Global Challenges Report

Innovation and Diffusion of Green Technologies: The Role of Intellectual Property and Other Enabling Factors

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WIPO
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ORGANIZATION

Abstract

Effective responses to climate change require efforts by both the public and private sectors to develop and disseminate new environmentally sound technologies (ESTs) on a global scale, as well as to adapt them to local needs. However, due to a number of market failures and specific uncertainties, the spread of green technologies is less than optimal, which necessitates additional incentives. Based on a review of recent literature, the present *Global Challenges Report* examines the role of enabling factors for the development, diffusion and financing of ESTs. It finds that relevant policies promote, among others, funding mechanisms, business partnerships, and the protection and enforcement of intellectual property rights.
The Report pays particular attention to the needs in developing countries, including emerging market economies, where the aforementioned challenges are particularly pronounced.

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Section 1:
Executive Summary

1.1 CHALLENGES IN ENVIRONMENTAL INNOVATION

A meaningful response to climate change involves the development and diffusion of a wide variety of new environmentally sound technologies (ESTs) in both developed and developing countries. However, environmental innovation faces considerable obstacles, in particular the so-called “dual externality” problem as well as uncertainties specific to this sector. In order to enhance and accelerate the spread of green innovation, it is crucial to identify, assess and leverage relevant enabling factors conducive to the development and diffusion of ESTs worldwide.

1.2 TECHNOLOGY DEVELOPMENT, DIFFUSION, AND FINANCING

A range of factors contribute to overcoming disincentives faced by companies as well as some public sector entities, thereby increasing the society’s ability to develop and to commercialize new and existing ESTs. These include the effective protection of patents and other industrial intellectual property (IP) rights, certain market-reinforcing measures such as the reduction of trade barriers for environmental products and the harmonization of environmental regulations, technical and other high-level education and training, financing, as well as carbon pricing. The effective diffusion of technology requires, in addition, openness to international trade and foreign investment, as well as measures to address local market challenges. Finally, technology-neutral government funding of research and development (R&D) may play a vital role, especially with respect to the market or policy failures in the three following areas:

- basic R&D, to overcome externalities and uncertainty faced by companies;
- pre-commercial R&D, which frequently lacks government support or private financing; and
- R&D by small and medium-sized enterprises (SMEs), which generally face significant difficulties in obtaining commercial financing.

1.3 LOW-CARBON INNOVATION IN DEVELOPING AND EMERGING ECONOMIES

Given the need to address climate change on a global scale, it is particularly important to foster environmental innovation in developing and emerging economies, where it has been less pronounced compared to mature markets. For these countries, the literature identifies specific patterns of technology development and diffusion, relevant local conditions, as well as enabling factors and related policies. Key enabling factors include soundness of environmental policies, openness to international trade and investment, effective protection of IP rights, access to financing, quality of education and training, as well as predictability of regulatory and legal frameworks.

1.4 COOPERATION BETWEEN PRIVATE COMPANIES AND OTHER ACTORS

Cooperation amongst businesses, governmental and non-governmental organizations, academic institutions through various forms of agreements, such as partnerships and joint ventures, can drive environmental innovation. In this context, non-commercial entities may play a significant role, especially by providing financing, technical expertise and coordination of research activities, thereby focusing in particular on the needs of SMEs.

1.5 THE ROLE OF INTELLECTUAL PROPERTY RIGHTS

By helping to establish secure channels for know-how transfer, IP rights like patents and trade secrets are means to address the externality problem that results in the imperfect appropriability of knowledge. As such, they can significantly further the development and diffusion of ESTs. By temporarily conferring exclusive rights, patents permit companies to capture the value of their inventions and investments in developing and scaling them. Frequently used in combination with patents, trade secrets are particularly useful in protecting tacit knowledge, notably non-codified know-how needed for the implementation and adaptation of technologies.

1.6 POLICY RESPONSES

Policymakers can effectively foster the development and diffusion of low-carbon technology through the creation of effective, market-based national systems of innovation. To this end, they need to develop and implement appropriate policies that take into account the above-mentioned factors. There is a variety of policy alternatives to select from to stimulate innovation and investment, but the impact of individual measures remains difficult to assess. Rather than focusing on a limited number of interventions, policymakers should consider a diverse portfolio of policy options, which provides greater flexibility in addressing issues that may be local, regional, national or international in nature, and learn from the experience gained.

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1 "Imperfect appropriability of knowledge creation due to positive externalities: due to the non-rivalry nature of many knowledge creations (*i.e.* the fact that the use of one piece of knowledge does not prevent its simultaneous use by another party), knowledge can generate spillovers: not only does the innovator benefit but also other agents, such as competitors and follow-on innovators. Unless otherwise compensated (*e.g.* by monopoly rights created by the IP system or grants for conducting innovation), this means that the social rate of return for knowledge production may exceed the private rate of return and, therefore, investment in the production of new knowledge would be below the socially optimal level. The issue of imperfect appropriability of knowledge creation is likely to be even greater for innovative entrepreneurs, since they may lack assets to protect their innovations from imitation (*e.g.* small firms are often disadvantaged when it comes to enforcing their IP rights due to the fixed costs involved)." http://ow.ly/Mthtl

Section 2: Introduction

2.1 BACKGROUND AND STUDY OUTLINE

Addressing climate change is one of the world's greatest policy and innovation challenges, requiring the development of a wide variety of new technologies as well as their diffusion to both developed and developing countries.[2] Due to a number of market failures and uncertainties, however, the innovation and diffusion of environmental technologies – like those of many other technologies – pose particular problems that necessitate a range of policy interventions, including an enabling policy framework. The present Report is an attempt to elucidate these issues by reviewing relevant recent literature on the innovation and diffusion of low-carbon technologies, thereby focusing on a range of enabling factors, in particular intellectual property (IP) rights.

This *Global Challenges Report* begins by presenting the concept of environmentally sound technologies (ESTs), followed by a discussion of the key challenges to their development and diffusion, *i.e.* the dual externality problem and uncertainty.[3] Sections 3 to 5 consider three main dimensions of environmental innovation: technology development, diffusion, and financing.[4] Section 6 analyses available policy instruments. Section 7 concludes the Report.

2.2 ENVIRONMENTALLY SOUND TECHNOLOGIES

ESTs are technologies that have the potential for significantly improved environmental performance relative to other technologies. Specifically, they "protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes" (UN 1993).[5]

According to the United Nations Framework Convention on Climate Change (UNFCCC), ESTs fall into two main categories: mitigation and adaptation. Mitigation technologies aim to reduce emissions of greenhouse gases or to capture them, while adaptive technologies allow users to adjust to negative effects of climate change, or exploit positive ones (UNFCCC 2006; Table 1).

Both the development and international diffusion of ESTs are lengthy processes. According to an extensive analysis of patent ownership and the market adoption rates of six energy technologies,[6] diffusion takes on average some 24 years (Lee *et al.* 2009). Obviously, in order to meet international climate targets, this adoption time will need to be reduced.

2.3 DUAL EXTERNALITY

An externality is a cost or benefit arising from any activity which does not accrue to the person or organization carrying on the activity, *e.g.* damage to the environment (Black *et al.* 2012). Compared to many other technologies, low-carbon innovation poses particular challenges due to the existence of a dual externality. First, environmental pollution involves a negative externality as its social costs may exceed the private costs it entails (Popp *et al.* 2010). Hence, polluters face few market incentives to develop greener technologies as society collectively bears the cost of pollution. Second, the knowledge required for the development of green technologies can have the characteristics of

Table 1:

ENVIRONMENTALLY SOUND TECHNOLOGIES (ESTS)

Mitigation	Adaptation
• Renewable energy technologies (*e.g.* biofuels, solar photovoltaic, solar thermal, wind)	• Climate-resistant infrastructures (*e.g.* sea walls, drainage capacity, water, forest and biodiversity management)
• Carbon capture and storage	• Irrigation systems
• Electric and hybrid vehicles	• Higher-yield seeds (for more arid and saline soils)
• Smart power grids	• Drought-resistant crops
• Clean coal technologies	
• Green buildings	

Source: Adapted from Hultman et al. *2012* a public good, *i.e.* non-excludability and non-rivalry. In other words, actors can neither be excluded from accessing and using the good, nor can its use by one actor reduce its availability to any other actor.

This dual externality presents a critical challenge to aspiring commercial innovators, as the R&D and commercialization of green technologies inevitably entail leakages of knowledge and thus of the very value that their commercial and financial investments created. These value leakages reduce the incentive for private-sector innovation and for the sharing of new and existing technologies and know-how with others.

2.4 MARKET AND POLICY UNCERTAINTIES

As other types of innovation, environmental innovation faces a range of uncertainties. These include uncertainty about:

- costs of technology development;
- outcome of the research process;
- uptake of the product by the market;
- ability to recoup the costs sunk into research; and
- pricing of competing and complementary goods.

However, innovation in green technologies also faces a number of uncertainties specific to the environmental sector. Four of these are of particular concern:

First, uncertainty around **future environmental policy** can impact negatively on innovation. A study based on data from 23 countries of the Organisation for Economic Co-operation and Development (OECD) shows that a 10% increase in policy uncertainty between 1986 and 2007 caused a 1.2 to 2.8% decrease in rates of environmental patenting, whilst a 10% increase in government support for R&D over the same period increased innovation by 2.6 to 3.9% (Kalamova *et al.* 2013).

Second, market actors can lack sufficient **information about future prices and costs**. For many companies and individuals, energy efficiency choices depend on informed assumptions about future conditions. Assessing future savings involves estimating future energy prices, operating costs related to energy use (*e.g.* factoring in future green taxes), intensity of use of the product and equipment lifetime (Gillingham *et al.* 2009). The smaller the variance in energy costs across products relative to the total purchase price, the greater the likelihood that consumers will remain uninformed about, or inattentive to, these costs (Sallee 2011).

Third, a significant proportion of the scholarly work on green technology may **over-estimate its cost savings**. According to the existing empirical literature on the magnitude of profitable unexploited energy-efficient investments, academic articles often fail to credibly estimate the net present value of energy cost savings, while leaving other benefits and costs unmeasured. As a result, on average the extent of profitably unexploited investment opportunities is much smaller than engineering-accounting studies suggest (Allcott and Greenstone 2012).

Fourth, wind and solar, the two key renewable energy sources, suffer from a particular uncertainty problem, namely **intermittency**. These energy sources are not continuously available due to the unpredictability of sunshine and wind. Intermittency is expressed by the "capacity factor", that is, the ratio of the actual power output and the amount that could be produced if the plant were to operate at its rated maximum capacity 24/7. Solar and wind plants have low capacity factors of 15 to 30%, as compared with 90% for geothermal or coal plants. This limits the markets in which these forms of renewable energy can compete without public subsidy, thus complicating the valuation of environmental innovations (Heal 2009).

