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What role for climate negotiations on technology transfer?

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Academic abstract

Little progress has been made in climate negotiations on technology since 1992. Yet, the diffusion of climate change mitigation technologies to developing countries (non-Annex I) has increased dramatically over the last twenty years. The shift has mostly concerned emerging economies, which are now reasonably well connected to international technology flows. This is good news, as the bulk of emissions increases are expected to take place in these countries in the near future. In contrast, least developed countries still appear to be excluded from international technology flows, mostly because of their negligible participation in the recent economic globalization. The paper derives policy implications on the contribution of climate negotiations to international technology diffusion.

Policy relevance statement

The discrepancy between the little progress made in climate negotiations on technology since 1992 and the steadily increase in the international diffusion of climate mitigation technologies leads to the perhaps controversial view that the diffusion of climate mitigation technologies does not need strong international coordination over technology issues under the UNFCCC. However, climate negotiations can play a key role to spur the demand for low carbon technologies by setting ambitious emission reductions targets and policies.

Keywords*:* climate-mitigation technologies, international technology transfer, climate negotiations, innovation policy, intellectual property rights, trade, economic globalization.

1 Introduction

Technology has been an important topic of international climate change negotiations since the adoption in 1992 of the United Nations Framework Convention on Climate Change, in which the parties committed themselves to “promote and cooperate in the development, application and diffusion, including transfer, of technologies” (UNFCCC, article 4.5). The focus is on North-to-South technology transfers, since technologies have so far been mostly developed in industrialized countries, while emerging economies, where the bulk of future emission increases are expected, are under urgent pressure to mitigate greenhouse gas (GHG) emissions.

Negotiations have been difficult between industrialized countries, which fear that ambitious technology transfer policies might deprive their innovative firms of vital intellectual assets, and developing countries, which see technology transfer as a costly process that should at least partially be funded by industrialized countries.. For these reasons, policy debates have so far revolved around the financing of technology transfer, capacity building, and the role of intellectual property rights (IPRs), which some countries view as a barrier to technology diffusion (Abdel-Latif, 2015). Important landmarks of the negotiation process include the Technology Transfer Framework adopted in 2001 as part of the Marrakesh Accords and the Poznan Strategic Programme on Technology Transfer in 2008. However, negotiations took a significant step forward in Cancun in 2010, when the so-called Technology Mechanism was established.

The Technology Mechanism is not a project-based mechanism like the Clean Development Mechanism (CDM). It is a coordination scheme made of two components: a body called the Technology Executive Committee (TEC) comprising 20 expert members whose role consists in identifying countries’ technological needs and providing governments with recommendations on policies that can promote technology transfer; and a Climate Technology Center and Network (CTCN), which facilitates a network of national, regional, sectoral and international technology networks, organizations and initiatives.

The outcome is arguably modest because the TEC is mostly a new forum to discuss future solutions that remain to be developed, and the CTCN has a limited capacity, with an annual budget of USD 14 million in 2015. However, this moderate influence is only a problem if the diffusion of climate mitigation technologies requires strong international coordination over technology issues under the UNFCCC. Against this background, the objective of this paper is twofold. The first aim is to examine the reality of the international diffusion of climate mitigation technologies since 1992. Based on this diagnosis, the second objective is to discuss how future international negotiations could contribute to increasing technology transfer. Our paper shows that, despite modest progress in climate negotiations, North-to-South transfer of climate mitigation technologies has dramatically increased since 1992. This has mostly concerned emerging economies, which are now reasonably well connected to international technology flows. This is good news, as these are the countries in which most emission increases are expected to occur in the near future. In contrast, the rest of developing countries still seem excluded from international technology flows. This is less significant in terms of climate mitigation in the short run, as their emissions are still limited, but we think these countries present a critical challenge for the future that should be the focus of negotiations in the coming years. We offer some thoughts on what could be on the agenda at future negotiations.

This paper presents up-to-date empirical evidence on the climate-related, capital-embodied technology transfer landscape, based on a combination of patent data, bilateral trade data and foreign investment data. To the authors' knowledge, this is the first time that such a multi-dimensional database on climate-related technology transfer has been assembled. Existing studies have essentially relied on two sources of data to describe climate-related technology flows: CDM projects (Haites, Duan and Seres, 2006; de Coninck, Haake, and van der Linden, 2007; Dechezleprêtre, Glachant, and Ménière, 2008; UNFCCC, 2012; Murphy, Kirkman, Seres, and Haites, 2015) and patent data (e.g., Hascic and Johnstone, 2011; Dechezleprêtre, Glachant, Haščič, Johnstone, and Ménière, 2011; Dechezleprêtre, Glachant, and Ménière, 2013).[1] Despite its success, the CDM only presents a very partial view of the global transfer of climate change-related technologies towards developing countries. The coverage offered by patent data is potentially wider, but using foreign patenting as an indicator of technology transfer[2] has several limitations. In particular, filing a patent in a recipient country does not guarantee that the technology will actually be transferred. Combining patent data with trade and FDI data partly addresses these shortcomings. However, despite their wide scope, our data do not comprehensively describe international technology transfer: information on some channels is missing (in particular, the international movement of qualified people), and, more fundamentally, quantitative indicators cannot fully reflect the qualitative richness of real-world knowledge transfers. We discuss these weaknesses and others in Section 3.

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[1] An exception is Pueyo and Linares (2012) who collected data on trade of equipment in hydro, wind and solar power and installed capacity in renewable electricity generation weighted by claims of technology transfer observed in CDM projects. The scope is however more limited than our study which covers a wide range of climate – mitigation technologies.

[2] The fact that an inventor located in one country applies for patent protection in another country is an indication that the inventor expects to transfer the technology, as patenting confers the exclusive right to commercially exploit the technology in that country.

The structure of the paper is as follows: We start by briefly summarizing the history of climate negotiations on technology. The indicators constructed to measure the cross-border transfer of low-carbon technologies since 1992 are then presented. The next section describes current patterns and trends in technology transfer. We then interpret these results and draw implications for the international coordination of technology issues.

2 A brief history of negotiations on technology

International negotiation on technology has a long history.[3] Technology development and diffusion is the fourth commitment of the Parties to the UNFCCC signed in Rio in 1992. The Convention also includes specific commitments by developed countries to transfer technologies in the developing world. The focus on technology transfer relative to innovation in the Convention meets a pressing demand from developing countries. Technology transfer is also systematically related to the transfer of financial resources to the South, in particular in its Article 11, which proposes the creation of a financial mechanism. This reflects the dual role of technology in the treaty. North–to-South transfer is obviously necessary to access technologies that have mostly been developed in industrialized countries[4] but it is also an indirect channel to compensate the developing world for industrialized countries' historical contribution to climate change.

