

Technology transfer in the clean development mechanism

Insights from wind power

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Technology transfer in the clean development mechanism: Insights from wind power

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ABSTRACT

International technology transfer is a key element in efforts to ensure low carbon growth in developing countries. A growing body of literature has sought to assess the extent of technology transfer in the clean development mechanism (CDM). In this paper we use the case of wind power CDM to expand the focus to how technology transfer occurs. We seek insights from the technology and CDM literatures to develop a framework with multiple technology transfer mechanisms. We then show empirically that technology transfer in CDM wind projects occurs through a greater variety of mechanism than is commonly assumed. The evidence suggests that the strengthening of host country capabilities changes the nature of technology transfer. The cases of China and India indicate that diversity in transfer mechanisms is an effect of the pre-existing industrial and technological capabilities. We show that CDM projects in China and India tend to utilise transfer mechanisms opened up prior to and independent of CDM projects, not the other way around. Our findings suggest that research and policy should pay more careful attention to the relationship between international low carbon technology transfer mechanisms and local technological capabilities.

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1. Introduction

Greenhouse gas emissions in developing countries are expected to account for up to 70% of the global increase in emissions in the period 2002–2030. It is therefore commonly agreed that low carbon technology must play a key role reducing the climate change effect of economic growth in developing countries (IEA, 2008). The clean development mechanism (CDM) is typically viewed as one of the most important vehicles for the transfer of low carbon technology and know-how between developed and developing countries. Yet, fairly little is known about the process of technology transfer in CDM. In this study we use the case of wind power to open the technology ‘black box’. We examine the mechanisms through which technology transfer occurs in CDM and how it differs between countries. This is important because there is increasing recognition that technology deliberations in the context of climate change mitigation need to be based on a deeper understanding of the processes and arrangements through which

technology is ‘transferred’ internationally (Ockwell et al., 2008; Berkhout et al., 2010; Lema and Lema, 2012).

The CDM is a useful case for examining international technology transfer. A growing body of literature has sought to assess the degree to which technology transfer occurs in the CDM (e.g. Dechezlepretre et al., 2008, 2009; De Coninck et al., 2007; Hascic and Johnstone, 2011; Seres et al., 2010; UNFCCC, 2011). In this paper we seek to engage with and add to this literature by expanding the focus from *whether* technology transfer occurs in CDM projects to *how* it occurs (if and when it does).

1.1. Research questions and value added of the paper

The empirical analysis in this paper seeks to identify the key technology transfer mechanisms in wind power CDM projects. We use the term ‘mechanisms’ to refer to organisational arrangements for technology transfer. The paper is driven by the following research questions: What are the key mechanisms of technology transfer in wind power CDM projects? To what extent do different countries utilise a variety of transfer mechanisms in their different CDM projects? To what extent do CDM projects open up new transfer mechanisms that have not previously been utilised in host countries?

These types of questions have received almost no attention in the existing literature on technology transfer in CDM. In addressing

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these questions we make conceptual, methodological and empirical contributions to the literature.

Conceptual: In order to address the research questions we develop a new framework to distinguish between different types of transfer mechanisms in CDM. We do this by drawing on the broader literature on technology transfer and technological learning and innovation in developing countries (e.g. Lall, 1993a; Bell and Pavitt, 1995; Bell and Figueiredo, 2012; Dunning, 1981; Maskus, 2004).

Methodological: As will be elaborated later, the existing studies of have considerable methodological weaknesses and we therefore adopt a novel approach in which we combine data on the specific organisational arrangements of CDM projects with detailed data on the nature of the utilised wind power technology and its origin. This allows for a deeper and more precise analysis of technology transfer mechanisms in CDM.

Empirical: The conceptual and methodological advances allow us to unearth new and substantial insights. We show that technology transfer mechanisms in China and India are more diverse – i.e. they include a broader variety of different types – than is commonly acknowledged. Much of the existing literature on technology transfer tends to assume that international trade and foreign direct investment are the channels of technology transfer (Less and Mcmillan, 2005; Brewer, 2008) although licensing is sometimes added to those (e.g. Popp, 2011, 137–139; Schneider et al., 2008, 2931). We find that the degree of diversity is closely associated with the industrial context of host countries, not least the pre-existing technological capabilities in the wind energy field. We find that CDM projects often reflect transfer mechanisms opened up prior to and independent of CDM projects. We also find that the nature of technology transfer changes – becomes more diversified – as local capabilities increase. This is an important insight with respect to the discussion about whether stronger local capabilities render technology transfer less relevant (Dechezlepretre et al., 2008; Doranova et al., 2010).

These findings advance the debate by specifying the nature of the mechanisms involved in CDM projects, but they also prompt important questions about the effectiveness of CDM as a vehicle of technology transfer. In turn, they raise much broader questions about what (low carbon) technology transfer is and how it occurs. Understanding technology transfer in CDM depends on an understanding technology transfer in general.

1.2. Structure of the paper

The remainder of the paper is structured as follows. Section 2 seeks insights from the general technology transfer literature and the existing empirical literature on technology transfer in the CDM.

Section 3 draws on these insights and develops a framework with multiple technology transfer mechanisms. Section 4 explains the methods of data collection and classification. Section 5 presents the finding of the empirical analysis of the mechanisms involved in CDM wind power projects. Section 6 delves deeper into these findings and provides added insights by (a) highlighting the different industrial contexts of wind power CDM host countries and (b) discussing the relationship between technology transfer which occurs in and independent of CDM. Conclusions and policy implications are brought out in Section 7.

2. Insights from the literature

In this section we first seek insights from the literature and distinguish between a broad and a narrow view of technology transfer. We then outline the main tenets of the existing literature on technology transfer in CDM projects. We find that it tends to adopt the narrow view of technology transfer. We argue that the analysis of technology issues in CDM can benefit from broader insights. This requires conceptual and methodological advances which are addressed in subsequent Sections 3 and 4.