The foregoing problems affect all countries, but their effects are particularly pronounced in developing countries, as explained in the following sections.

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2 This Report uses the following terms: developing countries, least-developed countries (LDCs), low-, middle-, and high-income countries, emerging economies or emerging market economies, developed countries, and countries of the OECD. While there is a significant overlap between some of the expressions, these are not identical. The specific term chosen generally reflects the terminology of the original paper.

3 The present Report is an update of a series of papers (Johnson and Lybecker 2009a, 2009b, 2009c). For other literature reviews, see Hall and Helmers (2010), Popp (2010), Popp *et al*. (2010), Vantoch-Wood (2012), IOB (2013), Allan *et al*. (2014).

4 In this Report, the term "technology" refers to production methods that are used to produce a good or service. In some instances, depending on context, the term also refers more broadly to the application of scientific knowledge for practical purposes, or more narrowly to inventions embodied in patents.

5 The definition is based on the Agenda 21, adopted by the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992. However, the literature also uses a number of other terms, including "clean", "green" and "low-carbon" technology, which often describe the same concept. While this Report uses all these terms interchangeably, the specific term chosen generally reflects the terminology of the paper cited.

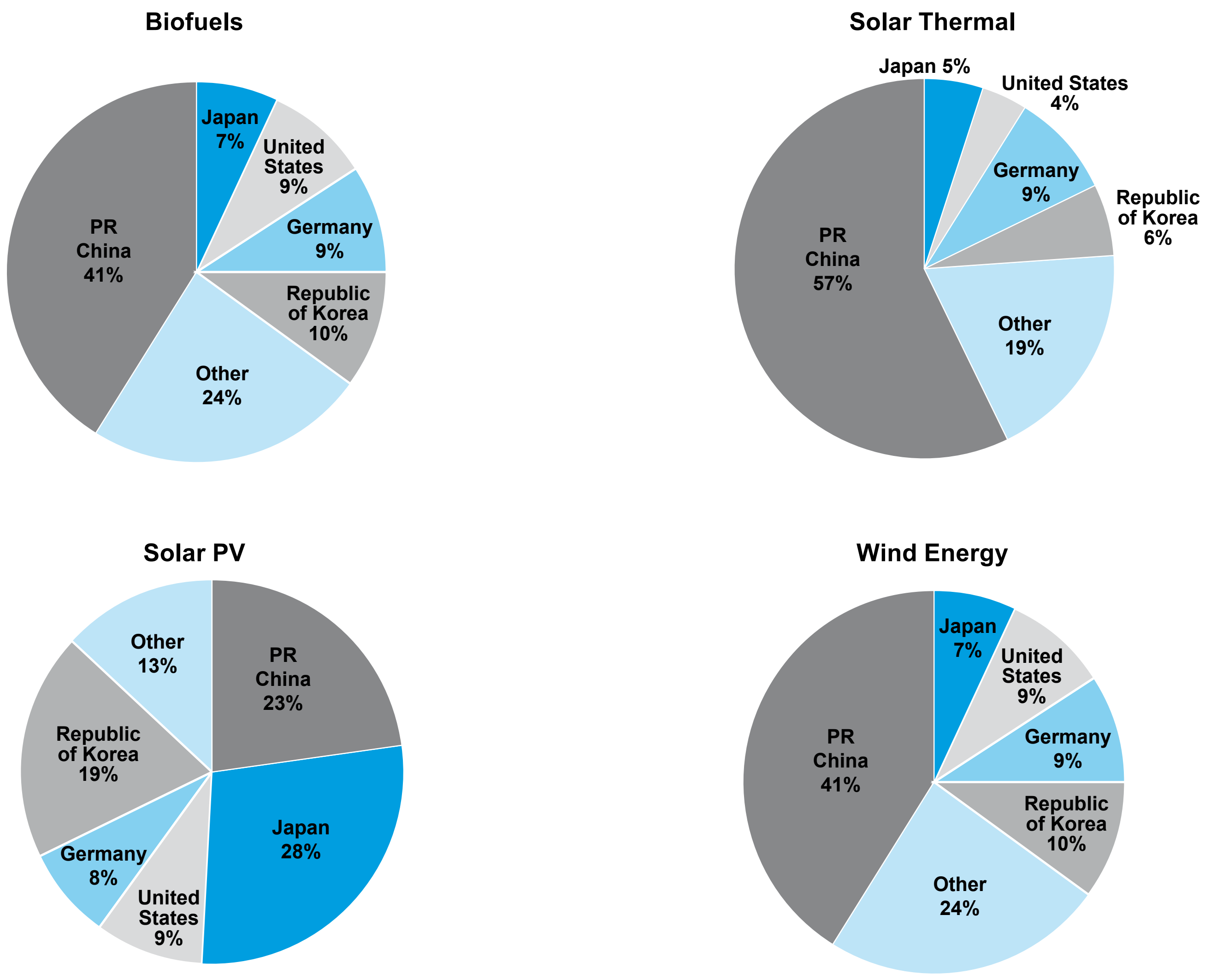
6 Wind, solar photovoltaic, concentrated solar power, biomass-to-electricity, cleaner coal, carbon capture.

Section 3:
Technology Development

Innovative activity in green technologies, as measured by patent filings, has increased significantly in recent years. Between 2006 and 2011, the annual growth rate of patent filings for four key mitigation technologies[7] was 24%, compared to a global average of just 6% for all technology sectors according to an earlier *Global Challenges Report* published by the World Intellectual Property Organization (WIPO) (Helm *et al.* 2014). Environmental innovation is largely concentrated in developed countries, in particular the United States, Germany, Japan and the Republic of Korea, while China is also becoming a major innovator in green technologies (Dechezleprêtre *et al.* 2011; Popp 2012). This is also true for individual technology categories, as the data for four key mitigation technologies show (Helm *et al.* 2014; Figure 1). However, except for China, emerging economies considerably lag behind in green technological innovation, with India, Russia, Brazil, and South Africa accounting for less than 2% of the global green patenting activity during the 2007-2009 period (Glachant *et al.* 2013a). Not even 3% of global patent applications for mitigation technologies were filed in Latin America in the 1995-2011 period (UNEP/EPO

Figure 1:

THE GEOGRAPHY OF GREEN INNOVATION: PATENT APPLICATION FILINGS FOR FOUR RENEWABLE ENERGY TECHNOLOGIES BETWEEN 2006-2011



Source: Helm et al. *2014*

2014). Green innovation in low-income countries, as the case of Africa shows, represents only a fraction of global efforts (Box 1).

The literature identifies a range of policies that foster domestic low-carbon innovation in emerging economies (Glachant *et al.* 2013b):

- more stringent environmental policies (*e.g.* emissions standards);
- effective protection and enforcement of IP rights;
- increased public R&D and public support to private R&D; and
- better access to finance for SMEs.[8]

International and national policies to combat climate change can also significantly help to promote the development of green technologies. For instance, a 2010 survey shows a significant increase in patent applications in four key areas – wind, solar, geothermal, ocean power – after the signing of the Kyoto Protocol in 1997 (Johnstone *et al.* 2010). The concept of "induced environmental innovation" serves to assess the impact of environmental policies on innovation. According to a literature review by Popp *et al.* (2010), many of these policies, including specific environmental regulations or pollution abatement mandates, have resulted in increased innovation or higher R&D spending (Table 2).

7 Biofuels, solar photovoltaic, solar thermal, wind.

8 The three last-mentioned factors will be discussed in more detail in the following sections.

Box 1:

ENVIRONMENTAL INNOVATION IN AFRICA

In Africa, innovation in mitigation technologies amounted to only 0.3% of the global total during 1980-2009. It is largely concentrated in a few countries, predominantly South Africa (84%), followed by Egypt, Algeria, Morocco and Kenya.

Overall, less than 1% of mitigation-related patenting activity worldwide targets African countries, of which South Africa is the leading market. Overwhelmingly, these patents protect inventions that come from OECD countries.

In Africa, the rate of international co-invention (*i.e.* inventors from more than one country) is considerably higher than in the rest of the world. On the whole, 23% of African inventions in mitigation technologies involve co-invention. Countries most likely to co-invent include Tunisia, Morocco, Egypt, Kenya and Mali. The most frequent partner countries are the United States, the United Kingdom, Belgium, Germany, France, Sweden and Canada.

Adaptation technologies patented in Africa also originate predominantly in OECD countries. However, in this category, the proportion of Africa's own inventions amounts to 17%, which is a far higher share than for mitigation.

Sources: Haščič et al. *2012; Ondhowe* et al. *2013*

Table 2:

THE IMPACT OF INDUCED ENVIRONMENTAL INNOVATION

Article	What is induced?	What causes innovation?	Data	Key results
Lanjouw and Mody 1996	Environmentally-friendly patents	Pollution Abatement Costs and Expenditures (PACE)	US, Japan, Germany, 14 other countries industry	PACE leads increase in environmentally-friendly innovation.
Jaffe and Palmer 1997	Overall R&D spending/patents	PACE	US industry 1974-1991	PACE affects R&D spending, but not patenting activity.
Newell *et al*. 1999	Energy efficiency technologies	Regulatory standards, energy price changes	Appliance characteristics and energy price 1958-1993	Energy prices and regulatory standards affect energy efficiency innovation.
Popp 2002	Energy and energy efficiency technologies	Price of fossil fuels, existing knowledge stock	US energy patents 1970-1994	Both energy prices and the existing knowledge stock induce R&D.
Hamamoto 2006	Overall R&D spending	PACE	Japanese industry 1966-1976	PACE leads to increased R&D expenditures.
Popp 2006	SO2 and NOx emission reduction patents	Environmental regulations	US, Japan, Germany patents, 1970-2000	Environmental regulations significantly increase SO2 and NOx reduction patents.
Haščič *et al*. 2008	Patents for 5 environmental technologies: air pollution, water pollution, wastes disposal, noise protection, and environmental monitoring	PACE and environmental stringency	PACE expenditures 1985-2004 and World Economic Forum survey	Private PACE leads to environmental innovation but government PACE does not. However, governmental R&D promotes increase of environmental patents.

Source: Popp et al. *2010*

Section 4:
Technology Diffusion

Green technologies, no matter how advanced, are essentially useless until they are actually deployed and used. While diffusion of such technologies in certain countries can mitigate the emissions caused in others that do not adopt them, a meaningful solution requires the world to collectively embrace such technologies (Chu 2013).

In this context, the transfer of green technologies to developing economies is of particular importance.[9] By 2020, the carbon dioxide emissions of these countries are predicted to outpace those from OECD countries given their higher rate of economic growth and continued reliance on fossil fuels (IEA 2013a). Even now, China's annual per-capita output of carbon dioxide clearly exceeds that of Europe (IGBP 2014). Moreover, developing countries are particularly vulnerable to the effects of greenhouse gas emissions (Bruckner 2012). In fact, while they have comparatively less capacity for devising and implementing adequate responses on their own, developing countries are likely to face the most pronounced consequences of climate change.