While the issue has been discussed at every COP since 1992, the first significant step was made with the Marrakesh Accords in 2001, which included the so-called Technology Transfer Framework.[5] The Framework essentially defined five working themes - Technology Needs Assessments (TNAs), technological information, enabling environments, capacity building, and mechanisms for technology transfer – and established the Expert Group on Technology Transfer to discuss how to implement the framework. The next significant steps were COP13, held in 2007 in Bali, where technology became one of the four pillars of an expected post-2012 climate change regime, and the Poznan Strategic Programme on Technology Transfer adopted in 2008 at COP14, which modestly allocated USD 50 million to the funding of TNAs and the piloting of technology projects.

The Technology Mechanism was adopted in 2010 at COP16 and has been fully operational since 2012. As mentioned above, the Mechanism is made of two components: the TEC and the CTCN. The

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[3] A briefing note on the history of negotiations on technology has been published by the TEC (2011).
[4] Dechezleprêtre et al. (2011) even show that around 60% of climate change mitigation inventions patented between 2000 and 2005 have been developed in just three countries: Germany, Japan and the United States.
[5] The TTF has been strongly influenced by a special report on technology transfer published in 2000 by the Intergovernmental Panel on Climate Change (IPCC, 2000).

TEC's official role is to “provide an overview of technological needs and an analysis of policy and technical issues related to climate technology development and transfer“[6]. It has held 11 meetings since 2011 and spent much time on defining working modalities and procedures. It has focused its discussions on TNAs, which are reports submitted by developing countries in which they identify the key technologies they need to reduce their emissions and adapt to climate change, and include plans for implementing technology deployment (see de Coninck and Puig, 2015, for an evaluation of the TNAs).

As the operational arm of the Technology Mechanism, the role of the CTCN is to provide technical assistance as a response to specific requests made by individual countries. To achieve this goal, the CTCN relies on its network of regional and sectoral experts from academia, the private sector, and public research institutions. As of 5 July, 2016, 127 requests have been made. For example, Mongolia, which is revising its Renewable Energy Law, has asked for expert reviews of existing foreign laws, and advice on various issues, such as energy conservation policies and competitive bidding to grant licenses to renewable energy producers.

The Paris Agreement adopted in December 2015 has not taken any significant step forward. Its Article 10 essentially confirms the role of the Technology Mechanism. It also insists on the importance of collaborative innovation and finance. The main novelty is the establishment of a Technology Framework, which will provide "overarching guidance to the work of the Technology Mechanism in promoting and facilitating enhanced action on technology development and transfer in order to support the implementation of this Agreement". However, its precise role remains to be defined.

One benefit of creating the Technology Mechanism is certainly that the discussion has been moved to a less politicized forum, as TEC members are not government representatives, but experts who serve in a personal capacity[7]. However, the outcome is arguably modest for a negotiation initiated more than twenty years ago and technology transfer has never been at the heart of climate negotiations Based on this brief review of technology negotiations and outcomes under the UNFCCC and although robust evidence is lacking, it is reasonable to assume that these activities have probably had little impact on international technology transfer since 1992, although they may have helped countries to improve their technological capabilities. This does not mean that the UNFCCC as a whole has not induced technology diffusion. In particular, the CDM has had significant impacts on

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[6] See http://unfccc.int/ttclear/pages/tec_home.html. Last accessed 20 June 2015.

[7] They are however proposed by countries and the committee should include an equal share of members from Annex I countries and non-Annex I countries.

many emerging economies (see Murphy et al., 2015, for the most up-to-date review of technology transfer within CDM projects). We come back to the impact of other components of climate negotiations in section 4.2.

3 Measuring technology transfer

The notion of "technology transfer" can be confusing, for these transfers may concern either intangible knowledge as such, or the physical support in which this knowledge is embedded. Its measurement is therefore inherently difficult. The economic literature[8] argues that technology and related knowledge may be transferred through voluntary transactions aiming at commercializing and/or exploiting technological products in the recipient country. Our first two indicators are based on two of these market channels: trade in capital goods and foreign direct investments (Popp, 2009).[9,10]

International trade in intermediate goods. Importing capital goods, such as machines and equipment, entails technology transfer because such goods embody technologies that can bring productivity benefits to the recipient countries. As an illustration, China acquired production technologies to create a highly efficient solar photovoltaic industry by purchasing turnkey production lines from German, US and Japanese suppliers (de la Tour et al., 2011). Chinese companies are now able to design production equipment on their own.

Trade data is readily available from public sources, in particular the United Nations COMTRADE database, which reports bilateral trade between countries at a highly disaggregated product level. The detailed trade classification system (a 6-digit classification of commodities) makes it possible to identify trade in equipment goods that incorporate technologies to reduce greenhouse gas emissions (for example wind turbines). Glachant, Dussaux, Ménière, and Dechezleprêtre (2013) identified trade flows in 14 different climate change-related technologies and we use this data as a proxy for technology transfer (see the commodities codes in Appendix A1 and the list of technologies in Appendix A5).

Foreign direct investment (including joint ventures). Several studies find evidence that multinational enterprises transfer firm-specific technology to their foreign affiliates or partners in joint ventures

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[8] Keller (2004) offers a comprehensive survey of the economic literature on technology diffusion.

[9] Licensing is a third channel of technology diffusion. Unfortunately, data on international flows of royalty payments are lacking. However, the evidence shows that technology transfers via licensing are of a much smaller magnitude than via trade and FDI.

[10] More details on the data used in the present paper are provided in Glachant et al. (2013).

(e.g., Lee and Mansfield, 1996; Branstetter, Fisman, and Foley, 2006). FDI induces more knowledge transfer than trade in goods, since it aims at directly exploiting knowledge in a local subsidiary of the source company or in a joint venture – and no longer in the source country. The transfer is particularly important with joint ventures as the local partner has direct access to the technology. This is for example the key vector of technology transfer in the wind industry (Kirkegaard, Hanemann, and Weischer, 2009).

In contrast with trade data, publicly available FDI data are too aggregated to identify investments specifically related to climate change mitigation. For example, one can identify investment flows in the "Production of Electricity" sector, but not in the renewable energy production sector. For this reason, FDI data have very seldom been used to study low-carbon technology transfer. We use firm-level data from Bureau Van Dijk's ORBIS database to measure technology transfer in 25 low-carbon technologies. ORBIS includes firm-level data on investment stocks in foreign countries (due to mergers and acquisitions, creation of a subsidiary, etc.). In order to identify parent firms using climate change-related technologies, we match the ORBIS database with the PATSTAT database (a global patent database, see below) and identify companies that own at least one patent in a climate-related technology. This makes it possible to provide an indicator of FDI at the technology level. The indicator is obviously imperfect as many companies are multi-technology enterprises: on average across the 4490 parent companies in our dataset, technologies related to climate change mitigation represent 36.9% of their patent portfolio. Since information on asset value is not comprehensive for developing countries, we assess the volume of FDI through the number of subsidiaries, which is a more approximate, but more reliable indicator.