2.1. Technology transfer and innovation literature

There are two main ways at looking at international technology transfer (Lema and Lema, 2012). The first is the view that underpins the most influential literature in the debate on technology in the climate change context (World Bank, 2008, 2010; IPCC, 2007; Commission on Growth and Development, 2008). We term this view the ‘narrow’ view because it exhibits a bounded notion of technology and the transfer process. This view is often apparent in the UNFCCC climate change negotiations (see Ockwell et al., 2010) and in influential international organisations (such as Commission on Growth and Development, 2008; World Bank, 2010). The second is an alternative view that has grown out of the literature on technological learning and innovation in developing countries (such as Lall, 1993a; Bell, 1990; Ernst and Kim, 2002). We call this the ‘broad’ view because the notion of technology is wider and the mechanisms involved in the transfer process include a more wide-ranging array of phenomena.

These two views differ with regard to key assumptions and the associated scope of the understanding of four issues of key concern to this paper. Table 1 contrasts the narrow and the broad view of these four issues in stylised form. We discuss these differences in more detail below.

The nature of ‘technology’: The term ‘technology’ often refers to physical equipment and machinery (‘hardware’). In the narrow view, the notion of technological ‘diffusion’ typically refers

Table 1
Contrasting views on international technology transfer.

	A (Narrow view)	B (Broad view)
1. The nature of technology	‘Technology’ refers to capital goods, product designs and operational know-how	‘Technology’ refers not only to artefacts and operational knowledge (cell A1). It also includes skills and capabilities for technical change
2. The transfer process	Technology transfer is the cross-border movement of ‘technology’ (cell A1) from supplier to host-country importer	Technology transfer not only involves movement of capital-embodied or paper-embodied technology (cell A2). It involves flows of people-embodied knowledge combined with a capability accumulation process in recipient organisations.
3. Cross-border interaction	The transfer process (cell A2) is rooted in a transaction agreement pertaining to the transfer of goods, documentation and (possibly) related services. It is achievable through a unidirectional flow of resources from supplier to importer.	Effective transfer (cell B2) depends on a contractual relation that goes beyond the sale of capital or paper-embodied technology. It depends on ‘thick linkages’ that enable iterative knowledge flows between supplier and importer.
4. Localised innovation	Cross-border transfer (cell A2 and A3) and local innovation are substitutable processes	Cross-border transfer (cell B2 and B3) and localised innovation are substitutable only in certain respects. They are predominantly complementary activities.

Source: Drawing on Lema and Lema (2012), Table 6.

primarily to flows of *artefacts* between suppliers and importers of technology. The term *artefact* refers, in turn, to capital-embodied technology (i.e. capital goods such as machinery) and paper-embodied technologies such as product design blueprints and manuals. It also usually includes the associated know-how for operating and maintaining equipment. This notion of technology is reflected in much literature on technology in the climate change context (Commission on Growth and Development, 2008; World Bank, 2010). However, technology can also be understood more broadly to encompass people-embodied knowledge and expertise. The alternative broad approach lends emphasis to the techniques, processes and skills (together known as ‘software’), not only for operating installed technology, but also for managing technical change. This requires an understanding of the knowledge that underlies principles, designs and production systems enabling further innovation by recipients (Ockwell et al., 2008, 4106; Unctc, 2009b, 1). Such ‘further innovation’ requires not only *know-how* but also *know-why*, the ‘deeper’ system specific knowledge required for managing technical change.

The technology transfer process: Closely related to the view of technology as an ‘artefact’, one view sees technology transfer as a matter of picking technology from the shelf, importing it and adopting it in the host economy. This narrow view of transfer refers primarily to the physical movement of equipment, which is the embodiment of technological knowledge generated externally. Transfer of capital-embodied technology and associated operational expertise increases the capacity to produce, install and operate equipment in a given industry. In wind power, for example, it adds to the ‘installed capacity’ and generation of renewable energy. However, as pointed out by Bell (1990, 75–81), the transfer of such forms of technology does not add to the importing firm or country’s capacity to innovate. For example, the transfer of a blueprint for a wind turbine enables its production, but on its own, it does not add to the capabilities required to improve and change it for future projects. Technology transfer, in the broader sense, is therefore dependent on a learning process in technology importing firms (Levin, 1993).

Cross-border interaction: The literature which adopts a narrow approach contends that technology transfer can be based on relatively simple market transactions complemented by the necessary documentation and training. This is evident in the numerous studies that see trade in arms lengths relationships as a key transfer mechanism (Less and Mcmillan, 2005; Ueno, 2009; World Bank, 2008). The transfer requirement is therefore a relatively ‘thin’ linkage for a unidirectional flow from technology supplier to technology importer. However, trade in capital goods does not constitute technology transfer in the broad sense unless it is part of special arrangements “that have as an element the movement of technical knowledge” (Unctc, 2009b, 2). This is because the alternative broad view posits that technology encompasses both codified and tacit knowledge. Tacit knowledge is stickier and difficult to transfer without close interaction between user and producer (Lundvall, 1992). This typically requires iterative flows of high intensity and relative long duration, and higher levels of cross-border interaction imply more learning opportunities in the transfer process (Lema and Lema, 2012). For instance, a new investment project may benefit significantly from knowledge and experience of the technology supplier. The technology supplier can potentially speed up and deepen the technological understanding within the importing firm. However, this requires prolonged interaction so that the technology suppliers’ involvement in the project activities facilitates ‘conversion and socialisation’ of the knowledge relevant to technical change (Ernst and Kim, 2002). It is such processes that may ‘transfer’ expertise related to changing, developing and introducing new systems, rather than just using them as given.

Localised learning and innovation: The assumption underlying the narrow view is that local innovation in developing countries is costly and is more likely to be of substandard quality and technical sophistication when compared to technology from so-called advanced countries. Local investment in learning and innovation is therefore often seen as an inferior alternative to technology transfer. In the broad view, there is no duality between technology imports and localised learning and innovation. On the contrary, the interaction between internal learning and external technology acquisition constitutes an integrated process. While the opportunities for learning rise with the level of interaction between supplier and importer, the level of the recipients’ own investment in capabilities is essential to accumulate technological capabilities (Reddy and Zhao, 1990; Lall, 1993b; Bell and Pavitt, 1995). Internal efforts are required for (i) raising the knowledge base prior to investment projects, including knowledge about technical options, sources and modes of acquisition (ii) for actively absorbing, integrating and using technology obtained from external sources and (iii) for engaging creatively with technology and knowledge to improve it and apply it in new projects (Bell and Figueiredo, 2012).

