoption of a technology and production for local circumstance is constrained where there exists shortages of skills, R&D experience and the appropriate institutional framework. International cooperation can provide technical assistance, training, and institutional cooperation to enhance the absorptive capacity of a country and assist with making optimal technology choices. While this has been an important item on the development cooperation agenda, the targeted nature of a solution can allow for enhanced cooperation, including south-south collaboration.

Absorptive capacity is not only a challenge for developing countries; all OECD countries have to improve on the domestic skills available. For example, in the building sector, the energy efficiency of houses needs to be improved through the installation of low-carbon heating and power technologies.

Local production for specialisation and local capacity

For the production of low-carbon energy technologies, specialisation choice in technology and components can be tailored to national priorities and local circumstances, whilst also contributing to growing global markets. Here, retaining some local content share can help support local adaptation and learning-by-doing, build absorptive capacity and also assist local R&D efforts to feed directly into commercial outputs. Hoekman et al (2005) propose that the local market size and technical capacity to absorb new technologies steers an investor's choices. Specialisation in component manufacture, such as specialised production of blades for gas turbines from Germany or nuclear boilers from Japan, can ensure a domestic contribution to global markets. In addition such specialisation can help support local absorptive capacity through building production, fostering skills and creating niches for local innovation.

Local demand to attract investment

Domestic actions can help foster a private sector investment climate through regulatory reforms, reduction of barriers to trade in low-carbon technologies and domestic policy support for innovation, production and use. Political stability, good governance, transparency of policies and the level of enforcement of contractual obligations all determine the risk of investing in a country and thus effect the securing of FDI (CanREA, 2006; Sierra, 2006). The GEF for example, has made cumulative investments of around $3.3billion since 1991, however, this money has leveraged up to an additional $14.4 billion through co-financing reflecting co-benefits for bilateral ODA, recipient countries and the private sector (Newell 2008).

Strategic deployment policies can be strengthened with international support

Local sourcing of established or lower grade technologies may initially incur efficiency or quality penalties and undermine efforts to improve local capacity and production.

Strategic deployment can be used to stimulate local production, innovation and carbon abatement whilst meeting the energy needs of a country and improving efficiency. Learning-by-doing based cost reductions resulting from accumulated deployment are generated in both the production and installation of technology; this can be consistent with national objectives where some innovation or production is retained locally and where consumers benefit from lower energy costs. Strategic deployment of renewables has the added advantage of strengthening domestic absorptive capacity.

International financial support can be used to support such deployment programs, e.g. by covering the incremental costs of the new technology. Also, where intellectual property makes latest technologies prohibitively costly, international support could cover costs of patent licensing or royalties for deployment, or assist in other ways to make the best-available technology publicly accessible.

A further motivation for the need for international support for deployment of low-carbon technologies is that they have higher investment requirements, after all energy efficiency and renewables replace fossil fuel costs with investment costs. This can create particular challenges for countries that face problems in accessing international capital markets or where the cost of capital is high. Furthermore, the regulatory and institutional challenges can be severe, particularly in some developing countries.

Innovating to Adapt to Local Needs and Resources

The majority of innovative effort takes place in developed (Annex I) countries (World Bank, 2008). This may be considered convenient as these countries are expected (initially) to take the most significant steps to mitigate GHGs (Newell, 2008). Here the capacity to innovate, the marginal benefit of additional R&D and the returns to innovation are arguably particularly high.

However, with most innovation pursued in developed countries, opportunities to tailor products and production processes to the needs and capacities of developing countries are easily lost.

Creating local demand for innovative and adapted products

With most of the innovation being pursued in the private sector and often as a consequence of market demand for new and improved products, policies that increase market demand not only contribute to absorptive capacity but also create incentives for innovation and adaptation of technologies by the private sector.

Network of innovation centres

Whilst public R&D spending should be increased, it is not clear any such spending should be concentrated regionally or nationally. The international benefits of diverse innovation systems and parallel innovation are strong. They can help support development of local innovation capacity, particularly for developing countries, whilst also supporting adaptation of technologies to local conditions. A network of innovation also allows the pursuit of a range of different technologies consistent with different national priorities (Sagar et al, 2008).