Non-resident patent filings

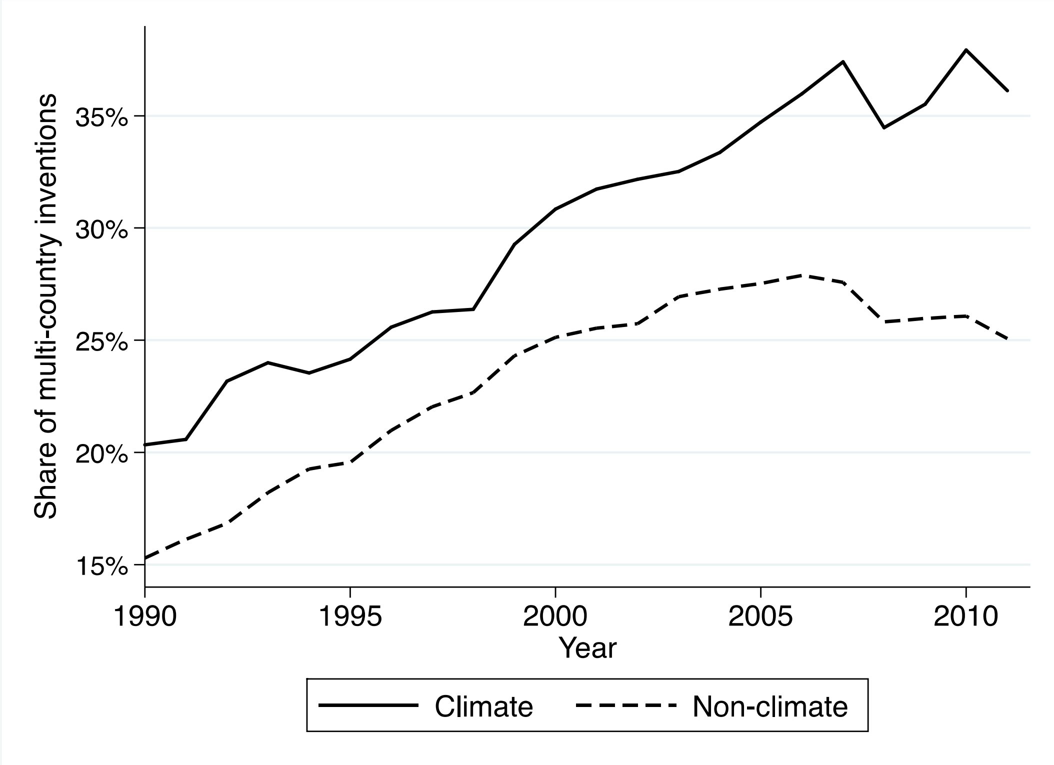
One drawback of the trade- and FDI-based indicators is that they do not directly measure cross-country knowledge flows, but rather the flows of goods or capital with which they are presumably associated. The actual contribution to technology diffusion made by trade and FDI is likely to vary considerably across industries, markets and technologies. We therefore complement our assessment with data on non-resident patent filings. Patenting can be a measure of technology transfer because it gives the exclusive right to commercially exploit the technology in the country where the patent is filed. As patenting is costly, inventors request protection when they have plans to use the technology locally. For this reason, a number of studies have used patent data to measure international transfer of climate change mitigation technologies (Dechezleprêtre et al., 2011). The main advantage of using patents to measure technology diffusion is that they are available at a highly technologically disaggregated level, but the indicator is not without limitations (see Dechezleprêtre et al. 2011 for a detailed discussion). First, the value of individual patents is heterogeneous, implying that simply counting patents gives an imperfect measure of the volume of technology transfer. This is less of an issue in the present study to the extent that we focus on “exported” inventions, which have typically more value (Harhoff, Scherer, Vopel, 2002). Second, the propensity to patent differs between sectors, depending on the nature of the technology (Cohen et al., 2000). This explains why, when comparing technologies in the following section, we do not rely on absolute figures (e.g. the count of patents in a given country), but on relative indicators (e.g. the share of patents from that country in the total number of patents filed at global level in the same technology). Last but not least, although a patent grants the exclusive right to use a technology in a given country, we do not know whether the technology has actually been used. However, evidence shows that patent protection is relied upon for voluntary transactions aiming at commercializing and/or exploiting technological products in recipient countries, including through trade, FDI and licensing, because each of these technology transfer channels brings a risk of leakage and imitation (Maskus, 2000; Smith, 2001; Dechezleprêtre et al., 2013).

4. Level of international diffusion of climate-related technologies

We now describe the international diffusion of climate mitigation technologies. The key message is that these technologies already cross national borders despite the absence of explicit international policies promoting technology transfer.

Figure 1 shows the evolution of the share of internationally patented inventions since 1990 for climate-related technologies and other technologies. "International" inventions are inventions that have been patented in at least two countries and can be used as an indicator of the level of international diffusion. More than 35% of climate inventions were patented in more than one country in 2011. This proportion is much higher than the average for non-climate technologies (around 25%) and the gap between climate and non-climate technologies has substantially increased since 2000. Trade statistics show the same pattern, with an 18% average annual increase in international trade of low-carbon equipment goods since 1990, compared to 13% for non-climate capital goods. The same trend is observed for technology transfer towards the South, which has increased significantly since 1990. In the case of patents, diffusion towards the South is on average around 50% higher for climate-related technologies than for non-climate technologies.

Figure 1: Share of internationally-patented inventions, 1990 – 2011



Source: Authors' calculations based on PATSTAT data (see the details in Appendix 1.3. Note: Climate mitigation technologies covered are listed in Appendix 1.5.

As a result of this evolution, technology transfer towards fast-growing economies is now significant. In particular, with 29% of global imports of low-carbon equipment goods, emerging countries play an active role in the international trade of these products. They are also significant exporters: 24% of the international trade of such goods originates from emerging economies. This indicates the success of countries like China in the production of equipment for producing renewable energy (e.g. photovoltaic panels, wind turbines). Statistics also suggest significant transfer in emerging economies through FDI (32% of the world's climate-related FDI links). Exchange of climate-related patents between the North and emerging economies is less significant (16% of global flows). A possible explanation is that technology owners mistrust the enforcement of intellectual property rights in emerging economies. The flow of climate-related patents or FDI between emerging economies is negligible (less than 1% of cross-country patent flows, 1.9% of FDI links), but trade between emerging economies is becoming significant (10% of the world's total). It is important to keep in mind, however, that trade embodies less knowledge than other channels of technology transfer.

The situation of the rest of developing countries is totally different. These states have nearly no access to foreign green technologies as they are mostly connected to the global economy through raw material markets. Only around 2% of internationally patented inventions are filed in a least developed country and together these countries represent around 1% of the world's inward flows of low-carbon equipment and FDI links.

In Table 1, we consider a particular set of large emerging economies. Along with the three indicators of technology diffusion, as a comparison we report the size of each country measured by their share in the world's GDP. The table suggests that the intensity of technology transfer in China, Mexico and South Africa is in line with the economic size of the country. To a lesser extent, Brazil is also well connected to international flows of knowledge through FDI. In contrast, Russia and India appear slightly less integrated in the global flows of technology. Statistics on technology transfer through the CDM give results in line with these patterns: China hosts about 45% of the world's CDM projects (CDM Pipeline, 2013) and 59% of Chinese projects involve technology transfer, compared to 12% for projects located in India, and 40% in Brazil (Dechezleprêtre, Glachant, and Ménière, 2009).