These points shows that in the broad view the ‘ambition’ is not only to use technology, but to *master and change* technology. Arguably, such capabilities are necessary in developing countries for effective reduction of greenhouse gas emissions that will be associated with economic growth over the coming decades (Bell, 2009; Ockwell et al., 2009). In view of this discussion of the broad and narrow view of technology transfer, the following section asks what we already know about technology transfer in CDM and explores how the insights from literature on technology and innovation can be brought into our study of transfer mechanism in the CDM.

2.2. Literature on technology transfer in CDM

CDM has since the adoption of the Kyoto Protocol been a key element in the political negotiation process under the UNFCCC on mechanisms to enhance international transfer of technology. CDM is a project based mechanism which allows for implementation of greenhouse gas emissions reduction projects in developing countries. These projects generate tradable carbon credits, used by developed countries to comply with Kyoto Protocol commitments. Kyoto Protocol documents states that CDM should aim to facilitate transfer of technology between developed and developing countries. However, it important to note that despite often being hailed as a technology transfer flagship, technology transfer is not a formal obligation in CDM.

Therefore, existing research on technology transfer in CDM has, as mentioned, tended to concentrate on determining to what extend CDM projects involves transfer. One set of studies analyse transfer claims made in the project design documents (PDD) of CDM projects (Haïtes et al., 2006; Seres et al., 2009; Seres et al., 2010; UNFCCC, 2011; Youngman et al., 2007; De Coninck et al., 2007; Schneider et al., 2008). A common feature of these studies is that they define technology transfer narrowly. However, they often do this implicitly by noting – although the concept itself is not specified in the PDDs – that most project participants interpret technology transfer as the use of equipment not previously available in host countries. Defined as such, these studies arrive at broadly similar conclusions, finding that about a third of PDDs claim technology transfer. They tend to interpret these findings positively, to imply that CDM can contribute to technology transfer by financing emission reduction projects using equipment not available in in the host countries.

A second set of studies has a similar point of departure; it “defines technology transfer as the import of technology from

abroad” and also searches PDDs for claims of technology imports (Dechezlepretre et al., 2008, 2009). These studies found that 43% of CDM projects involve technology transfer and specifically that 63% of wind energy projects transferred technology. In contrast to the first set of studies, these studies also used non-CDM proxy indicators of host countries to address how technological capabilities influence technology diffusion in the CDM. Dechezlepretre et al. found that “On the one hand, high capabilities may be necessary to adopt a new technology. On the other hand, high capabilities imply that many technologies are already available locally, thereby reducing transfer likelihood. Our estimations show that the first effect strongly dominates in the energy sector” (Dechezlepretre et al., 2008, 1282). In other words, these econometric results suggest that higher capabilities are positively associated with the frequency of transfer in the energy sector, although it is not in other sectors such as agriculture. Doranova et al. (2010) identified the technology sourcing origin as foreign, local or combined and found that 41% of projects involved relied on foreign technology fully or in combination with local technology. Although they did not distinguish between different sectors, they found that that a stronger knowledgebase in host countries is associated with less use of foreign technology. Hence the literature does not provide a clear picture about how the CDM-external prevalence of capabilities influences technology transfer in CDM projects.

The approaches of the CDM technology transfer literature does not suffice for our purposes for two main reasons. First, as noted, in terms of methodology the earlier literature searched PDDs for claims of hardware imports or claims of transfer or foreign technology sourcing. The findings of the literature are associated with a degree of uncertainty because of the self-reported and undefined claims. For our purposes, the projects’ own claims of technology transfer or lack thereof does not suffice since they are difficult to assume correct (Hansen, 2011). This is important in its own right. And, secondly, these studies do not utilise or devise analytical frameworks which can aid the analysis of transfer processes and its effectiveness. Our question is not (only) whether technology transfers occurs in CDM but rather ‘how’ it occurs, if it does. The existing literature has little to offer on this question. These studies shed little light on the mechanisms of transfer, let alone the key question of this paper about whether there is diversity in technology transfer mechanisms.

Using imports and foreign technology sourcing to categorise technology transfer in CDM projects does not capture local production which involves involve technology transfer. The limitation of this approach is that it may overlook technology transfer and learning through cross-border knowledge interaction between firms that does not involve flows of equipment. It is necessary to move beyond the dichotomy of foreign versus local equipment to determine technology transfer and include mechanisms such as license agreement or joint ventures where equipment is locally produced but often rely on knowledge from outside. This is what we do in this paper. In doing so, we expand the conceptual underpinning and focus of the CDM literature. Most of the studies on technology aspects of CDM (studies cited above) and climate change policy more broadly (Ueno, 2009; Less and Mcmillan, 2005; World Bank, 2010; Commission on Growth and Development, 2008) largely sidestep a number of insights made in studies of technological learning and innovation in developing countries (Lall, 1993a; Bell and Figueiredo, 2012; Ernst and Kim, 2002; Fu et al., 2011). Most of these CDM and climate technology studies tend to draw (implicitly) on the narrow notions of ‘technology transfer’ introduced by conventional economics in the 1960s and 1970s and visible in influential writing (Krugman, 1979; Romer, 1994; Grossman and Helpman, 1995). At that time it was difficult to see beyond

trade and foreign direct investments, but this narrow view of transfer mechanism is still visible in much of the literature on greenhouse gas emission reduction technologies (Popp, 2011; Schneider et al., 2008; Less and Mcmillan, 2005; Ueno, 2009). In this paper we take a modest step forward. We start from a simple typology tailored specifically to the analysis of wind power CDM.

This review showed that:

- The literature on technology in CDM is predominantly based on a narrow view of technology transfer.
- The existing studies of technology transfer in CDM rely mainly on claims in PDDs without examining the technology as such or the organisational arrangements through which it is transferred.
- The literature has mainly discussed whether transfer occurs but offers few insights with regards to the process and mechanisms involved.

3. The analytical framework

In the subsequent section of the paper we examine the mechanisms of technology transfer in CDM projects empirically. In this section we set out a typology to distinguish between the different mechanisms. Going beyond the narrow view of technology transfer, we define the main mechanisms of technology transfer that will be used to assess the research questions set out earlier in this paper.