The question, then, is how best to encourage and facilitate the transfer of green technologies to developing countries. The three essential vectors of international technology transfer are:

- licensing;
- imports; and
- foreign direct investment (FDI).

All of these correlate positively with several characteristics of the recipient country, such as strength of IP protection, openness to international trade, environmental policies, ability to absorb new technologies, market creation policies, economies of scale, institutional linkages, and networks. These factors are examined in the following sub-sections.

4.1 INTELLECTUAL PROPERTY RIGHTS

Well-developed systems to protect and enforce IP rights have been found to stimulate technology diffusion by providing secure channels for sharing know-how (Box 2). Rather than raising costs *per se* across the board, IP rights constitute a means for the commercialization of technologies, especially for SMEs. They enable companies to capture a portion of the added value associated with the introduction of a new technology (WIPO 2009; World Bank 2010b; ICCC and WIPO 2011). At the same time, they allow actors to distinguish between competing technologies.

Moreover, the availability and protection of IP rights determine not only whether diffusion takes place but also the speed with which it occurs (Lee *et al.* 2009; Du Plooy 2013). According to a major assessment based on patent data from some 120 countries over the period 1990-2005, IP rights clearly enhance the willingness of IP rights holders to transfer their new technologies overseas (Park and Lippoldt 2008). Specifically in the area of green technologies, they have been shown to facilitate the transfer of solar thermal technologies from the United States to China and India (Lane 2011).

In the political discussions, questions have been raised as to whether IP protection poses a barrier to the diffusion of ESTs in developing economies. According to *The New Climate Economy Report*, an extensive study commissioned by the United Kingdom, the Republic of Korea and five other states including Ethiopia and Indonesia, IP rights can hamper the transfer of green technologies, especially by raising costs, limiting access and putting countries with low institutional capacity at a disadvantage (Calderón and Stern 2014). Based on this type of research, in recent years, a phenomenon of "stealth licensing" has emerged on a global scale, *i.e.* efforts by policymakers, judicial organs and administrative agencies to facilitate compulsory licenses outside the TRIPS agreement exceptions or to relax those exceptions (Petit 2014).

However, it is important to recognize that the role of patents for renewable energy technologies differs from that in certain other sectors (Barton 2007). Compared with many other industries, the renewable energy sector displays a higher degree of substitutability and competition. In fact, a significant part of environmental innovation comes from incremental improvements to existing off-patent technologies, especially as they are adapted to local conditions. Even where these incremental innovations are patented – usually in only a few jurisdictions – there is sufficient room in the market for competing technologies, given the extensive variety of different solutions available for emission reductions. This reduces the influence that specific patents have on the technological progress and on prices in this area (Barton 2007).

There is, moreover, evidence that inadequate IP protection compromises the diffusion of technology. In fact, when enforcement of IP rights is perceived to be weak, foreign businesses are generally reluctant to license their technologies, for fear that competitors will use them without authorization and remuneration (Lee *et*

Box 2:

THE ROLE OF IP RIGHTS IN INNOVATION

IP rights, such as patents and trade secrets, are means to address the externality problem that results in the imperfect appropriability of knowledge. By conferring temporary exclusive rights, **patents** permit companies to capture a portion of the added value of their inventions and investments for developing and bringing them to market. In addition, strong IP positions based upon quality patents can help innovative businesses signal the value of their inventions to the market, in particular to potential partners, as well as investors. Thus they contribute to reducing information asymmetries that result from the outsiders' incapacity to adequately assess R&D projects. At the same time, patents underpin different forms of technology collaboration and partnerships, thereby fostering technology transfer and diffusion. For larger companies, moreover, they often play a key role in helping justify technology investments to shareholders as well as internal commercial and financial stakeholders and decision-makers.

Distinct from patents and other forms of more heavily regulated IP rights, **trade secrets** comprise any protected business information that is not generally known and that confers a competitive advantage to the owner. Readily available and more cost-effective than patents, they play a key role in helping to secure channels for exchanges of know-how, creating a safe environment for the diffusion of proprietary knowledge (Brant and Lohse 2014a). Frequently used in combination with patents and other forms of IP rights, trade secrets are particularly useful in protecting tacit knowledge, notably non-codified know-how needed for the implantation, improvement and adaptation of patented technologies (Friesike 2011; Brant and Lohse 2014a). Protecting adaption-related know-how is particularly valuable to developing countries which often need to modify technologies according to local conditions (Jorda 2007; Maskus 2012).

At the same time, trade secrets are substitutes for the physical and contractual restrictions which businesses would otherwise impose in order to prevent a competitor from acquiring their information. Without efficient trade secret protection, companies tend to make excessive investments in ensuring physical protection for their secrets, rather than in innovation (U.S. Chamber of Commerce 2013). In fact, stronger trade secret protection has been shown to correlate with more R&D investments in high-technology industries (Png 2012). An important facet of IP management, especially in licensing, is the overlap between patents (which require full disclosure) and trade secrets (which are confidential). In practice, they often complement one another and can be used synergistically in licensing deals. In fact, most technology licenses are hybrids, covering both patents and trade secrets as this approach allows for the licensing of collateral know-how usually not embedded in patents (Jorda 2007).

Moreover, given that trade secrets are significantly less expensive to obtain, maintain and enforce relative to patents, SMEs tend to rely disproportionately on them to protect their innovations (Brant and Lohse 2013).

Patents and trade secrets are of particular importance for the so-called "open innovation" systems, which some expect to become the dominant approach to innovation in the twenty-first century (Chesbrough 2006). Under the open innovation model, rather than developing and commercializing processes exclusively within the boundaries of a single entity, companies work with external collaborators in order to enhance the innovative process. To this end, they need to simultaneously disclose and protect their know-how to these collaborators. For example, through cross-licensing of patents, a company can offer the use of its proprietary technology in exchange for use of others' inventions (Brant and Lohse 2014b). Given the complexity of the technology involved and the global nature of climate change, open innovation is especially relevant for environmental innovation.

al. 2009; Maskus 2010; World Bank 2010a; Figure 2). Similarly, leading companies cite weak IP protection in host countries among the reasons for withholding their latest technologies from certain markets (Perez Pugatch 2011). Similar conclusions emerged from an analysis of the relationship between imports and IP protection in China, utilizing panel data for the 1991-2004 period. It finds that China's imports, in particular those in high-technology industries, increase with stronger patent protection (Awokuse and Hong 2010).

In addition, weak enforcement of IP rights can discourage foreign subsidiaries from increasing the scale of their R&D activities, and foreign venture capitalists from investing in promising domestic enterprises (World Bank 2010a). Despite the investments in local manufacturing and R&D by many foreign subsidiaries of global wind equipment producers register very few patents in Brazil, China, India, or Turkey, reflecting the relatively low level of R&D taking place in the countries where the subsidiaries are located.

Finally, an analysis of the IP regimes in five Asian countries at differing stages of economic development – China, India, Indonesia, Malaysia, and Thailand – highlights the opportunities for developing countries in strengthening enforcement and building administrative capabilities (Barpujari and Nanda 2012).

Published by the United Nations Environment Programme (UNEP), the European Patent Office (EPO) and the International Centre for Trade and Sustainable Development (ICTSD), a major survey on patents and clean energy found little out-licensing activity in clean energy technologies to developing countries: 58% of the respondents had not signed any licensing deals with partners in developing nations (Karachalios *et al.* 2010). However, at the same time, the survey suggests that the willingness to out-license exceeds the actual level of licensing. According to almost half of the entities based in high- and in some middle-income countries (*e.g.* China, South Africa), clean energy patents represented a significant or substantial part of their patent portfolio. 73% of the respondents considered out-licensing as important for their organization. What is more, 70% of the sample indicated they would be prepared to provide more flexible licensing terms to recipients from developing countries. The survey provides a number of interesting insights into the perceptions of the patent holders. For instance, when asked for the reasons of their reluctance to conclude licensing deals, 82% of the respondents pointed to deficient IP protection in developing nations.

However, the situation of least developed countries (LDCs) is somewhat different. A study on protection and ownership data for seven emission-reducing energy technologies in a representative sample of low-income countries with strict IP rights during the 1998-2008 period found very few registered patents, concluding that IP rights "cannot possibly be an obstacle" for green technology transfer (Copenhagen Economics 2009). Conversely, as these economies do not import ESTs despite low barriers to trade, FDI, or strict IP rights, those factors are unlikely to trigger technology transfer. Hence, in LDCs, the focus should be on building technological capacities (Glachant *et al.* 2013b; Calderón and Stern 2014). It has been suggested to set up a mechanism in conjunction with the Global Environment Facility or the new Green Climate Fund to provide for the necessary funding (Calderón and Stern 2014).

In addition to appropriate frameworks of IP rights, a range of other factors can contribute to the transfer of technology in and to developing countries. These are detailed below.

4.2 TRADE AND MARKET ASPECTS

Openness to international trade is essential to the dissemination of technological information (Dechezleprêtre *et al.* 2011). The presence of tariffs and non-tariff barriers can considerably inhibit the diffusion and use of environmental technology. A 2010 World Bank study of 18 developing countries emitting high levels of greenhouse gases estimated that the elimination of such obstacles could increase the traded volume of relevant technologies, *e.g.* cleaner coal, wind power, solar photovoltaics, energy-efficient lighting, by some 14% (World Bank 2010a). According to the study, trade barriers on imports raise domestic prices, making energy efficient technologies less competitive and less cost-effective. For instance, in Egypt, tariffs on photovoltaic panels average 32%, which is ten times the applicable tariff in high-income OECD countries. In Nigeria, photovoltaic panels face, in addition to tariffs of 20%, non-tariff barriers of some 70%.

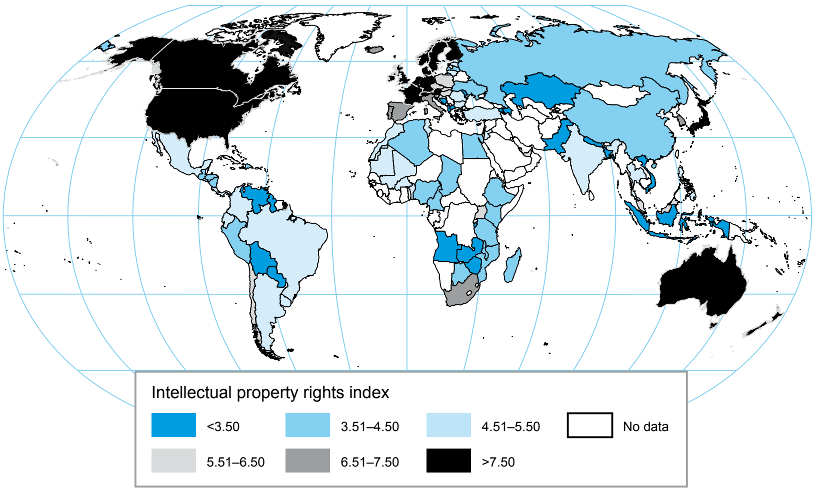
In the biofuel sector, both import and export duties as well as subsidies in OECD countries have hampered investments in Brazil, the world's most inexpensive ethanol producer. As a consequence, domestic production grew only a modest 6% in the period 2004-2005, whereas the United States and Germany saw production increases of 20% and 60%, respectively, protected by tariffs of over 25% in the United States and over 50% in the European Union (EU). Enhancing reliance on market forces and removing the tariffs and non-tariff barriers would reallocate production to the most efficient producers, allowing for increases in production and more competitive pricing (World Bank 2010a).