Table 1: Low-carbon patent inflows, import of capital goods, foreign direct investment, economy size in selected emerging economies as a share of world total

Country	Patent inward flows[a]	Import of low-carbon equipment[b]	FD inward FDI links[c]	Economy size (GDP)
Brazil	0.7%	0.7%	2.5%	2.9%
China	15.5%	8.3%	7.1%	11.1%
India	n.a.	1.5%	1.6%	4.9%
Mexico	2.2%	1.7%	2.5%	2.2%
Russia	1.3%	1.4%	2.2%	3.3%
South Africa	1.2%	0.4%	0.9%	0.7%

Source: PATSTAT, COMTRADE and ORBIS data. Notes: Results for all technologies and equipment goods appear in parentheses. [a] Average of patent flows to the country as a share of world inward flows, covering 25 technology classes, except agriculture and forestry (2007-2009). [b] Average of the import of low-carbon equipment as a share of world imports, covering 18 products/sectors (2007-2009). [c] Capital links between a source company owning at least one low-carbon patent and a foreign company in 2011 as a share of world total. More details are provided in Appendix.

5 What role can future international negotiations play in increasing climate-related technology diffusion?

The above description suggests that the absence of strong international cooperation under the UNFCCC has not prevented climate-related technology transfer from occurring at a significant scale over the past decades. However, this does not mean that diffusion will keep increasing, or that cooperation will remain unnecessary in the future. The adoption of the Paris agreement brings new challenges in terms of enhanced climate action. Emerging economies are now major emitters and some LDCs may join this club in the coming years. What, then, should be the future priority for international coordination on technology diffusion? Given that the reality of technology diffusion is extremely contrasted between emerging economies and LDCs, the answer to this question is necessarily different for these two groups of countries.

5.1 The case of emerging economies

Promoting market-driven technology transfers. In the case of emerging economies, there is no reason to think that they will not continue to effectively absorb foreign technologies. In this group, some laggards – South Asia and India in particular – will benefit from growing participation in economic globalization. In this regard, lowering barriers to trade and foreign investments is an important policy leverage to foster the transfer of green technologies. There is ample empirical evidence that technology diffusion is facilitated by an open trade regime (Saggi, 2002; Duke, Jacobson, and Kammen., 2002; Dechezleprêtre et al., 2013). Regarding FDI, evidence also suggests that foreign investment responds to an adequate business environment, including governance and economic institutions (Maskus, 2004; Dechezleprêtre et al., 2013). In this respect, Table 7 in the Appendix compares the major fast-growing economies featured in Table 1 along different indices that measure potential barriers to technology transfer. It clearly shows that there is scope for improvement. Tariffs on low-carbon equipment are particularly high in Brazil and India. The enforcement of patent rights seems particularly weak in Brazil, India and South Africa.

The case of patent law deserves more development, as some participants in the UNFCCC negotiation process argue that strict intellectual property rights may hinder the transfer of green technologies towards developing countries. It is worth restating that globally firms are by far the prime owners of technologies. The role of the private sector is thus absolutely critical. Keeping in mind that the prime goal of IPR is to promote innovation, the question of whether a stronger IP regime fosters international technology diffusion raises serious arguments and opposing conclusions. On the negative side, patents give market power to innovators, who may then be able to raise prices. This could in turn reduce demand, thereby slowing down diffusion (Maskus and Penubarti, 1995). This property issue is particularly critical for inventions that are needed in developing countries with limited financial resources (for a discussion, see Drahos and Braithwaite, 2002). On the positive side, a patent is a property right, and the existence of property rights is a precondition for the emergence of markets that will diffuse technologies across market participants. Furthermore, patenting requires that inventors publicly disclose information on their technology. This publication generates positive knowledge spillovers, as other inventors may be inspired to develop new technologies

As a result, the question of whether or not IPR promotes technology diffusion cannot be answered based solely on theoretical arguments; it is ultimately an empirical matter that has been tackled in a number of papers. Studies dealing with all technologies generally suggest that strict IPR enforcement has a positive effect on the volume of foreign technology transfers to developing countries. This effect is clear when the recipient country is technologically advanced and open to international trade (Sampath and Roffe, 2012). In this case, strong local absorptive capacities enable effective transfers, but also create a serious threat of imitation for foreign innovators (Maskus, 2000; Smith, 2001; Hoekman, Maskus, and Saggi 2005; Mancusi, 2008; Parello, 2008). Because it provides a safeguard against such imitation, strong IP protection facilitates technology transfers in the recipient country. However, IP rights have no significant impact in poor countries with less imitation capacity (Smith, 2001; Park and Lippolt, 2008). Few specific results on climate mitigation technologies yield the same type of results (Ockwell, Watson, MacKerron, Pal, and Yamin*,* 2008; Barton, 2007; Dechezleprêtre et al. 2013; de la Tour et al. 2011). The empirical literature thus does not support the view that IP rights are barriers to technology diffusion, particularly in emerging economies like India, Brazil and South Africa, which have imitation capacities.

What does the above imply for the UNFCCC negotiation process? Instruments targeting trade and foreign investments are traditionally regulated by the General Agreement on Tariffs and Trade (GATT) administered by the World Trade Organization. The WTO also implements the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) that sets down minimum standards for intellectual property regulation and was adopted in 1994. These agreements both offer some flexibility to introduce specific rules or exemptions to accommodate environmental policy objectives such as border carbon adjustments. This was explicitly set out for trade measures in a joint report by the WTO and UNEP (UNEP – WTO, 2009), which clarifies the conditions under which trade restrictions can be justified for climate change objectives. Flexibility is potentially lower under the TRIPS Agreement, as its Article 27.1 requires that patent rules should not discriminate across fields of technology. However, a WTO dispute settlement panel ruled that this provision only prohibits unjustified distinctions in patent law among technological areas and does not prohibit differences in legislation and processes based on legitimate policy preferences (Maskus, 2010). This possibility has been used for pharmaceuticals. Against this background, there is serious motivation to transfer the discussion of trade and IP rules from the UNFCCC to the WTO, as both the GATT and the TRIPS seem sufficiently flexible to introduce climate-specific provisions if agreed by the parties.

Creating a demand for low-carbon technologies in emerging economies. Strengthening environmental regulation is a pre-condition to diffusing eco-innovations, as cutting emissions is generally not yet profitable under standard market conditions. In the absence of public policies imposing constraints on carbon emissions, households and companies are unlikely to adopt climate-friendly technologies. This conveys what is probably the most important message of this discussion. Diffusion of technologies towards emerging economies can only increase in the presence of ambitious climate policies (e.g. carbon taxes, cap-and-trade system, emissions standards).