3.1. Types of mechanisms

According to Maskus (2004), the main market-based mechanisms of international technology transfer are trade in goods and services, licensing, FDI and joint ventures. Furthermore, it is also useful to consider mechanisms that are not international technology transfer because such modes may play a key role in CDM projects and our subsequent empirical analysis (Doranova et al., 2010). We therefore include ‘local’ sources of technology as a separate ‘mechanism’. This data category should essentially be understood as ‘no-transfer’. We thus define five mechanisms as listed in Table 2.

3.2. The main variables

It is commonplace to distinguish between inter-firm mechanisms (trade, licensing, joint ventures) and intra-firm mechanisms (wholly owned subsidiary) (Lall, 1993a; Dunning, 1981). Each of the mechanisms in Table 2 include a number of variations or subtypes. In the real world, the distinction between different mechanisms may be blurred. However, for operational analysis it helps to establish three distinguishing variables: (i) the origin of proprietary technology, (ii) the ownership of manufacturer and (iii) the location of production. As Table 3 shows, these variables differ between the five mechanisms.

The *origin* of proprietary technology refers to whether technological knowledge is produced within the host country or whether that development has taken place in foreign countries. It may be thought of as the location of the ‘core’ or ‘initial’ innovation process. Only in local technology provision is it internal to the host country. In the cases of international technology transfer, the origin of the technology is external by definition.

With regard to the *ownership* of the manufacturer, the binary distinction between external and internal is not applicable. While ownership is clearly external in trade and FDI and internal in local technology and licensing, joint ventures present a shared model of ownership.

Table 2
Technology transfer mechanisms.

Mechanism	Definition
1: Trade	Trade refers to the import of hardware developed and produced outside the host country. Trade can take place at arm's-length, with little interaction other than the transaction and its negotiation. Or it may involve broader 'interfaces' such as turnkey plants or service contracts.
2: Foreign Direct Investment	FDI refers to the establishment by a multinational company (MNC) of a wholly owned subsidiary in the host country. This mechanism refers to resource transmission from parent to subsidiary.
3: Joint venture	A joint venture is business association between an MNC and a local firm who agree to share equity capital, risks and decision-making authority. They share profits and other benefits of a local operation. There are many models of ownership ratios. The MNC partner typically provides new technology for local sales.
4: Licensing	A legal contract in which the licensor transfers specified rights such as intellectual property rights to the host country licensee for a specified duration. This type also includes full (indefinite) purchase of property rights by the recipient firm.
5: Local technology	'Local technology' refers to the case in which a locally owned firm (host country) with own innovation and proprietary technology ownership provides locally manufactured technology for investment projects. Local technology may also involve local technology transfer linkages (e.g. from universities).

Production is – in this context – the transformation of disembodied knowledge into physical machinery. In terms of the *location* of production, solutions are manufactured externally in trade relations, but internally in the four other mechanisms. This variable thus concerns whether hardware equipment has crossed borders in the transfer process or is produced in the host country. The identification of these defining variables aided the empirical analysis of the types of mechanisms involved in CDM projects. This is explained further in the next section.

4. Methodology

The aim of the study is to investigate the diversity of technology transfer mechanisms in wind power CDM. In order to investigate this, there was a need for methodological innovation. Unlike existing studies we do not rely on self-reported claims in CDM documents or on proxy indicators. Rather, we rely on a systemic analysis of the specific organisational arrangement and technological content of the projects, combined with an assessment of the technology using CDM-external sources. This section explains how the analytical framework has been applied to CDM and how the research was carried out.

4.1. Applying the analytical framework to wind power in the CDM

To apply the framework to wind power in CDM some issues were taken into consideration. First, CDM projects themselves are starting points. Transfer mechanisms are the concrete arrangements that underlie the supply of wind turbines used in a specific CDM project. These technology providers – the firms that produce and supply wind turbines – are the key to categorise CDM projects using our framework.

As Fig. 1 illustrates, these technology providers can be located either in the CDM host country or in a technology exporting country. Secondly, the technology providers are firms that have CDM projects as one market among others. As mentioned, the implication is that to understand technology transfer in CDM requires understanding technology transfer more broadly. The

non-CDM technological context of technology providers is crucial to explain technology transfer in CDM projects.

4.2. Data collection and classification

Much data on CDM projects are available from UNFCCC approved PDDs and 'validation reports' delivered by project participants and independent accredited consultants to the CDM Executive Board. This makes it fairly easy to access information on individual projects such as technology types and emissions reductions. However, when it comes to technology transfer, there are no mandatory guidelines or a common definition of technology transfer. As mentioned, this means that the usefulness of PDD claims is bounded and that there is a need to also collect and assess data from external sources.

Data collection: To collect data on firms and wind turbines used in each project we assessed three key questions derived from the three distinguishing variables presented above: who owns the technology supplier, where has the turbine been produced and where was the technology developed? All examined projects required CDM-external information and a large number of sources were needed to collect and consolidate data. The sources were each project's PDD and validation report, websites of specific wind turbine companies as technology suppliers in each project, and secondary sources such as industry periodicals, reports and academic journals. Industry experts and company officials were consulted to provide additional or confirmatory information. This was a difficult and lengthy process which required information about specific wind turbine companies, their wind turbine model portfolio, and their R&D and production locations. However, when several projects in the same country used the same technology supplier's turbine model, the additional project did not require new information. Data collection based on the actual firm and piece of technology (wind turbine model) is to our knowledge the first of its kind in multiproject CDM technology transfer analysis.

All 193 wind power CDM projects which were registered by April 1 2009 were examined during our research. In 11 CDM projects we did not find the required information for categorization. For the most part, this was when a project used a turbine

Table 3
The key variables.

No	Mechanism	Origin of proprietary technology	Ownership of manufacturer	Location of production
1	Trade	External	External	External
2	FDI	External	External	Internal
3	JV	External	Shared	Internal
4	Licensing	External	Internal	Internal
5	Local technology	Internal	Internal	Internal

Note: The categories of internal and external refer to the 'recipient' country (CDM project host country).