In addition, **market creation** is key to ensuring that green technologies find a place in developing

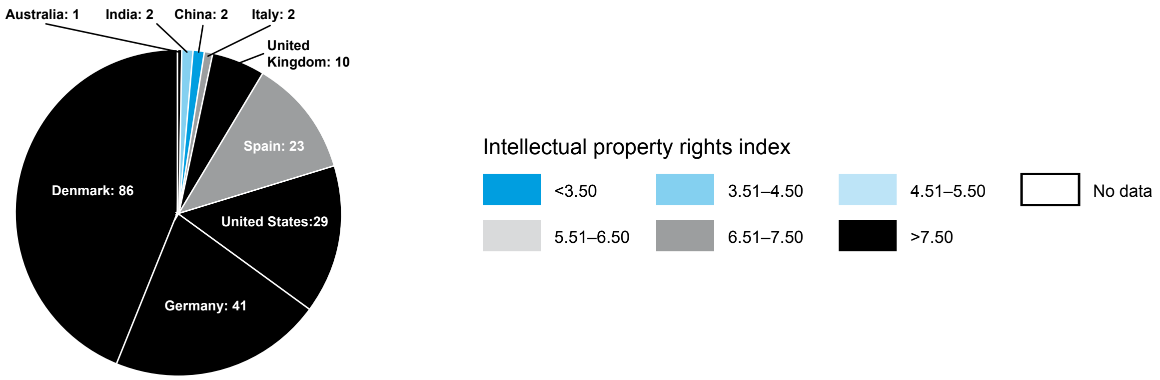
Figure 2:

MIDDLE-INCOME COUNTRIES ARE ATTRACTING INVESTMENTS FROM THE TOP FIVE WIND EQUIPMENT COMPANIES, BUT WEAK IP RIGHTS CONSTRAIN TECHNOLOGY TRANSFERS AND R&D CAPACITY

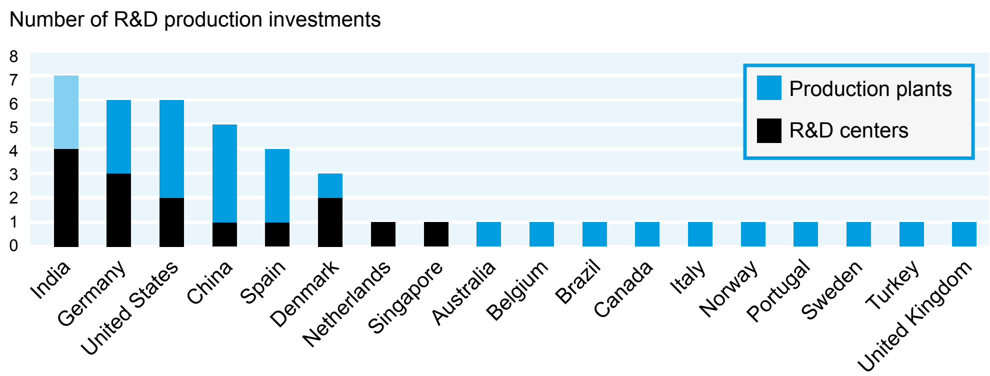
A. INTELLECTUAL PROPERTY RIGHTS PERFORMANCE



B. INTELLECTUAL PROPERTY RIGHTS PERFORMANCE



C. LOCATION OF INVESTMENTS OF TOP FIVE WIND FARMS



Sources: Published patent data from U.S., Japanese, European and international patent application databases, annual reports and Web sites of Vestas, General Electric, Gamesa, Enercon, and Suzlon (accessed on March 4, 2009); Dedigama 2009. Note: A country's IPR score reflects its ranking according to an IPR index based on the strength of its intellectual property protection policies and their enforcement.

Source: World Bank 2010a

countries (Gallagher 2014). Market formation policies comprise a range of measures, including carbon taxation, subsidies, and policies designed to create niche markets. These policies are needed to integrate the benefits of technologies that the market does not value naturally into their costs.

In the context of market creation, scale represents an important challenge. In fact, the markets of many middle- and low-income countries are too small to be attractive to entrepreneurs looking to launch new (or even transfer more proven) technologies (Copenhagen Economics 2009; World Bank 2010a). Bordering countries could overcome this challenge by engaging in joint procurement or regional economic integration so as to achieve critical mass. Furthermore, the necessary scale of investment typically requires participation of the private sector (Du Plooy 2013). The dissemination of technology may also depend on achieving an efficient scale of production, in order to reduce the per-unit production costs. In addition, the overall scale of technology diffusion yields additional benefits through learning-by-using, learning-by-doing, or network externalities. Thus, the value that an innovation has to one individual or company is also dependent on the number of other users who have adopted it (Popp *et al.* 2010). Put differently, the size of the actual or potential market for a technology and its customer base will often matter.

Finally, another market-related problem is the inertia that results from the path-dependent character of innovation (Aghion *et al.* 2014). For example, incentives to use innovations that leverage existing – rather than new – infrastructure are much higher (*e.g.* conventional cars are easier to sell than electric vehicles because there are more petrol stations than charging stations).

4.3 SCIENCE, R&D AND ADAPTATION CAPACITY

To bridge the gap between exposure to new technologies and their diffusion, an economy must also possess an appropriate level of **absorptive capacity**, *i.e.* the ability to do basic and/or applied research, to understand, implement and adapt technologies arriving from other countries (World Bank 2008; Dechezleprêtre *et al.* 2011; Popp 2012). Absorptive capacity depends on the macroeconomic and governance environment, on education systems, particularly tertiary education, which influence the willingness of businesses to take the risks associated with new technologies. Moreover, it hinges upon the technological skills in the population, as well as access to financing (World Bank 2008). It should be noted that greater absorptive capacity can also enhance the potential for domestic innovation, thereby reducing the country's need for knowledge transfer from outside, as suggested by a study using data on wind energy patent applications filed by developed countries in developing countries (Dechezleprêtre *et al.* 2011; Figure 3).

Adaptation to local characteristics is another important determinant of technology diffusion. Rather than relying on one-size-fits-all solutions, effective innovation strategies need to take account of country-specific and regional characteristics of developing economies. In particular, regulatory, geographic, technological and cultural idiosyncrasies pose significant challenges for both innovators and policymakers. Therefore adaptive innovation is essential to developing technologies that are appropriate for local conditions (Box 3). It is important to note that, other than the benefits at the local level, knowledge on adaptive technologies also produces the spillover effects that can benefit the wider economy. Since the types of technologies needed to adapt to climate change tend to vary according to local conditions, R&D should also support adaptation options for developing countries, thereby taking into account future environmental changes (Popp 2012).

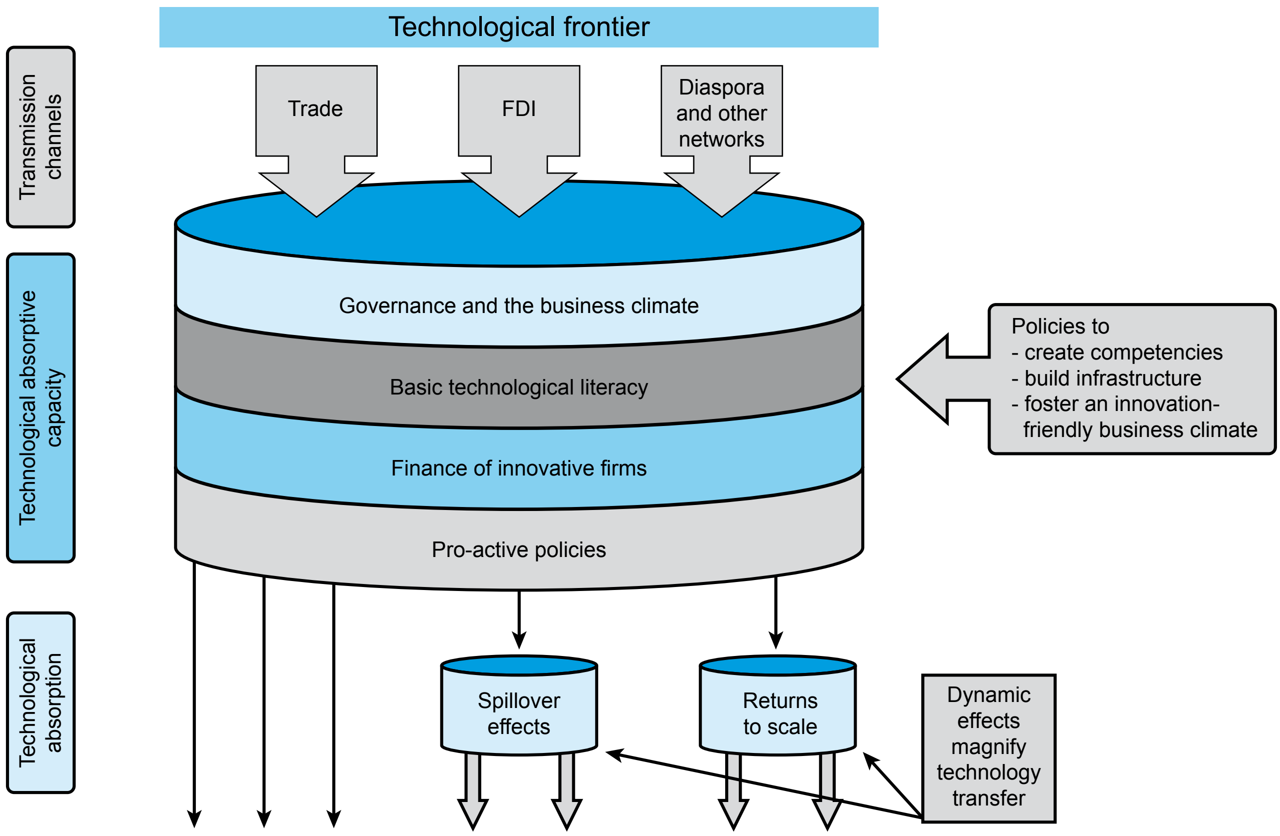
What is more, the diffusion of know-how depends, to a considerable degree, on **customer choices**. It has been long established that the diffusion of efficient energy technologies is slower than a comparison of private costs and benefits would suggest (Shama 1983). A range of potential market and behavioral failures can explain this paradox (Jaffe and Stavins 1994; Gillingham *et al.* 2009; Popp and Newell. 2009; Table 3). In particular, customers are reluctant to be the first to adopt a new technology. The so-called "dynamic increasing returns" appear only slowly, as early adopters are observed and copied by others, until the learning-by-doing effect is so important that diffusion becomes widespread. Obviously this requires certain interventions which are discussed further in sections 4.5 and 5.