During the past decade, three major channels have induced the diffusion of low-carbon technologies to emerging economies. First (but probably least importantly), the CDM has played a role in increasing domestic demand for low-carbon technologies. The empirical literature agrees that the CDM has encouraged North-to-South technology transfer (de Coninck et al., 2007; Haites et al., 2006; Dechezleprêtre et al., 2008; Gandenberger, Bodenheimer, Schleichab, Orzannaa, and Gandenberger, 2015; Murphy et al., 2015). Roughly 40% of CDM projects induced a technology transfer. Second, companies located in emerging countries have also imported technologies with a view to serving foreign demand driven by climate and environmental policies implemented in richer countries. For example, Chinese photovoltaic companies acquired the necessary technologies abroad before exporting PV cells and solar panels back to countries such as Germany, Spain, and the US, where feed-in tariffs and renewable portfolio standards triggered massive deployment of PV electricity. Third, emerging economies have implemented domestic policies to promote the deployment of green technologies. In India, the growth of wind energy was primarily driven by state-level feed-in-tariffs (FITs) introduced in 2000. This induced the development of domestic turbine manufacturers, which initially served domestic demand, but now compete in international markets -- Suzlon is the 6th world producer with a global market share of 5.5% in 2014. The same evolution has been observed in China, which has also seen dramatic growth in producers of wind power equipment. Four Chinese companies ranked among the world's Top 10 turbine manufacturers in 2014, Goldwing coming third behind Vestas and Siemens.

Looking forward, the CDM period is over. Almost 8,000 CDM projects have been registered to date, but the submission of new CDM projects has almost completely stopped since the end of the first Kyoto commitment period 2008-2012 (the price of carbon credits generated by existing CDM projects is close to zero at €0.39/tCO_2 on 23 June, 2015) and the future of offset mechanisms in the post-Paris period is unclear. Article 6 of the Paris agreement allows for "the use of internationally transferred mitigation outcomes to achieve nationally determined contributions" and establishes a new mechanism to this effect, but the rules, modalities and procedures for this mechanism are yet to be adopted. Demand in foreign countries is likely to keep rising, but the relocation of the PV industry to China is a very contentious subject, in particular in Germany, and will probably remain so, as illustrated by the proliferation of local content requirements. Therefore, we see the implementation of emerging economies' Intended Nationally Determined Contributions (INDCs) as central to the acceleration of technology transfer in the near future.

5.2 The rest of developing countries

The situation of LDCs is paradoxical. On the one hand, accelerating technology diffusion is critical as these countries are not yet connected to international flows of climate-related technologies; on the other hand, dealing with the problem is less urgent as their contribution to global emissions will remain limited in the near future. In these countries, the priority is to build technological capacities and promote their integration into the global economy. In fact, this means solving a very general problem: the economic development of certain countries and regions, in particular in Africa. In this context, the discussion of specific trade and IP rules for low-carbon technologies is at odds with the challenges these countries face today.

There is strong evidence that technological capabilities – such as availability of skilled technical personnel, information on available technologies, and social institutions that reduce transaction costs – determine a country's ability to successfully absorb foreign technologies (Worrell, Levine, Price, Martin, Van Den Broek, and Blok, 1997). These skills are referred to as absorptive capacities (Keller, 1996). Building capacities should thus be given priority through various means, including education, cooperative research, development, and demonstration programs. Importantly, green technologies draw on scientific knowledge from many sciences, among which energy and environmental sciences only play a marginal role (OECD, 2010). This suggests that encouraging education and training in narrow technology fields may be less important than, and at best complementary to, generic programs that address a broad range of disciplines. Here again, the UNFCCC – which focuses on climate by its very nature – is probably not the only framework to coordinate internationally on these issues.

6 Conclusion

In this paper, we show that the lack of progress in climate negotiations on technology transfer has not prevented the international diffusion of low-carbon technologies to date, at least not towards fast-growing emerging economies. These countries are reasonably well connected to international flows of climate technologies. This evolution has mainly been driven by the growing integration of emerging economies into the global economy, as technological knowledge mostly crosses borders though international trade of capital goods and foreign direct investments. The Clean Development Mechanism, which, among developing countries, has almost exclusively involved emerging economies, has contributed to creating domestic demand for green technologies in some countries (e.g. wind energy in India and China). In other cases, technologies have been transferred with a view to meet demand induced by climate policies in the North (e.g. solar photovoltaics). Domestic policies have also played a role (e.g. feed-in tariffs in India). In contrast, the rest of developing countries import negligible technologies, which can be related to their low participation in the recent economic globalization.

What do these findings imply for climate negotiations on technology? First, they suggest that the UNFCCC's Technology Mechanism, as modest as it is, might be sufficient to cover the requirements for coordinating technology transfer. The function of the Mechanism should essentially consist in providing local private and public actors with information to facilitate coordination (e.g. through Technology Needs Assessment) and should focus on least-developed countries. The TEC could also use its technological expertise to identify on a case-by-case basis barriers that could emerge for certain technologies and that would then require different treatment with respect to trade or IP laws.

This does not mean that international coordination on technology transfer and technological capabilities is useless. Nevertheless, we suspect that these issues might be better addressed outside the UNFCCC. This includes efforts to reduce trade barriers and resolve intellectual property issues in emerging economies, which are best addressed through the World Trade Organization, and generic capacity building in least-developed countries, which could be managed by established international institutions in charge of economic development in the South (i.e. World Bank, UNIDO).

In this international architecture, the UNFCCC will mostly contribute to encouraging the diffusion of low-carbon technologies by spurring demand for these technologies through ambitious emissions-reduction objectives both in the North and South, as set out in the INDCs. Ambitious climate change policies will also induce more research and development activities in low-carbon technologies in countries with strong research capabilities (including both developed and emerging countries), which will reduce the cost of deploying low-carbon technologies, thereby boosting their international diffusion.

These implications do not address the distributional dimension, which is essential in any negotiation. As explained in section 2, technology transfer has become a prominent issue in negotiations, partly because it is seen as a way to compensate the developing world for the role played by industrialized countries in creating the atmospheric stock of carbon dioxide. For this reason, we believe it is important to establish a strong link between the Technology Mechanism and the Financial Mechanism in international discussions. In this respect, Article 10 of the Paris Agreement, which explicitly makes this connection, is clearly a step in the right direction. In particular, the Green Climate Fund can play a positive role to materialize compensations through technology-related projects.

References

Abdel-Latif, A. (2015). Intellectual property rights and the transfer of climate change technologies: issues, challenges, and way forward. *Climate Policy*, 15(1), 103–126. doi: 10.1080/14693062.2014.951919.

Barton, J. (2007). Intellectual Property and Access to Clean Energy Technologies in Developing Countries. An Analysis of Solar Photovoltaic, Biofuel and Wind Technologies (Issue Paper No. 2). ICTSD Programme on Trade and Environment.