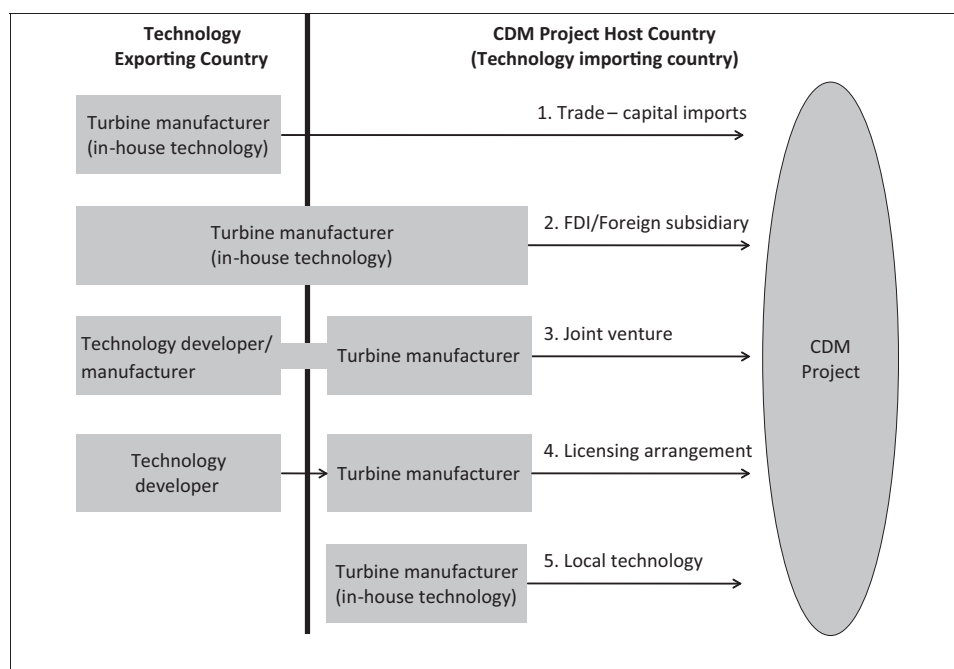


Fig. 1. Illustration of technology transfer mechanisms in CDM.

model which is produced by the same company in different locations in the world, and we could not confirm where the exact turbines were produced. Excluding these 11 projects allowed us to construct a database of 182 registered CDM wind projects. Some projects used more than one turbine model with the implication that we identified 189 transfer mechanisms in the sample of 182 projects.

Classification of data: To classify projects there is need to go beyond PDDs. One wind power CDM project in China claims that “There is no technology transfer for the proposed project” (UNFCCC, 2010). In previous studies this claim would have been evidence of ‘non-transfer’. However, with our methodological data collection exercise we can learn that this project’s turbines (model JF50/750) have been manufactured (i) in China, (ii) by a Chinese owned company and (iii) using proprietary technology external to the company developed outside of China (in Germany) and introduced to the company through a license agreement. Accordingly, it may actually be the case that technologies in CDM projects are supplied through transfer mechanisms despite claims by project owners (or vice versa).

It is the variability along the three distinguishing variables of Table 4 (ownership, location and origin of technology) that enables

us to guide the data collection and, in turn, enables us to apply the analytical framework. Although the framework is a conceptual construct, we did use an iterative process to ensure that no projects fell outside our categories.

4.3. Determining sequence

Once transfer mechanisms are identified in CDM projects, there is a need to determine whether CDM was a key driver of establishing these mechanisms. A first step is to assess in general whether mechanisms existed in the country prior to CDM projects using those mechanisms. For instance, did a country import turbines before they started import turbines used in CDM projects? Next, we explore this in more detail by looking at the sequence in which (a) a specific mechanism observed in CDM came into existence and (b) when projects using those mechanisms started. Each project’s PDD provide information on the start of the project. To identify the ‘starting date’ of transfer mechanisms, such as when wind power FDI took place for the first time or when a license agreement entered into force, we have used secondary literature and company sources such as annual reports. If, for example, FDI took place up in a country before the foreign subsidiary started to

Table 4
Categorisation of technology transfer mechanisms in CDM projects.

	1	2	3	4	5
	International trade	Foreign subsidiary	Local joint venture	Technology license	Local technology
<i>Ownership of manufacturer</i>					
Technology provider owned in host country				X	X
Technology provider owned outside host country	X	X			
Technology provider owned jointly			X		
<i>Location of production</i>					
Technology provider located in host country		X	X	X	X
Technology provider located outside host country	X				
<i>Origin of proprietary technology</i>					
Technology solution developed in host country		(X)	(X)		X
Technology solution developed outside host country	X	X	X	X	

Note: Variables in brackets are secondary possibilities.

Table 5

Key data regarding registered CDM wind power projects.

Countries	Number of projects	Share of projects (%)	Installed capacity (MW)	Share of installed capacity (%)	Average turbine size (MW)	Emissions reductions by 2012 (ktCO ₂)
China	94	51.6	4707	60.3	1.12	53,835
India	63	34.6	1524	19.5	0.88	20,053
Other countries	25	13.8	1576	20.1		14,732
Argentina	1	0.5	11	0.1	0.6	302
Brazil	4	2.2	166	2.1	0.95	1043
Colombia	1	0.5	20	0.2	1.3	161
Costa Rica	1	0.5	20	0.2	0.66	126
Cyprus	2	1.1	44	0.6	1.5	355
Dominican Republic	1	0.5	65	0.8	0.85	299
Israel	1	0.5	12	0.2	2.3	208
Jamaica	1	0.5	21	0.3	0.9	456
Mexico	6	3.3	958	12.3	1.21	8744
Morocco	2	1.1	70	0.9	0.85	1144
Philippines	1	0.5	33	0.4	1.65	436
South Korea	4	2.2	156	2	2.04	1458
Total	182	100	7804	100		8862

Source: Own calculations based on CDM PDDs.

supply turbines to CDM projects, we can argue that the CDM has operated through an already existing mechanism of transfer. However, if the CDM project and creation of the mechanism coincide, this may be an indication of a possible relation. We cannot argue that the coincidence in time is strong enough as evidence of causation because there may be multiple push and pull-factors at play when new mechanisms are established. But it can point to a possible link which can be 'backtracked' in further empirical research.

5. Wind power technology transfer in the CDM

This empirical section first provides an overview of wind power in the CDM, explores who the main host countries are and examines the origins of technology providers. The second part identifies the key technology transfer mechanisms.