4.4 PUBLIC AND PRIVATE SECTOR INTERACTIONS

A range of different interactions between market players and other stakeholders have demonstrated to significantly facilitate green technology transfer to developing countries. For instance, a study on the patenting history of more than 800 Chinese solar photovoltaic companies between 1998 and 2008 finds that companies whose leaders have international experience are more likely to patent, which points to a higher propensity to innovate (Luo *et al.* 2013). Patenting activity can also increase for neighboring companies as they reap knowledge spillover benefits from the returning emigrants, often bringing the benefit

Figure 3:

DOMESTIC ABSORPTIVE CAPACITY CONDITIONS AND EXTERNAL FLOWS



Source: World Bank 2008

Box 3:

ADAPTING GREEN TECHNOLOGIES TO LOCAL CONDITIONS

- The Chinese government scrutinizes potential Clean Development Mechanism (CDM) projects with respect to local features. In general, it refrains from embracing technologies that are unsuitable for Chinese conditions because poor compatibility would increase the risk to the CDM credits, thus lowering their value (Wang 2010).

- Chinese photovoltaic manufacturers adapt certain production processes so as to replace costly capital with less expensive labor (De la Tour *et al.* 2011).

- In India, since the prevailing wind speeds are lower than those in Europe, companies need to adapt wind turbine technology (Kristinsson and Rao 2007).

Table 3:

MARKET AND BEHAVIORAL FAILURES THAT EXPLAIN THE SLOW DIFFUSION OF ENERGY EFFICIENCY TECHNOLOGIES, AND POSSIBLE POLICY RESPONSES

Potential market failures ····►	Potential policy options
Energy market failures	
Environmental externalities	Emissions pricing (tax, cap and trade)
Average-cost electricity pricing	Real-time pricing, market pricing
Energy security	Energy taxation, strategic reserves
Capital market failures	
Liquidity constraints	Financing/loan programs
Innovation market failures	
R&D spillovers	R&D tax credits, public funding
Learning-by-doing spillovers	Incentives for early market adoption
Information problems	
Lack of information, asymmetric information	Information programs
Principal-agent problems	Information programs
Learning by using	Information programs

Potential behavioral failures ····►	Potential policy options
Prospect theory	Education, information, product standards
Bounded rationality	Education, information, product standards
Heuristic decision making	Education, information, product standards

Source: Gillingham et al. *2009*

of established networks. In light of this success, three national middle- and long-term plans have identified recruiting high-skill returnees as a strategic imperative for China. Today China's policies not only provide incentives for the return of emigrants but, in some sectors, also include requirements of relevant international experience (Luo *et al.* 2013).

In a similar vein, Puga and Trefler (2010) examine a number of factors that help to attract innovative companies from abroad and to increase the share of foreign companies involving locals in the innovative process. These factors, which are present in China and India, include the existence of world-class engineering schools, a high share of people studying in developed countries who subsequently return to their home countries, a pronounced commitment on the part of the diaspora abroad, a clear emphasis on standards and quality control, as well as extensive collaborations with foreign multinationals in developing products destined to particularly large local markets.

Companies use various kinds of cooperative agreements, such as joint-ventures, joint research and development, technology exchange agreements, direct minority investments and sourcing relationships, but also restructurings to access technologies. In 2009, total global acquisitions, partnerships and joint ventures by renewable companies amounted to some USD 33.4 billion (PwC 2009). A growing number of businesses from emerging economies such as China, India and Brazil engage in inter-company cooperation, as the following examples illustrate (Perez Pugatch 2011):

- In 2008, the large Indian wind power company Suzlon Energy Ltd secured a 30% stake in the German turbine manufacturer REpower Systems AG. Valued at USD 770 million, this is one of the most important renewables deals in the world to date.

- In 2008, Xinjiang Goldwind Science and Technology of China obtained a 70% stake in the German wind turbine maker Vensys Energy AG in order to gain access to the company's technological expertise and knowledge resources.

- In 2009, the China Investment Corporation, a sovereign wealth fund, acquired a 15% stake in the AES Corporation of the United States, one of the largest energy generating companies in the world, which has made considerable investments in renewables.

- In 2010, Cosan SA, Brazil's leading ethanol producer, signed an agreement with Royal Dutch Shell to form a USD 12 billion joint venture. The accord marks one of largest investments by a traditional oil and gas energy company into biofuels and alternative energy.

- In 2010, General Electric (GE) and Petrobras successfully co-developed a bio-ethanol-fired gas turbine power station in Brazil, with GE providing the turbines and Petrobras modifying them to allow for the use of ethanol.

A variety of non-commercial and/or pre-competitive collaborative arrangements involving businesses, research institutions and other organizations also play a crucial role in stimulating green innovation and diffusion in developing countries:

- Research coordination agreements remedy certain market failures, preventing duplicative R&D efforts across countries. For example, the International Energy Agency (IEA) frequently uses this type of instrument, which allows countries to fund and implement their individual contributions to different sector-specific projects. Research coordination agreements ensure that responsibilities along the value chain are clearly demarcated and assigned. What is even more important, they ensure that all key technologies with particular relevance for developing countries are included, e.g. biofuels from developing-country feedstock and lower-capacity power generation (World Bank 2010a).

- Cost-sharing agreements are tools through which multiple countries can subsidize the joint development of promising technologies. A case in point is the International Thermonuclear Experimental Reactor (ITER), a USD 12 billion project to demonstrate the feasibility of nuclear fusion for electricity generation involving considerably less radioactive waste.[10]

- Launched in 2008 by IBM, Nokia, Pitney Bowes and Sony and coordinated by the Environmental Law Institute, the Eco-Patent Commons is a private open-access initiative. It facilitates cooperation between businesses that pledge patents, and potential users, so as to foster joint innovation projects aimed at innovating and diffusing green technology solutions.[11]

- WIPO GREEN is an interactive marketplace that promotes innovation and diffusion of green technologies by connecting technology and service providers with those seeking innovative solutions. WIPO GREEN consists of an online database and network that brings together a wide range of players in the green technology innovation value chain, and connects owners of new technologies with individuals or companies looking to commercialize, license or otherwise access or distribute a green technology.

Table 4:

BARRIERS TO DIFFUSION OF GREEN TECHNOLOGIES

Article	Technology	Barrier(s) to Diffusion	Data	Key Results
Jaffe and Stavins 1995	Thermal insulation	Up-front costs matter more	US residential construction 1979-1988	Lower adoption costs are 3x more likely to encourage adoption than increased energy costs.
Hassett and Metcalf 1995	Residential energy conservation	Up-front costs matter more	US households 1979-1981	Installation cost savings via tax credits encourage adoption.
Kemp 1997	Thermal home insulation	Inadequate information	Netherlands households	Government subsidies do not lead to adoption. Epidemic model fits data better than rational choice model.
Metcalf and Hassett 1999	Attic insulation	Inadequate information	US Residential Energy Consumption Survey, 1984, 1987, and 1990	Actual energy savings are less than promised.
Reppelin-Hill 1999	Clean steal technologies	Import barriers	Adoption of electric arc furnace in 30 countries, 1970-1994	Import barriers restrain the adoption of foreign-produced goods.
Howarth *et al*. 2000	Energy-saving technology (efficient lighting equipment)	Agency decision making problems, inadequate information	Green Lights and Energy Star programs	Voluntary programs lead to wider adoption in companies. Inadequate information inhibits adoption.
Nijkamp *et al*. 2001	Energy-efficient technology	Economic barriers - alternative investment - low energy costs - capital replacement	Survey of Dutch companies	Economic barriers affect adoption more than financial and uncertainty barriers.
Mulder *et al*. 2003	Energy efficiency technologies	Complementarities among technologies	N/A	Complementarities and learning-by-doing process impede adoption.
Anderson and Newell 2004	Company-level adoption of energy-saving projects recommended by energy audits	Inadequate information on technologies, initial costs and payback years of adoption	U.S. Department of Energy's Industrial Assessment Centers database, 1981-2000	Companies adopt additional projects with improved information. Up-front costs have 40% greater effect than energy costs.

Source: Modified from Popp et al. *2010*

4.5 POLICY CONSIDERATIONS

A key factor that stimulates technology transfer towards emerging economies relates to **environmental policies** in high-income countries (Lovely and Popp 2008; Popp *et al.* 2010; Glachant *et al.* 2013b; Table 4). A case in point is the introduction of advanced emission controls by automotive manufacturers in the Republic of Korea in order to meet the regulatory requirements of the markets in the United States and Japan. Eventually, the Korean government adopted domestic regulations requiring the advanced emission controls as well (Medhi 2009).

In summary, while the literature on the diffusion of environmental technologies is relatively sparse, it is possible to identify a number of enabling factors. These include strengthening IP protection, removing barriers to international trade and investment, developing sufficient absorptive capacity, and promoting collaboration between market actors. As recent empirical evidence suggests, foreign technology suppliers take all these factors into account when defining their strategies with respect to emerging markets (Rai *et al.* 2014). In addition to considering the degree to which their intellectual property can be effectively protected, they assess the level of relevant expertise and the overall business environment, in particular the country's ability to coordinate institutional policies to attract technologies and investments (Woodhouse 2005). In other words, IP protection and enforcement in a given jurisdiction is only one of several factors that technology providers consider, albeit an important one. Finally, in devising innovation policies for developing countries, special attention should be given to SMEs, which significantly contribute to innovation, growth and employment in these economies.

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9 Technology transfer refers to the movement of knowledge or technology between two specific entities, for instance, from one business to another (Roessner 2000; Wahab *et al*. 2012). In principle, a technology transfer transaction results in the sustainable deployment of a solution and improvements in the recipient's knowledge base (Brant and Parthasarathy 2015). Vertical transfer refers to the transfer of technology from basic to applied research. By contrast, horizontal transfer designates the movement of a more mature technology from one organization in a specific socio-economic context to another organization in a different context. It can take place within a company, across industries, or across geographical areas. While technology transfer is generally viewed as a linear process, however, in practice, it occurs often in an interactive manner, especially if a technology needs to be adapted to local circumstances. Technology diffusion is a broader concept that captures the social change to which the transfer of technology may give rise over time (Brant and Parthasarathy 2015).