Branstetter, L. G., Fisman, R., & Foley, C. F. (2006). Do stronger intellectual property rights increase international technology transfer? Empirical evidence from U.S. firm-level panel data. *Quarterly Journal of Economics*, 121(1), 321–49. doi: 10.1093/qje/121.1.321

de Coninck, H. & Sagar, A. (2015) Making sense of policy for climate technology development and transfer. *Climate Policy*, 15(1), 1-11. doi: 10.1080/14693062.2014.953909

de Coninck, H., & Puig, D. (2015). Assessing climate change mitigation technology interventions by international institutions. *Climatic Change*, 131(3), 417–433. doi: 10.1007/s10584-015-1344-z.

de Coninck, H., Haake, F., & van der Linden, N. (2007). Technology transfer in the Clean Development Mechanism. *Climate Policy*, 7, 444–456. doi: 10.1080/14693062.2007.9685667

De la Tour, A., Glachant, M., & Ménière, Y. (2011). Innovation and International Technology Transfer: the Case of the Chinese Photovoltaic Industry. *Energy Policy*, 39(2), 761–770. Doi: 10.1016/j.enpol.2010.10.050.

Dechezleprêtre, A., Glachant, M. & Ménière, Y. (2008). The Clean Development Mechanism and the international diffusion of technologies: An empirical study. *Energy Policy*, 36(4), 1273–1283. Doi: 10.1016/j.enpol.2007.12.009.

Dechezleprêtre, A., Glachant, M., & Ménière, Y. (2009). Technology transfer by CDM projects: a comparison of Brazil, China, India and Mexico. *Energy Policy*, 37(2), 703-711. doi:10.1016/j.enpol.2008.10.007.

Dechezleprêtre, A., Glachant, M., & Ménière, Y. (2013). What Drives the International Transfer of Climate Change Mitigation Technologies? Empirical Evidence from Patent Data. *Environmental and Resources Economics*, 54(2), 161-178. Doi: 10.1007/s10640-012-9592-0.

Dechezleprêtre, A., Glachant, M., Haščič, I., Johnstone, N., & Ménière, Y. (2011) Invention and Transfer of Climate Change Mitigation Technologies: a Global Analysis. *Review of Environmental Economics and Policy*, 5(1), 109–130. Doi: 10.1093/reep/req023.

Drahos, P., & Braithwaite, J. (2002). *Information Feudalism: Who Owns the Knowledge Economy?* New York, NY: The New Press.

Duke, R., Jacobson, A. & Kammen, D. (2002). Photovoltaic module quality in the Kenyan solar home systems market. *Energy Policy*, 30, 477–99. Doi: 10.1016/S0301-4215(01)00108-2

Eaton, J. & Kortum, S. (1996). Trade in ideas Patenting and productivity in the OECD. *Journal of International Economics*, 40(3–4), 251–278. Doi: 10.1016/0022-1996(95)01407-1.

Gandenberger, C., Bodenheimer, M., Schleichab, J., Orzannaa, R. & Gandenberger, L. M. (2015) Factors driving international technology transfer: empirical insights from a CDM project survey. *Climate Policy*, 1(20), 1469-3062. Doi : 10.1080/14693062.2015.1069176.

Glachant, M., Dussaux, D., Ménière, Y. &Dechezleprêtre, A. (2013). *Promoting International Technology Transfer of Low-Carbon Technologies: Evidence and Policy Perspectives*. Paris: France Stratégie. Retrieved from France Stratégie website: http://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/rapport-TTBC-anglais-31-10-2013.pdf

Gwartney, J., Lawson, R. & Hall, J. (2014). 2014 Economic Freedom Dataset. In Economic Freedom of the World: 2014 Annual Report. Retrieved from the Fraser Institute website: http://www.freetheworld.com/datasets_efw.html.

Haites, E., Duan, M. & Seres, S. (2006). Technology Transfer by CDM Projects. *Climate Policy*, 6(3), 327-344. doi:10.1080/14693062.2006.9685605

Harhoff, D., Scherer, F.M.,& Vopel, K. (2002). Citations, family size, opposition and the value of patent rights. *Research Policy*, 1596, 1-21. Doi: 10.1016/S0048-7333(02)00124-5.

Hoekman, B.M., Maskus, K.E. & Saggi, K. (2005). Transfer of technology to developing countries: Unilateral and multilateral policy options. *World Development*, 33(10), 1587–602. doi:10.1016/j.worlddev.2005.05.005.

Johnstone, J., Haščič, I. & Watson, F. (2011) Methodological Issues in the Development of Indicators of Innovation and Transfer in Environmental Technologies. In *Invention and Transfer of Environmental Technologies*. Paris: OECD.

Keller, W. (2004). International Technology Diffusion. *Journal of Economic Literature*, 42, 752–782. Doi: 10.1257/0022051042177685.

Kirkegaard, J.F., Hanemann, T. & Weischer, L. (2009). *It Should Be a Breeze: Harnessing the Potential of Open Trade and Investment Flows in the Wind Energy Industry* (Working Paper Series WP09-14). Peterson Institute for International Economics. Retrieved from The World Resources Institute website: http://www.wri.org/publication/it-should-be-breeze.

Lee, J.-Y., & Mansfield, E. (1996) Intellectual property protection and U.S. foreign direct investment. *Review of Economics and Statistics*, 78, 181–5. doi:10.2307/2109919.

Mancusi M. (2008). International spillovers and absorptive capacity: A cross-country cross-sector analysis based on patents and citations. *Journal of International Economics*, 76(2), 155–65. doi:10.1016/j.jinteco.2008.06.007.

Maskus K. (2004). Encouraging international technology transfer. UNCTAD-ICTSD Project on IPRs and Sustainable Development, Issue Paper No. 7.

Maskus K.E. (2000) *Intellectual Property Rights in the Global Economy.* Washington, DC: Institute for International Economics.

Maskus K.E. (2010). *Differentiated Intellectual Property Regimes for Environmental and Climate Technologies* (OECD Environment Working Papers No. 17). Paris: OECD. doi: 10.1787/5kmfwjvc83vk-en.

Maskus, K.E. & Penubarti, M. (1995). How trade-related are intellectual property rights? *Journal of International Economics*, 39(3–4), 227-248. Doi: 10.1016/0022-1996(95)01377-8.

Murphy, K., Kirkman, G.A., Seres, S., & Haites, E. (2015). Technology transfer in the CDM: An updated analysis. *Energy Policy*, 15(1), 127-145. Doi: 10.1080/14693062.2013.812719.

Ockwell, D., Watson, J., Mallett, A., Haum, R., MacKerron G. & Verbeken, A-M. (2010). Enhancing Developing Country Access to Eco-Innovation: The Case of Technology Transfer and Climate Change in a Post-2012 Policy Framework (OECD Environment Working Paper No. 12). Paris: OECD. Doi: 10.1787/5kmfplm8xxf5-en

Ockwell, D.G., Watson J., MacKerron G., Pal P. & Yamin F. (2008). Key policy considerations for facilitating low carbon technology transfer to developing countries. *Energy Policy*, 36, 4104–15. Doi: 10.1016/j.enpol.2008.06.019.