5.1. Wind power in the CDM

Fourteen developing countries were by April 2009 hosts to almost 200 individual CDM wind projects (Table 5). India and China are by far the major host countries. Projects elsewhere constitute merely around 14% of projects. Wind CDM has followed the general (i.e. non-CDM) trend of wind power in developing countries: The same two CDM-leading developing countries, China and India, are also in the top-10 countries in terms of installed capacity globally (BTM, 2011). They are also outstanding as the only two developing countries (alongside a number of developed countries) that have emerged as major wind technology producers with increasing technological and innovation capabilities (Lewis, 2007). China and India are not only special cases in that the bulk of CDM projects are located in their countries; they are also major technology providers as 73.6% of wind turbines for CDM projects are manufactured within their borders.

Table 6

Top wind power supply companies in CDM.

Rank	Company	Country of origin	Number of projects	Countries of CDM operation
1	Vestas	Denmark	41	China, India, Costa Rica, Jamaica, Philippines, South Korea
2	Suzlon	India	31	India
3	Gamesa	Spain	30	Argentina, China, Dominican Republic, India, Mexico, Morocco
4	Goldwind	China	24	China
5	Enercon	Germany	21	Brazil, India
6	Sinovel Wind	China	14	China

Source: Own calculations.

Of the top six suppliers to wind power CDM projects, two are Chinese and one is Indian. The other three are developed country global market leaders. This picture shows a relatively strong representation of home market focused, developing country wind turbine producers despite dominance of developed country companies in the global non-CDM market (Table 6).

It is significant although unsurprising that those countries that are closer to catching up with developed countries as producers and developers of technology are also those with the most CDM projects and large non-CDM wind markets. However, this does not imply that the proprietary technology is developed within these countries and that no technology transfer is involved. There is a need to look closer at the different mechanisms that are represented as a first step to assess the question of technology transfer.

5.2. Wind power technology transfer mechanisms in CDM

The following provides an overview of the mechanisms that are represented in CDM wind power projects, that is, through which mechanisms wind turbines have been supplied. In comparison to the earlier literature on technology transfer in CDM, this analysis shows more diversity in technology transfer with a number of notable mechanisms in addition to import of hardware. Tables 7 and 8 provide this overview of technology transfer mechanisms in the countries that host wind power CDM projects. Below we discuss each of them in turn.

International trade: The bulk of host countries with wind power CDM projects are involved in technology transfer through arms-length import of foreign turbines from Europe, most notably Spain and Denmark, and to a lesser extent Germany and the Czech Republic. From these countries, technology manufacturers produce wind turbine systems and export to CDM host countries for individual projects. The key exporting companies are Spanish

Table 7

Technology transfer mechanisms in CDM per country.

Mechanism/Country	1 International trade	2 Foreign subsidiary	3 Joint venture	4 Technology license	5 Local technology	Total
China	28	15	7	45	3	98
India		18	21		31	70
Other countries	17	4				21
Argentina	1					1
Brazil		4				4
Costa Rica	1					1
Cyprus	2					2
Dominican Rep.	1					1
Israel	1					1
Jamaica	1					1
Mexico	5					5
Morocco	1					1
Philippines	1					1
South Korea	3					3
Total	45	37	28	45	34	189

Source: Own calculations.

Note: A project may involve different wind turbine models; in such cases the project has been coded as comprising several mechanisms. Our sample of 182 projects involves 189 mechanisms.

Gamesa (exports to 23 projects) and Danish Vestas (exports to 15 projects) while also GE Wind, Vensys-CKD, Nordex and Siemens engage in international trade. Even though China and India has emerged as manufacturers of wind power equipment, they have not exported to CDM projects in other countries. So far, developing countries engage merely in trade in CDM as importers of technology. Roughly one quarter (24.2%) of the wind power CDM projects fall within this first category of low carbon technology transfer.

Imports of wind turbines are predominant for the group of countries with only one or few projects (with the exception of Brazil). Operational knowledge flows may follow the import of technology hardware, although the extent is difficult to measure. Estimates have shown that transfer of knowledge is a companion to import of equipment in 20–50% of CDM projects across a variety of technologies (Dechezlepretre et al., 2008; UNFCCC, 2010b).

FDI: CDM wind power projects source 19.5% of their wind turbines from foreign companies' subsidiaries in host countries. However, only a few countries host manufacturing facilities of foreign wind companies. In Brazil, CDM projects have been supplied by Wobben Windpower, a subsidiary of the German wind turbine manufacturer, Enercon, which in 1996 started production partly as a response to a 60% local content requirement. In India there is a subsidiary by Vestas; and in China, Vestas, Gamesa, GE and Suzlon have subsidiaries supplying local CDM projects. There are some indications that foreign companies in high-growth developing countries do not find the CDM market particularly important compared to non-CDM demand. Moreover, smaller wind markets do often not justify FDI.

Joint ventures: Joint venture companies have supplied wind turbines to CDM projects in two countries and are the least used source of technology transfer with supply to 14.7% of wind power CDM projects. The wind joint ventures in developing countries are so far production-oriented and focused on access to the local market (Lema and Ruby, 2007). In general, there are few wind power joint ventures in developing countries and some have

ceased to exist. This is also reflected in the few CDM projects that source turbines from this mechanism. Examples include Germany's Enercon in India and Spain's Acciona Energia in China.

Licensing: Only China has CDM projects supplied by local companies using licensing arrangements although this mechanism accounts for almost a quarter (23.7%) of the wind power projects in all countries. This transfer mechanism allows the manufacturer to produce wind turbines not previously a part of the company's competences. Chinese companies that use technology transfer through licensing come from quite different circumstances. Some are already manufacturers of other energy or industrial equipment such as Sinovel Wind, a subsidiary of steel manufacturer Dalian Heavy Industry and Dongfang Steam Turbine Works, an energy and industrial equipment conglomerate. Others have historical experience in importing wind systems and running wind farms, such as Goldwind and Windey.

Local technology providers: Local technology is used in 17.9% of CDM wind projects. Not surprisingly, as research and development of own technology requires significant technological capabilities and investments, it is only China and India that have succeeded in developing indigenous technology and supplied it to wind farms through CDM. India's Suzlon is the most notable example (see below) while also smaller Chinese companies such as China Creative Wind and Windey have supplied turbines with local technology. As CDM projects, wind power projects that involve local technology are not significantly different from projects using transferred technology. On average, they are somewhat smaller projects but the average size of turbines is slightly larger. The reason is not least because of the dominance of Suzlon in this data category, which has internationally competitive technology.