10 Members include China, the European Union, India, Japan, the Republic of Korea, Russia and the United States.

11 To date, 100 eco-friendly patents have been pledged by 13 companies representing a range of industries worldwide: Bosch, Dow Chemical, DuPont, Fuji-Xerox, Hitachi, HP, IBM, Nokia, Pitney Bowes, Ricoh, Sony, Taisei and Xerox. These are cross-listed on the WIPO GREEN website (www.wipo.int/green)

Section 5:
Financing

In addition to the enabling policy framework outlined in the previous section, the development and diffusion of innovative green technologies require considerable funding efforts. According to the most recent estimates by the IEA, an additional USD 44 trillion of investment is needed through 2050 to decarbonize the energy system in line with the global climate targets (IEA 2014).

In 2013, total investment in renewable power and fuels fell to USD 214 billion worldwide, some 23% lower than the 2011 peak (UNEP 2014).[12] The two main reasons for the decline in financial commitments to renewables were concerns about future policy support for renewables in several countries (*e.g.* United States, Germany), as well as reductions in technology costs, especially in solar systems (UNEP 2014).

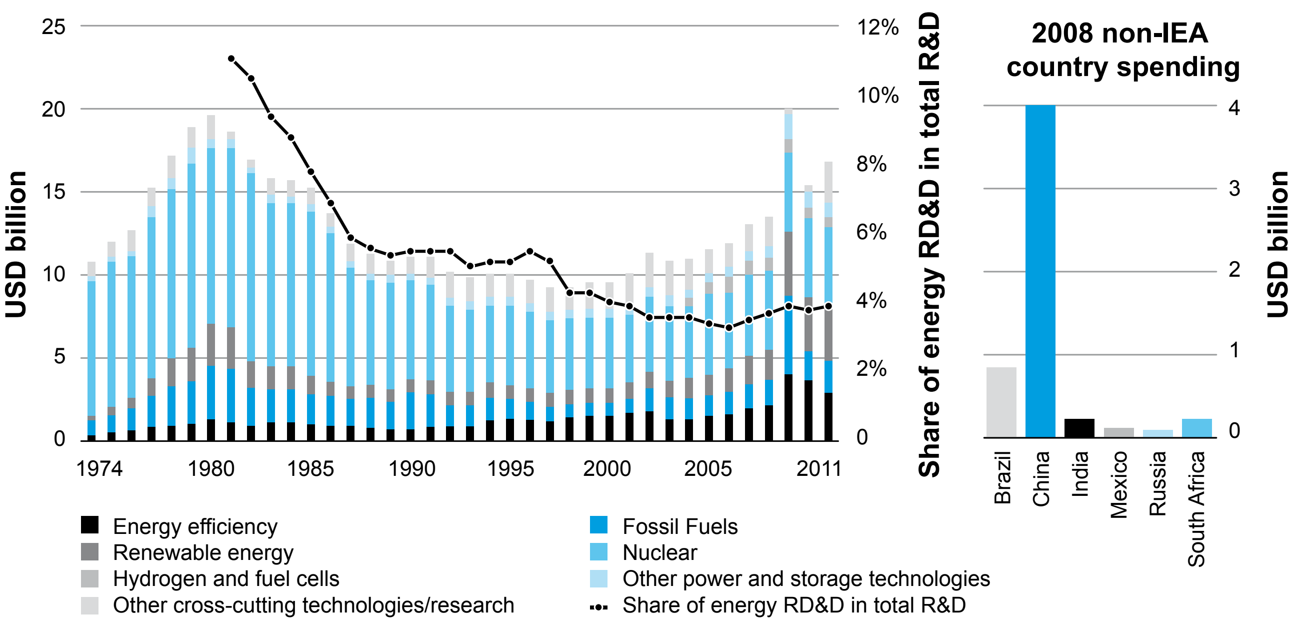
Government spending on renewable energy R&D has grown significantly in recent years (Rhodes *et al.* 2014), doubling over the decade following the 1997 signing of the Kyoto Protocol, while overall public energy spending rose by just 45% (Popp 2010). In 2013, public renewable energy R&D spending amounted to USD 4.6 billion, approximately leveling with corporate expenditures (USD 4.7 billion) (UNEP 2014). However, renewable energy R&D still represents only a small share of the overall energy R&D, accounting in 2011 for USD 3.7 billion, out of a total energy R&D spent of USD 17.2 billion (IEA 2013c). What is more, overall energy R&D represents an even smaller share of total R&D (Figure 4). In a similar vein, according to a recent analysis on national trends in investments in global energy research, development, and demonstration (RD&D), BRICS[13] country energy R&D focuses predominantly on fossil fuel and nuclear technologies (Gallagher *et al.* 2011).

Public funding of environmental R&D plays a crucial role as it may partly compensate for the underinvestment on the part of companies. In fact, when making investment decisions, governments are able to account for both social returns and profits, whereas companies focus in general exclusively on the latter. Public funding of environmental R&D is especially important in three areas affected by market or policy failures: basic R&D, pre-commercial R&D, and R&D by SMEs. However, it should be noted that effective mechanisms exist to ensure that public funding does not crowd out private investment (Henderson and Newell 2010).

First, in basic R&D, businesses generally need to deal with longer-term payoffs and greater uncertainty which complicate both evaluation and eventual returns on research investments (Popp 2010).

Figure 4:

GOVERNMENT RD&D EXPENDITURE IN IEA MEMBER COUNTRIES



Source: IEA 2013b

Second, pre-commercial R&D frequently involves the so-called "valley of death" or the lack of financing for bringing applied research to the market (Figure 5). Both governments and private sector may be prepared to fund R&D for unproven technologies or technologies that have been demonstrated in the market. However, there is limited funding for technologies at the demonstration and deployment stages. Governments are often reluctant to finance early-stage ventures for fear of distorting the market, while private investors deem them too risky (independent investors termed "business angels" form a limited exception). As a result, venture capitalists, who typically fund companies with demonstrated technologies, have been able to provide a majority of capital available for investments in the clean technology sector – some 73% in 2006 – given that so few companies in this sector survive the phase of pre-commercial R&D (World Bank 2010a).

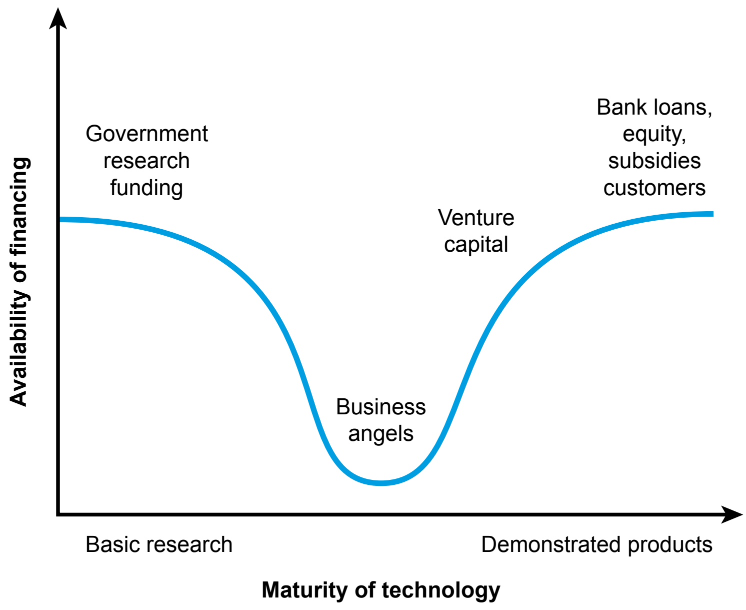
As noted earlier in this Report, IP rights also assume an important signaling function that helps businesses to attract private investors. Venture capitalists are of key importance for the commercialization of ESTs. Unlike debt funding, venture capital is risk capital, *i.e.* the return to the investor depends on the success of the company. Venture capitalists assess investment opportunities according to a range of criteria, including adequate protection from third-party entrants. If the technology is protected by enforceable IP rights, other businesses using it would face an infringement action, unless they enter into a licensing agreement, which is likely to generate additional profits for the venture capitalists (McGrory 2013).

Third, government support is particularly important for SMEs in the green technology sector (World Bank 2010a). While having the potential to contribute substantially to technological progress, SMEs often face considerable financial constraints. In general they lack not only resources but also a record of success and assets that banks can use as collateral (Rassenfosse 2012). Worldwide there is therefore a range of mechanisms to facilitate the funding of innovative green technology SMEs:

- In the United States, the Environmental Protection Agency funds SMEs through the Small Business Innovation Research (SBIR) Program.
- In the United Kingdom, the Down to Zero Procurement Compact provides government incentives to invest in environmental technologies.
- In Brazil, the National Innovation Agency FINEP offers loans and non-reimbursable financial support to innovative SMEs that it selects through public calls for proposals, invitation letters, and bids.

Figure 5:

THE "VALLEY OF DEATH" BETWEEN RESEARCH AND THE MARKET



Source: World Bank 2010a

- In India, the European Business and Technology Centre (EBTC) in New Delhi, a program co-funded by the European Union, is a lead coordinator of the largest technology platform connecting SMEs in India and Europe. It has a “Cleantech database” which Indian companies can access to discover innovative technologies that correspond to their needs. The EBTC also has a “Cleantech incubator” which *inter alia* offers individual workstations.

A number of case studies point to the importance of access to continued financing for successful technological diffusion in developing countries (Box 4).

To sum up, both public and private R&D are complementary tools necessary to further develop and disseminate environmentally sound technologies. Overall, while it still focuses on the non-renewable energy sector, public funding has a key role to play in low-carbon innovation. The most effective financing mechanism depends on the type of technology, the maturity of the market, competing technologies, the lifecycle stage of the technology, as well as the risk and uncertainty surrounding the development process.

As a consequence, some authors have argued that it may be necessary to develop a variety of new arrangements to generate public and private financing for climate technologies (Stewart *et al.* 2009).

What is more, the results of publically financed R&D often require significant effort to translate them into useful and scalable technology offerings (Booker *et al.* 2012). The ability to use and transfer the underlying IP rights that emerge from publically funded R&D between entities can play a crucial role in reducing risk for downstream development and adaptation of technologies (Langer 2013).

Finally, it should be noted that effective IP protection is a prerequisite for much private funding.

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12 Excluding large hydro-electric projects.

13 BRICS is the acronym for an association of five major emerging national economies: Brazil, Russia, India, China and South Africa.

Box 4:

FINANCING GREEN TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES – CASE STUDIES

- Created as a result of the Kyoto Protocol, the Clean Development Mechanism (CDM) is the primary channel for funding the development and diffusion of ESTs in developing nations. It has leveraged a combination of public and private capital to finance more than 4,000 low-carbon projects (World Bank 2010a). However, the vast majority of these projects do not involve the transfer of either knowledge or equipment from industrialized to developing nations.