OECD (2010). *Measuring Innovation: A New Perspective*. Paris: OECD.

OECD (2011). *Invention and Transfer of Environmental Technologies*. Paris: OECD.

Parello, C. (2008). A North–South model of intellectual property rights protection and skill Accumulation. *Journal of Development Economics*, 85, 253–81. Doi: 10.1016/j.jdeveco.2006.08.001.

Popp, D. (2009). Policies for the Development and Transfer of Eco-Innovations: Lessons from the Literature. Prepared for the OECD Global Forum on Environment on Eco-Innovation, 4-5 November 2009, OECD, Paris (France).

Pueyo, A., Linares, P. (2012). Renewable technology transfer to developing countries: One size does not fit all. IDS working paper, No.412. Doi: 10.1111/j.2040-0209.2012.00412.x.

Saggi, K. (2002). Trade, foreign direct investment, and international technology transfer: A survey. *World Bank Research Observer*, 17(2), 191–235. Doi: 10.1596/1813-9450-2349.

Sampath, G. & Roffe, P. (2012). Unpacking the International Technology Transfer Debate (Issue Paper No. 36). ICTSD Programme on Innovation, Technology and Intellectual Property. Retrieved from ICTSD website: www.ictsd.org.

Smith, P.J. (2001). How do foreign patent rights affect U.S. exports, affiliate sales, and licenses? *Journal of International Economics*, 55, 411–439. Doi: 10.1016/S0022-1996(01)00086-1.

Technology Executive Committee (2011) Briefing note on the development and transfer of technologies under the UNFCCC process. Retrieved from UNFCCC website: http://unfccc.int/ttclear.

UNFCCC (2012). Benefits of the Clean Development Mechanism. Retrieved from UNFCCC website: https://cdm.unfccc.int/about/dev_ben/ABC_2012.pdf

Worrell, E., Levine, M., Price, L., Martin, N., Van Den Broek, R., & Blok, K. (1997). *Potentials and policy implications of energy and material efficiency improvement*. New York: United Nations Division for Sustainable Development. Doi: 10.2172/842870.

WTO–UNEP (2009). Trade and Climate Change. Retrieved from WTO website: https://www.wto.org/english/res_e/booksp_e/trade_climate_change_e.pdf.

Appendices

Data sources

We gathered data from four main sources: the United Nations Commodity Trade Statistics Database, Bureau van Dijk's ORBIS database, the EPO/OECD World Patent Statistical Database, and the World Bank World Development Indicators.

A1 Trade data

Trade data in US dollars comes from the United Nations COMTRADE database, which reports bilateral trade between countries at a highly disaggregated product level. Trade data in the COMTRADE database covers between 70% to 90% of world trade obtained from the WTO Statistics Database, depending on the year. As is the case with patent data, the very detailed classification system used in the COMTRADE database (6-digit classification of commodities) makes it possible to specifically identify trade in equipment goods that incorporate technologies to cut greenhouse gas emissions (for example wind turbines). We then measure technology transfer by the value of trade in these goods between trading partners. The HS codes of the goods considered in the study are listed in Table 2

Table 2. Description and HS codes of low-carbon goods considered in the study

Technology class	HS code	Description
Hydro energy	841011	Hydraulic turbines & water wheels, of a power not >1000kW
	841012	Hydraulic turbines & water wheels, of a power >1000kW but not >10000kW
	841013	Hydraulic turbines & water wheels, of a power >10000kW
	841090	Parts (incl. regulators) of the hydraulic turbines & water wheels of 8410.11-8410.13
Nuclear energy	840110	Nuclear reactors
	840120	Machinery and apparatus for isotopic separation, and parts thereof
	840140	Parts of nuclear reactors
Solar photovoltaic	854140	Photosensitive semiconductor devices, incl. photovoltaic cells whether/not assembled in modules/made up into panels; light emitting diodes
Solar thermal	841919	Instantaneous/storage water heaters, non-electric (excl. of 8419.11)

Wind energy	850231	Wind-powered electric generating sets
Energy storage	850710	Lead-acid electric accumulators (vehicle)
	850720	Lead-acid electric accumulators except for vehicles
	850730	Nickel-cadmium electric accumulators
	850740	Nickel-iron electric accumulators
	850780	Electric accumulators
	850790	Parts of electric accumulators, including separators
	853224	Fixed electrical capacitors, other than those of 8532.10, ceramic dielectric, multilayer
Electric and hybrid vehicles	870390	Vehicles principally designed for the transport of persons (excl. of 87.02 & 8703.10-8703.24), with C-I internal combustion piston engine (diesel/semi-diesel), n.e.s. in 87.03
Energy efficient cement	252390	Hydraulic cements (e.g., slag cement, supersulphate cement), whether not coloured/in the form of clinkers (excl. cement clinkers, Portland cement & aluminous cement)
Heating	903210	Thermostats
	841861	Compression-type refrigerating/freezing equip. whose condensers are heat exchangers, heat pumps other than air conditioning machines of heading 84.15
	841950	Heat exchange units, whether/not electrically heated
Insulation	680610	Slag wool, rock wool & similar mineral wools (incl. intermixtures thereof), in bulk/sheets/rolls
	680690	Mixtures & articles of heat-insulating/sound-insulating/sound-absorbing mineral materials (excl. of 68.11/68.12/Ch.69)
	700800	Multiple-walled insulating units of glass
	701939	Webs, mattresses, boards & similar non-woven products of glass fibres
Lighting	853120	Indicator panels incorporating. liquid crystal devices (chemically defined)/light emitting diodes (LED)
	853931	Electric discharge lamps (excl. ultra-violet lamps), fluorescent, hot cathode
Transportation	860120	Rail locomotives powered by electric accumulators
Energy efficiency in heavy industries	840410	Economizers, super-heaters, soot removers, gas recoverers and condensers for steam or other vapour power units

A2 Foreign investment data

To measure foreign direct investment, we rely on the financial database ORBIS, provided by Bureau Van Dijk under a commercial license. The ORBIS database includes firm-level data on investment stocks in foreign countries (due to mergers and acquisitions, creation of a subsidiary, etc.). In order to identify foreign direct investment by firms involved in sectors related to climate change, we matched the ORBIS database with the PATSTAT database and identified companies that own at least one patent in climate-related technology. The rationale for this restriction is twofold. First, it makes it possible to provide an indicator of FDI at the technology level. Economic sector classifications available at company level are too aggregated to allow for meaningful analyses at technology level. For example, we can only identify companies in the "Production of Electricity" sector, but cannot identify renewable energy producers. Second, it allows us to identify foreign investment that potentially involves the transfer of climate-friendly technology. This explains why patent and FDI statistics have the same technology scope (see below).

FDI data pose a specific challenge, as information on the volume of investments is frequently lacking, in particular in developing countries. As an indicator of technology transfer, rather than measuring the volume of investment in ‘country B’ by companies located in ‘country A’, we use the number of capital links between companies in the source country and companies in the recipient country. This gives an indication of the intensity of capital links between country pairs.