Other support scheme options

Prizes for innovation in low-carbon technologies may have a role to play, particularly for technologies specifically adapted to developing country conditions, where the market potential for such designs may be limited. The idea would be to create financial or other incentives for meeting technological objectives, specified in advance (Newell and Wilson, 2005). This has been advocated for medical advances relevant for developing countries, e.g. anti-malarial drugs (Love and Hubbard, 2004).

Sharing of technology

Collaboration can form an important part of technology development and diffusion, drawing on different approaches and expertise from around the world. Multinational companies are well placed to foster international collaboration in innovation efforts, with strong internal coordination of actions. However, as noted earlier, access to technology may be restricted even within an organisation due to fears of confidentiality. Coordination in policy can help overcome these problems by ensuring better access to relevant technologies according to national technology needs whilst supporting an international market for the technologies.

Creating Multiple Experiences to Drive Innovation

Global markets support ‘smooth’ investment decisions

Where there is domestic regulatory uncertainty or fluctuating public expenditure for R&D or feed-in-tariffs; expansions in innovation and use can occur at a global level. Where innovators and producers have access to growing markets elsewhere, domestic uncertainties are compensated for by international commitment. As suggested by Brandzaeg and Hansen (2005), the upholding of government commitments is one of the key incentives for investment in the power sector. Additionally expansion in markets elsewhere can generate opportunities that might not have occurred in the domestic environment alone. For example, Asian demand for nuclear reactors is at present a key factor in supporting European innovation, where market demand has waned in recent years.

Further, robust and ongoing support for wind deployment in Europe, unlike the previous aborted program in California, was able to build and sustain international wind innovation and production capacity. This could then ensure cost reductions and steadily increasing deployment across a range of countries. As explored previously, it was the timing of policies and measures across several countries that ensured growing markets and growing production could be matched over time- giving confidence for investors and innovators in future returns. For example the support for wind turbine deployment in California, initially created demand that stimulated the wind turbine industry in Denmark (Karnøe, 1989).

International cooperation can support investment in production capacity for future markets

Expectations of future markets and the expansion of foreign markets through policies elsewhere can support domestic production and innovation. An example of this is the growing production of Solar PV in China. Driven in part by strong and growing markets for PV in Europe and Japan, stimulated by domestic policies and measures, Chinese PV manufacturers have the confidence to invest in increased production. This makes China well placed to meet future domestic demand whilst also providing some investor security for large investments today in silicon plants. In contrast European policy, and the establishment of a carbon price, has also supported growth in PV production within the EU, where strong process-learning has driven continued cost reductions. Expectations of a steady and growing global market for PV, allows for experimentation in production lines to yield learning benefits for the future whilst also meeting present demand.

Technology standardisation can improve access and local production

Coordination on technological standards and commercial access to technological intellectual property can support domestic policies to deploy best available technologies. Further technological financial support mechanisms can help cover the costs of licensing the best available technology, to help ensure all countries can achieve high efficiency at low cost, without compromising incentives to innovate.

Harmonisation of technology development activity, such as national reporting of plans and priorities can help bring technology standards closer whilst avoiding duplication of efforts.

A recent study highlighted by Newell (2008) on trade and climate change found that varied levels of tariff and non-tariff barriers are a very significant impediment to the transfer of technologies to developing countries. Eliminating these barriers could result in a 14% increase in trade, of four basic clean energy technologies (wind, solar, clean coal and efficient lighting), with high-GHG-emitting developing countries (World Bank, 2007, international trade and climate change). Some of these barriers are aimed to create incentives and opportunities for domestic producers of low-carbon technologies. Such multiple objectives require a more transparent evaluation of different policy instruments to find suitable ways for their joint implementation.

International scale to pick several potential 'winners'

Learning-by-doing works best with the right technologies, however this process can be hindered if technology uncertainties create the risk of supporting the wrong technology and forgoing the benefits of an alternative option. International cooperation and coordination can help ensure multiple technologies are pursued on a large scale and deployed widely to learn from market feedback and gain experience in manufacturing and use. Thus the performance and cost of several options can be compared and it is more likely that a suitable technology option is developed, explored and deployed.

Other considerations include the trade-offs between R&D and deployment. Financial support for either can risk neglect of the other, despite them being complementary components of the innovation chain. Whilst domestic innovation with iterative learning between both the development and the deployment of a technology can be effective, international cooperation can expand the financial support available whilst ensuring policies to support all aspects of the innovation process are pursued in at least some countries.