- In light of relatively high start-up costs, financial assistance can be crucial for the diffusion of ESTs in low-income countries, as shown in a study on the diffusion of efficient stoves and tobacco barns, as well as small biogas plants by commercial farmers in Rwanda, Tanzania and Malawi. Moreover, there is a need to plan and set aside funding for ongoing operational costs at the outset of such projects (Barry *et al.* 2011).

- An assessment of China’s Renewable Energy Development Project has identified access to financial credit and quality of after-sales service as critical conditions for the diffusion of solar home systems in China (D’Agostino *et al*. 2011).

- A study on the relationship between the maturity of the financial sector and the diffusion of renewable energy finds that investments in this area often require long-term loans. However, in low-income countries, access to such credit is limited, particularly for SMEs, as a result of shortcomings in the financial sector. Therefore, improving a country’s financial infrastructure may not only lead to wider macroeconomic benefits, but may also encourage green growth by providing easier funding for green infrastructure (Brunnschweiler 2010).

Section 6:
Policy Tools

Ambitious policy tools, including their proper enforcement, constitute probably the most significant factor in promoting environmental innovation (Newell *et al.* 1999; Popp 2002; Brunnermeier and Cohen 2003; Crabb and Johnson 2010; Glachant *et al.* 2013a), and international technology diffusion in particular (Lanjouw and Mody 1996; Verdolini and Galeotti 2011; Dechezleprêtre *et al.* 2013).

Policymakers can select from a variety of supply- and demand-side approaches (Box 5), including:

- environmental and technical standards and regulations;
- carbon pricing;
- subsidies;
- mandates;
- funding grants; and
- public-private partnerships.

This diversity of policy options provides greater flexibility in addressing issues that may be local, regional, national or international in nature. A key challenge is to generate political support for legislation that prioritizes environmental innovation. In this context, transparency is of fundamental importance as it helps to identify the costs and benefits of the policies, thus attracting the necessary support from relevant interest groups.

The 2010 World Development Report has classified a range of policy priorities to encourage innovation in climate-smart technologies according to national income level (Table 5). It recommends improvements in the overall business environment, greater funding for research institutions, and the removal of trade barriers for green technologies (World Bank 2010a). As discussed above, IP rights are a partial solution to the dual externality problem. While they fail to remedy environmental externalities, IP rights can address the public good characteristics of knowledge (Hall and Helmers 2010). Moreover, given that knowledge spillovers occur generally across technological innovation, policies to overcome knowledge market failures may be general, addressing the issue across all sectors of the economy (Popp 2010). Finally, it is important to understand how these policies impact on the different phases of the innovation chain (Figure 6).

Box 5:

ENVIRONMENTAL POLICIES – COMMAND-AND-CONTROL AND MARKET-BASED TOOLS

“Environmental policies can be characterized as either uniform ‘command-and-control’ standards or market-based approaches.

Market-based instruments are mechanisms that encourage behavior through market signals rather than through explicit directives regarding pollution control levels or methods. Such regulations allow companies the flexibility to choose the least-cost solutions to improved environmental performance.

In contrast, conventional approaches to regulating the environment are often referred to as ‘command-and control’ regulations, since they allow relatively little flexibility in the means of achieving goals. These regulations tend to force companies to take on similar magnitudes of the pollution-control burden, regardless of the cost. Command-and-control regulations do this by setting uniform standards for companies.

The most commonly used types of command-and-control regulation are performance- and technology-based standards. A performance standard sets a uniform control target for companies (emissions per unit of output, for example), while allowing some latitude in how this target is met. Technology-based standards specify the method, and sometimes the actual equipment, that companies must use to comply with a particular regulation.”

Source: Popp et al. *2010*

Table 5:

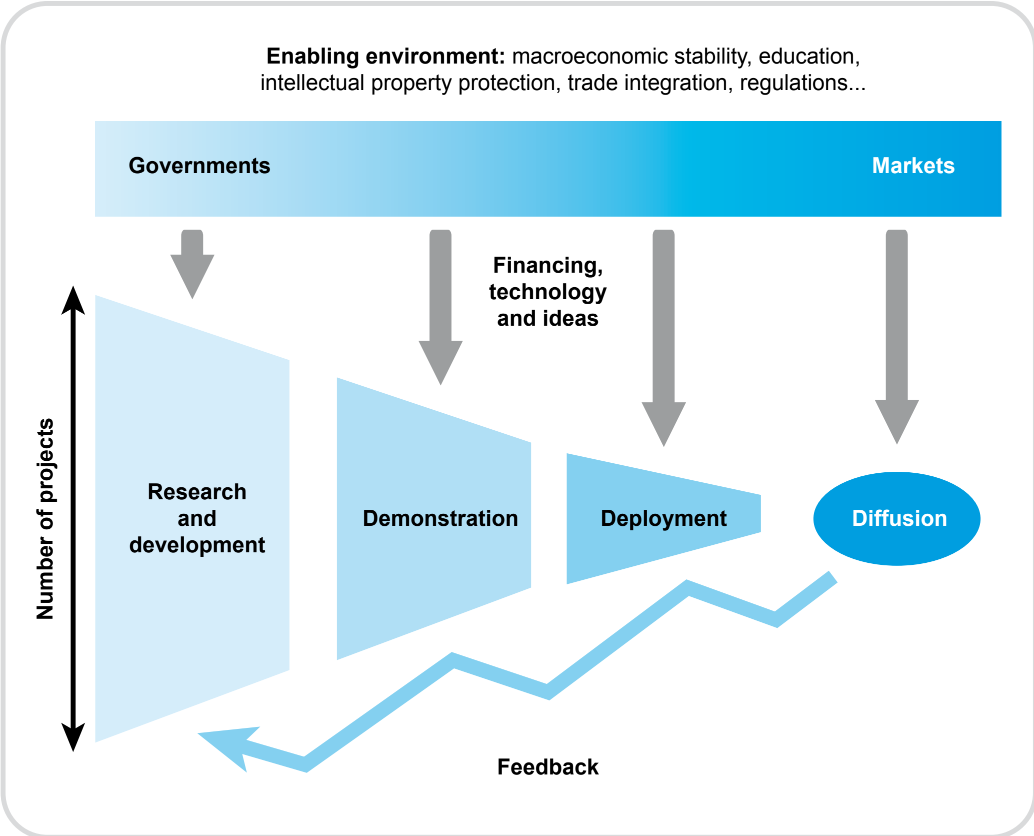
KEY NATIONAL POLICY PRIORITIES FOR INNOVATION IN COUNTRIES OF DIFFERENT INCOME LEVELS

Countries	Main Policies
Low-income	Invest in engineering, design, and management skills. Increase funding to research institutions for adaptation research, development, demonstration, and diffusion. Increase links between academic and research institutions, the private sector, and public planning agencies. Introduce subsidies for adopting adaptation technologies. Improve the business environment. Import outside knowledge and technology whenever possible.
Middle-income	Introduce climate-smart standards. Create incentives for imports of mitigation technologies and, in rapidly industrializing countries, create long-term conditions for local production. Create incentives for climate-smart venture capital in rapidly industrializing countries with a critical density of innovation (such as China and India). Improve the business environment. Strengthen the IP regimes. Facilitate climate-smart foreign direct investment. Increase links between academic and research institutions, the private sector, and public planning agencies.
High-income	Introduce climate-smart performance standards and carbon pricing. Increase mitigation and adaptation innovation and diffusion through subsidies, prizes, venture capital incentives, and policies to encourage collaboration among companies and other sources and users of climate-smart innovation. Assist developing countries in enhancing their technological absorptive and innovative capacities. Support transfers of know-how and technologies to developing countries. Support middle-income-country participation in long-term energy RD&D projects. Share climate change-related data with developing countries.
All countries	Remove barriers to trade in climate-smart technologies. Remove subsidies to high-carbon technologies. Redefine knowledge-based institutions, especially universities, as loci of the diffusion of low-carbon practices.

Source: World Bank 2010a

Figure 6:

POLICY AFFECTS EVERY LINK OF THE INNOVATION CHAIN



Source: World Bank 2010a (adapted from IEA 2008)

According to a comprehensive literature review by Popp *et al.* (2010), most papers evaluating the effect of different policy instruments on environmental innovation are theoretical rather than empirical. Moreover, the study finds that the theoretical studies largely focus on the supply side of the market, examining the incentives companies face in determining whether or not to incur R&D costs in the face of uncertain outcomes (Table 6). Apparently there are very few empirical studies that assess the impact of different policy instruments on innovation (Table 7), which may be primarily due to the lack of data on all relevant aspects of environmental innovation (Popp *et al.* 2010). Other authors caution that the ability to conceptually model technological change exceeds the ability to validate the models empirically – a fact which necessitates particular care on the part of policymakers (Gillingham *et al.* 2008; Karakaya *et al.* 2014).

The implementation of environmental policies poses further challenges. One study considers carbon taxation as the only reliable manner of correctly signaling to entities whose actions impact on global warming (*i.e.* consumers, governments, producers and innovators) (Nordhaus 2009). However, in order to be truly effective, a carbon tax would require implementation on a global level. In a similar vein, the 2010 World Development Report emphasizes the relevance of international cooperation which has the potential to produce scale effects (World Bank 2010a). International cooperation involves a variety of agreements aimed at legislative and regulatory harmonization, knowledge sharing and coordination, cost sharing, and technology transfer (Table 8).