To sum up, the analysis in this section generated two main insights.

- The sources of technology in CDM wind power projects are manifold. International trade – although a major mechanism – is far from an all-dominant mechanism of technology transfer. FDI,

Table 8

Technology transfer mechanisms per country (%).

Mechanism/Country	1 International trade	2 Foreign subsidiary	3 Joint venture	4 Technology license	5 Local technology	Total
China	28.6%	15.3%	7.1%	45.9%	3.1%	100%
India	–	25.7%	30%	–	44.3%	100%
Other countries	82%	18%	–	–	–	100%
All countries	24.2%	19.5%	14.7%	23.7%	17.9%	100%

Source: Own calculations.

licensing, joint ventures and local technology are also major sources. A broader variety of sources than commonly assumed is utilised.

- There are major variations between countries. The inclusion of a pallet of transfer mechanisms in the nation's portfolio of CDM projects (diversity) is only a feature of China and India. These two countries document a considerable variety of technology transfer mechanisms. Other countries have far fewer projects and rely on the 'standard' transfer mechanisms which tend to be emphasised in the climate technology literature.

We explore the reasons for these patterns in the next section.

6. The industry context of CDM host countries

The broad view of technology transfer suggests that one should pay attention to local capabilities and dynamics. This is what we do in our effort to explain the findings unearthed in section 5. The core question that drives this section is why China and India exhibit a diversity of mechanisms. In the following we first examine the wind industry context of China and India focusing on the existence of local capabilities. This opens up questions about capabilities developed in CDM projects and independently of CDM. We therefore go on to ask whether CDM seems to induce the establishment of new mechanisms or whether countries tend to utilise already existing ones. Finally we discuss the relationship between technology transfer and local capabilities in relation to the existing literature.

6.1. Industry context in China and India

The wind power industries in China and India have grown and matured significantly in recent years. Sectoral innovation systems for wind power has formed in both China (Klagge et al., 2012) and India (Kristinsson and Rao, 2008). Common to these innovation systems is that they have strengthened local actors while simultaneously drawing heavily on global sources of technology. A further commonality is the important role government policies have played in growth and development in both countries.

The Chinese government has implemented ambitious energy and industrial policies. On the demand side, concession projects, feed-in tariffs and wind energy obligations for electricity companies were introduced to create a stable and growing market for wind turbines (Conrad and Meissner, 2011; Lema and Ruby, 2007; Lema et al., 2011). On the supply side, technology subsidies and financial incentives for R&D have been important (Conrad and Meissner, 2011; Lema and Lema, 2012).

The Chinese wind power adventure began in the 1980s with *trade* as a dominant feature. Turbines were imported from Europe, primarily through bilateral aid projects. But from being largely an import country with about 97% of wind turbines imported in the late 1990s, the share of turbines manufactured domestically rose to nearly 100% by 2010 (CWEA, 2011). Some *joint ventures* emerged encouraged by government directed market-access, including between Nordex (Germany) and Xi'an Aero Engine Corporation and between Acciona Energy (Spain) and China Aero Engine Corporation. *Foreign direct investments* became important and all major wind companies, including Vestas, GE Wind, Gamesa, Suzlon and Nordex have set up shops in China. These firms have pointed to Chinese market and policy conditions as a key factor for their investments. In 2005–2006, when Chinese wind power demand started to rise very rapidly most foreign technology suppliers were seeking access to the market. However, due to a 70% local content requirement policy and to some extent rising customs duties, market access was largely restricted to foreign companies willing to invest in factories in China (Lema and Ruby, 2006).

Supported by government policies, the domestic Chinese firms overtook foreign firms in terms of market share in 2006. The majority of Chinese wind manufacturers initially produced turbines based on *license agreements* with foreign technology developers (Lewis and Wiser, 2007). The renewable energy law from 2005 spurred a dramatic boom in licensing activities. Several of the leading manufacturers in China, including Goldwind, Dongfang and Windey, have all acquired wind turbine licenses from one German company, REpower Systems. Other Chinese manufacturers, such as Sinovel and Shanghai Electric have similar license arrangements. These Chinese companies were newcomers to wind manufacturing and embarked on licensing as an initial entry strategy. A number of Chinese companies including Goldwind and Sinovel have now also begun to develop *local technology* by investing own resources in R&D and jointly with foreign partners. However, this trend has only become established in the most recent years.

India has for several years been a key player in the wind industry – both as a market and in terms of wind turbine manufacturing (Kathuria, 2002). Several Indian states have successfully deployed financial incentives such as feed tariffs for wind power and for the creation of an industrial base through tax incentives. Imports of turbines – *international trade* – occurred in the early days, although to lesser degree of that of China. As India adopted a trade policy in which it imposed higher customs duties for key components and whole turbines in order to attract FDI and stimulate domestic manufacturing, imports had become miniscule already by the mid-2000s (Mizuno, 2007; Kristinsson and Rao, 2008).

Several of the globally leading firms have made *foreign direct investments* in India, including Vestas, Gamesa and Enercon. The experience with wind in India began when Danish firms Vestas and NEG Micon (now a part of Vestas) first entered India as *joint ventures* in 1987. However, both firms later detached from its partners to become wholly owned subsidiaries in 1996. Enercon entered India in 1994, also initially through a joint venture.

Several smaller domestic wind turbine firms such as BHEL, Global Wind Power, Reegen Powertech, Siwa Wind Turbine have *licensing agreements* for turbine designs from firms such as Norwin (Denmark), Nordex, Vensys Energy (Germany) and Lagerway (Holland). The Indian flagship firm Suzlon also followed a route of technology licensing not only for wind turbine systems but also for key components such as blades and gearboxes from the mid-1990s through the early 2000s (Lewis, 2007). As Suzlon advanced, the company increasingly abandoned licensing and developed *local technology* through in-house research and development in India and abroad (Kristinsson and Rao, 2008). Gradually, and especially after 2000, Suzlon has become an indigenous manufacturer of own technology.