A3 Patent data

Patent data are drawn from the World Patent Statistical Database (PATSTAT) maintained by the European Patent Office. PATSTAT is the largest international patent database available to the research community with nearly 70 million patent documents included. Patent documents are categorized using the International Patent Classification (IPC) and national classification systems. This allows us to identify climate change mitigation technologies. In particular, we use the new “Y02” category developed by the European Patent Office to identify patents in PATSTAT pertaining to “technologies or applications for mitigation or adaptation against climate change”. This new category is the result of an unprecedented effort by the European Patent Office, whereby patent examiners specializing in each technology, with the help of external experts, developed a tagging system of patents related to climate change mitigation technologies. The Y02 category provides the most accurate tagging method of climate change mitigation patents available today, and is becoming the international standard for clean innovation studies. We identify internationally transferred patents as patents filed by an inventor from a country different from that in which protection is sought, e.g., patents filed in the US by a German inventor.

A4 Geographical coverage

Table 3 presents the geographical coverage of the data along with their time dimension. Geographical coverage is almost comprehensive for trade and FDI data: the COMTRADE database includes all 192 United Nations member countries and the ORBIS database gathers information from

197 countries. With 80 patent offices in PATSTAT, patent data is not as comprehensive, but they include the major patent offices in the world. Given the geographical coverage of the combined dataset, we can confidently consider that if some countries (in particular least-developed countries) do not appear across all three dimensions of the data set, the reason is that they do not participate in the international diffusion of technologies. There are, however, a few important exceptions: India, Indonesia, the Philippines, Vietnam, Pakistan, Bangladesh, Nigeria and Thailand.

Table 3. Geographical coverage of various data sources

	Definition	Data source	Geographical coverage	Period
International trade	Volume of bilateral trade of low-carbon equipment goods (in value)	COMTRADE	205 countries	1990-2009
Foreign direct investment	Number of subsidiaries in the recipient country owned by companies from the source country having at least one low-carbon patent	ORBIS	197 countries	2011
Patent flows	Volume of patents filed in the recipient country by inventors located in the source country	PATSTAT	80 patent offices Major exceptions : India, Indonesia, the Philippines, Vietnam, Pakistan, Bangladesh, Nigeria and Thailand	1990-2009

A5 Technological scope

Our study covers a wide range of technologies across most sectors of the economy. Table 4 presents the precise technology coverage of the study. Obviously, not all technologies with a potential to mitigate climate change could be included in the analysis. The main reason is that their diffusion does not entail any patenting or international trade. This is the case for agriculture and forestry: technologies such as soil restoration, reforestation, rice and grassland management are simply not present in either trade or patent data. Another reason is that classifications used in trade and patent data do not allow us to identify some technologies, in particular technologies aiming at improving industrial energy efficiency. In practice, saving energy in the industrial sector mostly consists of using a more energy-efficient version of production equipment; it does not consist of adding a device that specifically saves energy in the production chain. The problem is thus that patent and trade statistics are not detailed enough to distinguish between different versions of the same equipment. To give an example, the COMTRADE code 841780 describes “industrial/laboratory furnaces & ovens”, but no distinction is made between inefficient and energy-efficient furnaces. Nevertheless, the technologies in our data set represent 65% of the abatement potential until 2030 as identified in the McKinsey abatement curve.

Patent and FDI data offer the most extensive coverage: they are comprehensive for energy production (including cleaner coal). They are also very good for transport and energy efficiency in buildings (insulation, heating, and lighting). Data on energy efficiency in industry are more limited (except for aluminum and certain equipment goods in heavy industries). Trade data are not as comprehensive, because product classifications used to organize trade data do not offer the same level of disaggregation, as illustrated above.

Table 4. Technology fields included in the study

Technology group	Technology class	Patent flows	Trade flows	FDI
Renewables	Biofuels	X		X
	Fuel from waste	X		X
	Geothermal	X		X
	Hydro	X	X	X
	Marine	X		X
	Solar photovoltaic	X	X	X
	Solar thermal	X	X	X
	Wind	X	X	X
Nuclear	Nuclear	X	X	X
Combustion	Cleaner coal	X		X
Climate change mitigation	CCS	X		X
	Capture or disposal of non-CO2 GHG	X		X
Indirect contribution to mitigation	Energy storage	X	X	X
	Hydrogen technology	X		X
	Fuel cells	X		X
	Electricity distribution	X		X
Fuel efficiency transportation	Electric vehicles	X	X	X
	Hybrid vehicles	X	X	X
	Fuel efficiency in motors	X		X
	Fuel efficiency-improving vehicle design	X		X
	Rail locomotives powered by electric accumulators		X	
Energy efficiency in buildings	Energy efficient cement	X	X	X
	Heating	X	X	X
	Insulation	X	X	X
	Lighting	X	X	X
Energy efficiency in industry	Electric arc furnace for aluminum production	X		X
	Economizers, super-heaters, soot removers, gas recoverers		X	

A6 Country groupings

Table 5. Country groupings

LDC (Least Developed Countries)	Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Rep., Chad, Comoros, Dem. Rep. of the Congo, Djibouti, Equatorial Guinea, Eritrea, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Dem. Rep., Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Rep. of Tanzania, Vanuatu, Yemen, Zambia
OECD countries*	Australia, Austria, Belgium, Canada, Chile, Czech Rep., Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Rep. of Korea, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA
Emerging countries	Refers to Non-OECD countries that are not LDC

* Members in 2007

A.7 Low-carbon patent inflows, import of capital goods, foreign direct investment, economy size in selected emerging economies as a share of world total

Table 6. Low-carbon patent inflows, import of capital goods, foreign direct investment, economy size in selected emerging economies as a share of world total

Country	"Freedom to Trade Internationally" index, 2012[a]	Average tariffs on low carbon equipment, 2013[c]	IP index, 2014[b]
Brazil	7.1	14.0%	1.25
China	6.7	3.3%	4.10
India	6.2	6.9%	1.00
Mexico	7.0	1.5%	3.24
Russia	6.0	3.9%	3.10
South Africa	7.2	2.6%	1.00
World average	7.0	6.1%	-
OECD average	8.8	1.7%	5.50[d]

[a] An index with scale of 1 to 10, where 10 is best constructed by Economic Freedom of the World. For more details, see: http://www.freetheworld.com/2014/EFW2014-POST.pdf.

[b] An index with scale of 1 to 7 which the strength of an economy's environment for patents, constructed by the Global IP Center. For more details, see: http://www.theglobalipcenter.com/.
[c] Extracted from the TRAINS database (http://wits.worldbank.org/wits). The number is an average of the tariffs applied to the low carbon capital goods included in our data, weighted by the value of trade in the different products.
[d] Data is not available for some OECD countries. The average is calculated for these countries: USA, UK, Switzerland, Germany, France, Japan, Australia, South Korea, New Zealand, Canada, Chile, Mexico.