Several economic studies conclude that environmental and technological policies work best in tandem (Popp 2010; Popp *et al.* 2010). The role of technology policy is to facilitate the development of green (and other) technologies, while environmental policy encourages the diffusion of these technologies. Accordingly, an optimal portfolio of emission-reducing policies generates results at significantly lower cost than any single policy (Popp 2010). For instance, technology subsidies alone have a smaller environmental impact than policies that

Table 6:

KEY THEORETICAL PAPERS ON INNOVATION AND ENVIRONMENTAL POLICY INSTRUMENTS

Article	Policies	Key results
Magat 1978	Effluent taxes, uniform standards	Ranking is ambiguous.
Magat 1979	Taxes, subsidies, permits, effluent standards, technology standards	All except technology standards induce innovation. Taxes, permits, and effluent standards have similar effects.
Carraro and Siniscalco 1994	Environmental policy instruments, industrial policy instruments	Innovation subsidies have the same effects as environmental policy instruments, except for emissions reduction from pollution taxes.
Laffont and Tirole 1996	Tradable permit system	Futures markets for permits lead to innovation.
Cadot and Sinclair-Desgagne 1996	Incentive scheme	Government-issued threats of regulation can be a solution for information asymmetry.
Carraro and Soubeyran 1996	Emission tax and R&D subsidy	R&D subsidies are desirable if decrease of product output is small or considered negative.
Katsoulacos and Xepapadeas 1996	Tax and environmental R&D subsidy	Tax and subsidy together can overcome the market failure.
Ulph 1998	Pollution taxes, uniform standards	Stricter standards and taxes do not have significant effect on R&D level. There are two competing effects: policies increase costs (and R&D), but also lower output (which decreases R&D).
Montero 2002	Various policy instruments under non-competitive environments	Types of market affect the level of R&D incentives from standards and taxes. Cournot competition leads to higher incentive, while Bertrand competition leads to lower incentive.
Innes and Bial 2002	Environmental regulation, behavior of companies	Technology leaders favor stricter environmental regulations, as these policies raise the costs of competitors.
Fischer *et al*. 2003	Market-based policies, uniform standards	Ranking is ambiguous, and depends on ability to diffuse technologies, cost, and number of polluting companies.
Requate 2005	*Ex post* regulation, interim regulation, *ex ante* regulation (with different tax rates), regulation (with a single tax rate)	*Ex ante* policies with different tax rates dominate, and tax policies are always preferred to permit policies.
Baker and Adu-Bonnah 2008	Alternative energy with no carbon emission, conventional energy with efficiency improvement	With uncertainty, stringency of policy matters. With weak environmental policy, improvements in conventional energy efficiency are acceptable. However, strong standards require alternative energy (no carbon emissions).
Bauman *et al*. 2008	Market-based policies, uniform standards	If command and control policies lead to innovation which lowers the marginal abatement cost curve, they may induce more innovation than market-based policies.

Source: Popp et al. *2010*

Table 7:

KEY EMPIRICAL PAPERS ON INNOVATION AND ENVIRONMENTAL POLICY INSTRUMENTS

Article	Policies	Data	Key results
Newell *et al*. 1999	Energy price-based policies, energy efficiency standards, labelling	Appliance model characteristics and energy prices 1958-1993	Energy price changes lead to the introduction of new technologies in the market and removal of old models, while regulation works only by eliminating old models.
Popp 2003	SO2 permits, direct regulation	US coal-fired power plants 1985-97	Command-and-control innovation led to cost savings. Innovation with permit trading led to both cost savings and emissions reductions.
Lange and Bellas 2005	Clean Air Act	US coal-fired power plants 1985-2002	Permit trading systems lead to lower capital and operating costs. Mandatory regulation alone does not promote change in costs.
Lanoie *et al*. 2007	Environmental policy instruments, environmental R&D	Survey of companies in 7 OECD countries	For inducing environmental R&D, stringency of policies is more important than policy type.
Johnstone *et al*. 2008	Environmental policy instruments, environmental R&D	EPO pollution control patents to OECD countries, 1978-2004	Flexible policies lead to higher quality innovations (measured by patent family size).
Taylor 2008	SO2 permits, direct regulation	U.S. patents 1975-2004	Uncertainty over future permit prices reduces innovation incentives for 3rd party producers.
Johnstone *et al*. 2008	Price-based policies, quantity-based policies	EPO renewable energy technology patents from 25 OECD countries, 1978-2003	Price-based policies lead to solar and waste-to-energy technologies, while quantity-based policies lead to wind energy (closest to current energy market).

Source: Popp et al. *2010*

Table 8:

INTERNATIONAL TECHNOLOGY-ORIENTED AGREEMENTS SPECIFIC TO CLIMATE CHANGE

Type of agreements	Subcategory	Existing agreements	Potential impact	Risk	Implementation	Target
Legislative and regulatory harmonization	Technology deployment and performance mandates	Very little (mainly EU)	High impact	Wrong technological choices made by government	Difficult	Energy technologies with strong lock-in effects (transport) that are highly decentralized (energy efficiency)
Knowledge sharing and coordination	Knowledge exchange and research coordination	Many (such as International Energy Agency)	Low impact	No major risk	Easy	All sectors
	Voluntary standards and labels	Several (EnergyStar, ISO 14001)	Low impact	Limited adoption of standards and labeling by private sector	Easy	Industrial and consumer products; communication systems
Cost-sharing innovation	Subsidy-based “technology push” instruments	Very few (ITER)	High impact	Uncertainty of research outcomes	Difficult	Precompetitive RD&D with important economies of scale (carbon capture and storage, deep offshore wind)
	Reward- based “market pull” instruments	Very few (Ansari X-prize)	Medium impact	Compensation and required effort may result in inappropriate levels of innovation	Moderate	Specific medium-scale problems; solutions for developing-country markets; solutions not requiring fundamental R&D
Technology transfer	Bridge-the-gap instruments	Very few (Qatar-UK Clean Technology Investment Fund)	High impact	Funding remains unused due to lack of deal flow	Moderate	Technologies at the demonstration and deployment stage
	Technology transfer	Several (Clean Development Mechanism, Global Environment Facility)	High impact	Low absorptive capacities of recipients countries	Moderate	Established (wind, energy efficiency), region-specific (agriculture) and public sector (early-warning, coastal protection) technologies

Source: World Bank 2010a

directly address the environmental externality (Popp 2010). Similarly, government support for emissions control R&D has been found to be only effective in the presence of an at least moderate environmental policy to encourage diffusion of the resulting technologies (Fischer 2008).

In a paper using a two-sector model of directed technical change to evaluate the impact of taxes and R&D subsidies, Acemoglu *et al.* (2009) show that the optimal policy mix includes both carbon taxation and R&D subsidies. According to their findings, R&D subsidies direct research toward the clean energy sector. As a result, the latter requires a lower carbon tax compared with a scenario in which a carbon tax alone was used to both reduce emissions and influence the direction of innovative activity. Moreover, the study concludes that the combination of policies is less distortive than relying on a carbon tax alone.

The majority of economic studies conclude that market-based tools are more efficient than regulatory ones in incentivizing the diffusion of new technologies. For numerous authors, this is particularly true in the international context where uncertainties are especially pronounced and hence contractual solutions difficult to obtain. However, in their study on pollution reduction through a change in process (*i.e.* cleaner fuel) – as distinct from an end-of-pipe mitigation (*i.e.* methods used to remove already formed contaminants from a stream of air, water, waste, product or similar; these techniques are called “end-of-pipe” as they are normally implemented as a last stage of a process before the stream is disposed of or delivered; Bauman *et al.* 2008) make the opposite claim. The authors find that, depending on the marginal abatement costs, command-and-control standards may actually provide greater incentives for innovation than market-based policies.

Policymakers need to take account of the specific effects produced by the available policy instruments. One study considers the impact of a range of market-based policy tools on renewable energy innovation across 25 OECD countries, pointing to significant differences across technologies (Johnstone *et al.* 2010). In particular, it compares price-based policies (*e.g.* tax credits and feed-in tariffs) to quantity-based policies (*e.g.* renewable energy mandates). Quantity-based policies favor the development of technologies related to wind energy, which is the closest substitute for traditional energy sources. In fact, when mandated to provide alternative energy, companies target technologies that are closest to the market or consumer. By contrast, price-based policies, such as direct investment incentives stimulate in particular solar and waste-to-energy technologies, which are less competitive. These findings are particularly relevant for policymakers seeking to encourage long-run innovation in technology areas that are not yet competitive. A related study concludes that more flexible regulations result in higher quality innovation (Johnstone and Haščič 2008). Drawing on a survey of business executives, the authors demonstrate that environmental patents have larger family sizes when companies perceive greater freedom of choice in complying with environmental regulations in the innovator’s home country.

A study on renewable energy policies under differing levels of competition attributes special importance to the interplay between environmental policies and market competition (Nesta *et al.* 2014). The cross-country analysis reveals that the combination of environmental policies and market deregulation is the most effective means of incentivizing innovation in renewable energy, especially near the technological frontier. This finding appears to corroborate the complementarity hypothesis according to which environmental policies are more effective in competitive markets (Nesta *et al.* 2014).

Ganesan *et al.* (2014) examine the direct and indirect policies adopted in India in order to stimulate development of renewable energy technologies. While involving relatively low costs, the policies have resulted in only slow non-sustained growth of the sector, failing to produce the desired impacts in terms of energy security, avoided health costs, and abatement of greenhouse gas (GHG) emissions (Table 9). Given the nascent stage of the renewable energy industry in the country and the multiple policy objectives it encompasses, the authors consider an evaluation based on purely economic grounds as impossible.

In summary, a meaningful comparative analysis of policy options poses, even within a single country, significant challenges. Several authors highlight the difficulties associated with the ranking of available policy instruments, arguing that such an assessment depends on a range of factors, for instance, the perceived costs of environmental externalities and the state of technology (Borenstein 2011), as well as the innovator’s ability to appropriate spillover benefits of new technologies to other companies, the costs of innovation, environmental benefit functions, and the number of companies producing emissions (Popp *et al.* 2010). At the same time, the existing literature has repeatedly stressed the need for policymakers to select and combine different instruments, thereby taking into account the country and industry specific conditions.

Table 9:

IMPACTS OF DIRECT AND INDIRECT POLICIES IN INDIA

POLICIES/ IMPACT CATEGORIES	DIRECT POLICIES						INDIRECT POLICIES				
	Financial Incentives (FiT/GBI/ VGF)	Preferential Tax Treatment	Demand Stimulation	R&D	DCR	Investment Promotion Schemes	JV/FDI/ Technol-ogy Transfer	NCEF	Pricing Carbon	Human Resource Develop-ment	Power Evacua-tion
Technology advancement				√		•	√	x			
Solar-domestic competitiveness	•	•	x	x	x						
Wind-domestic competitiveness	•	√	x	x		√	√			•	
Wind-competition in the international market	•					√					
Local environment and GHG emissions	•		x						√		x
Energy access and security	•	√	x					x			x
Employment	•	√	x		•					•	

- • extent of impact unclear
- √ positive impact (intended or otherwise)
- x impact not as desired
- (blank) no impact/change

Source: Ganesan et al. *2014*

Section 7:
Conclusion

Environmental innovation is key to addressing the global challenge of climate change. Robust IP protection and a sound enabling policy environment in particular can afford innovators the security to invest in the development of relevant technologies as well as their transfer and diffusion on an international scale, in particular to low- and middle-income countries. However, the presence of environmental externalities, and market and regulatory uncertainties requires complementary policy interventions. These measures aim to create the conditions that are necessary for the development, diffusion and transfer of green technologies. When defining their interventions, policymakers need to take account of the local context and ensure transparency. A combination of R&D and environmental policies has proven to be most effective. Moreover, studies have shown that environmental policies are more effective in competitive markets. Public and private sector funding is essential for the development and diffusion of ESTs. The most effective mechanism depends on a range of factors, such as the type of technology, the maturity of the market, competing technologies, the lifecycle stage of the technology, as well as the risks and uncertainty surrounding the process of technology development.

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