Committing to Low-Carbon Objectives for Direction and Market confidence

With climate change and development objectives, technology policy cannot be blind towards society's needs for new technologies. Only 4% of public sector R&D is currently devoted to energy, which is a large decrease from a peak of 11% in the early 1980s. Climate change and development objectives can provide new criteria to re-evaluate the allocation of public R&D.

Government policy also has to play a strong role in removing barriers and supporting initial market opportunities for low-carbon technologies. However, given uncertainties about future political, and thus policy development, this is associated with significant uncertainties for investors and technology companies.

A shared understanding and commitment to low-carbon and development objectives can improve regulatory certainty. Independent of the specific set of policy instruments implemented in a country or emphasised by a government, international cooperation is likely to create profitable opportunities for energy-efficiency and low-carbon technologies and reduce the attraction of pursuing higher carbon alternatives.

6. Conclusion

The paper expands the concept of the innovation chain to an international setting using evidence and examples from literature, recent experience and a novel dataset of clean coal patents. Research points to four areas where international support can enhance the development, adoption and use of energy efficiency and low-carbon technologies.

First, for a technology to have an impact it has to be sold in national markets. Public policy can create stimuli for initial use and appropriate regulatory frameworks for larger scale application of the technology. International cooperation can accelerate this process by providing technical assistance and supporting the incremental costs incurred during early deployment. This offers the opportunity to develop, in parallel, the markets and the absorptive components (skills, training, institutional setting and finance) necessary to produce and use the technology.

Second, for a technology to be viable in the national context, it has to be adapted to the context of local capacity for manufacturing, installation, operation, maintenance, requirements for use and the availability and constraints of resources in a country. The growing demand for the technology, triggered by domestic policies and facilitated by domestic regulatory frameworks and training, can create incentives for the private sector to pursue this adaptation. International support can enhance information sharing and innovative capacity development e.g. with a network of low-carbon innovation centres, and early-stage, tailored financial support for demonstration programs.

Third, the experience and innovative activities from various national contexts provide the opportunity to explore different technologies and concepts. Market-based mechanisms and other processes of information sharing and technology cooperation give firms the opportunity to make optimal technology choices. The global benefit of learning, which accumulates more quickly if technology is deployed across multiple markets, creates an additional motivation for developed countries to contribute towards the incremental costs of accelerated deployment strategies in developing countries.

The existence of international markets for energy efficiency and low-carbon technologies gives local firms the opportunity to sell to multiple markets, and thus reduces their vulnerability to local domestic policy uncertainties and shifting government priorities. The necessity of international value chains for more complex low-carbon technologies highlights the challenge of needing to balance open markets with tailored support programs for specific technologies and the early stage adoption of these technologies.

Finally, as policy frameworks, including support for R&D and demonstration, strategic deployment programs and carbon pricing will influence much of the development of energy-efficiency and low-carbon technologies, all market participants are impacted by policy risks and uncertainties. At the same time it is impossible, and probably not desirable, for governments to commit to a fixed policy framework in the light of technology uncertainty and the growing experience (benefits and drawbacks) gained from implementing different policy instruments. Through an international alignment of climate and technology deployment objectives, domestic uncertainties and risks can be alleviated.

A global commitment indicates that there will be an attractive market for low-carbon technologies despite the implications of changing local government priorities and therefore provides firms with the confidence to invest in production.

In summary, domestic policies play a central role in facilitating the adoption and consequent absorption of new technologies into the industry of a country. This process contributes to domestic and international learning-by-doing experience and creates incentives for further innovation. International support can cover the incremental costs of technologies that are initially more expensive than established technologies. More holistic collaboration could also support the development of appropriate regulatory and institutional frameworks, contribute to training, provide technical assistance and offer the opportunity for knowledge and experience sharing. A shared understanding and ownership of the social and environmental objectives, defined in domestic policies and augmented by international cooperation, can enhance the credibility and effectiveness of a technology deployment program in guiding private sector innovation and investment. The paper explored the role of IP and licensing in the process of technology transfer in the energy sector, however leaves the debate on the effects of stringent property laws on innovation and diffusion to other works.

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