Both China and India have developed mature wind power equipment industries through ambitious policy measures and technology transfer which has occurred independently of CDM. Experiences with the full range of transfer mechanism were gained over the last 20 years. This suggests that China and India have considerable diversity in wind power technology transfer mechanisms within CDM because their wind turbine industries are relatively mature. To discuss this point further, the next section discusses the sequences in which mechanisms were utilised inside and outside CDM.

6.2. The sequence of technology transfer mechanisms in China and India

Was CDM a key factor in the establishment of the observed mechanisms? Or were these mechanisms established already prior to their use in CDM? Table 9 shows the sequence of the

Table 9

Time difference in the start of technology transfer mechanisms and start of CDM projects.

Country	Mechanism	(A) First use of mechanisms outside CDM ^a	(B) First use of mechanisms in CDM	(C) Establishment of the channels that introduced the mechanism in CDM ^b	(D) Minimum time difference
China	Trade	1986	2003	1986	7 years
	FDI	2005	2007	2005	1.5 years
	License	1996	2006	1996	10 years
	Joint venture	1997	2007	2006	1 years
	Local technology	2006	2007	2006	1.5 years
India	Trade	1986	–	–	–
	FDI	1997	2001	1997	4 years
	License	1994	–	–	–
	Joint venture	1987	2000	1995	5 years
	Local technology	2001	2001	2001	0 Years

Source: Own calculations and specified in Section 4.3.

^a Date of the first established mechanism, irrespective of a potential CDM connection.

^b Date of the establishment of the specific channel (firm) of technology transfer that introduced the use of a particular mechanism in CDM projects (i.e. Column B).

establishment of mechanism. In order to show the sequence in detail we distinguish between the *mechanisms* in general (e.g. FDI) and the specific *channels* within the different types of mechanisms. The channels concern the specific exporters (trade), multinationals (FDI), foreign proprietary technology holders (licensing) firm alliances (joint ventures) or domestic technology holders (local technology). This is important because a mechanism often involve several channels that are established at different times. In Table 9, Column A draws on Section 6.1 to show when the different mechanisms were established in China and India, i.e. when they occurred for the first time in each country. Column B then shows the year in which the different mechanisms were introduced for the first time in CDM projects. Column C is concerned with the specific channels (firm) that pioneered the use of a particular mechanism in CDM projects. In this column we thus identify the date of establishment of the specific channel that – simultaneously or later – was used in the first CDM project that used a given mechanism (i.e. Column B). Column A and C are different because – to take a fictive example – the firm that first exported wind technology to a given country is not necessarily the first firm that exported technology into a CDM project in that country. Column D then simply calculates the time difference between B and C. The advantage of using this approach is that it enables us to consider the possible role of CDM in establishing the mechanisms.

To illustrate the data in the table, consider the following example. We note in Column A that the first (two) joint ventures established in China were in 1997 (Xi'an Nordex and Yituo-Made). These joint ventures, however, have not supplied CDM projects. In Column B we note that the first CDM projects were supplied by joint ventures in 2007 (by CASC Wanyuan Acciona). In Column C we then trace the establishment of CASC Wanyuan Acciona to 2006, one year before it supplied CDM projects.

In China wind turbines were imported and assembled in ad-hoc plants from the mid-1980s. Vestas pioneered imports to China in 1986, seven years before the use of trade in CDM. So, the wind market was quite mature when the first CDM projects started to generate carbon credits in 2003. Licensing strategies were also common prior to CDM. The inflow of FDI to China took place in the mid-2000s while the supply by foreign subsidiaries to most CDM projects took place several years after. CDM projects are only a part of foreign companies' market in China while the non-CDM markets are more important in terms of their overall sales. Some subsidiaries, such as General Electric, has supplied turbines to some CDM projects within a year after its investment but has referred to local content requirements as the

main factor for its investment (Lema and Ruby, 2006). As noted, the joint venture, CASC Wanyuan Acciona, supplied turbines to one CDM project around a year after it was formed. This joint venture was fairly small and was established shortly before its supply to CDM. As CDM was a large share of the early sales portfolio of this joint venture it seems plausible that it was financially influenced by the CDM but our data does not allows us to verify this hypothesis.

In India the picture is slightly different. Table 9 shows that the subsidiaries and joint ventures which supplied to CDM operated already before CDM was established. For example, the first Indian CDM project supplied through a joint venture was in 2000. This project used turbines supplied through the joint venture, Enercon India, which had opened production five years earlier in 1995. Licensing also existed prior to CDM but have not been utilised in CDM projects, mainly because many small licensees had exited the wind business in the late 1990s. Moreover, the flagship firm Suzlon had developed proprietary technologies at the same time as it started to engage in CDM projects. Imported turbines have not played a role in Indian CDM.

This analysis supports our argument that the diversity of mechanisms in CDM projects in China and India is a reflection of pre-existing transfer mechanisms. There is nothing inherent in the demand created from CDM which facilitates the broadening of technology channels. In terms of such broadening, local supply and demand-side policies seem to have been more important independently of CDM, as argued above. CDM does not seem to have been be a major factor in opening up new mechanisms overall although it may sometimes have played a role in establishing specific channels, i.e. by connecting to particular firms as sources of technology.

The number of projects in which CDM may potentially have been playing a spearheading role in opening new channels is quite small. In less than 10 projects there is about a year between the start of the (actual) channel and the start of CDM projects. This small gap could be consistent with a connection between CDM and mechanisms as it simply reflects the time it takes before e.g. a license can be 'converted' into an installable turbine. In other words CDM may have played a role in opening up the new channel. One the other hand, there may have been multiple demand side drivers. Established CDM wind plants constituted 37% and 16% of the wind markets (installed capacity) by 2009 in China and India, respectively. The small number of CDM projects which were proximate (in time) to the establishment of channels would have to be examined in-depth in order to assess their actual causal role.

6.3. The relationship between technology transfer and local capabilities

In India and China the development of the domestic wind turbine industries explains why considerable diversity is found. A substantial number of domestic and foreign companies supply CDM from within these countries. Many of these technology providers have under various policy conditions used conventional technology transfer such as licensing, joint ventures and FDI and some have also started to develop indigenous technology. The diverse industrial and technological context of China and India is reflected in CDM wind power technology transfer. In all other countries, except Brazil which has foreign investments, there is no diversity as international trade is the only source of hardware supply for CDM projects (see Table 7). These countries have no wind industries and little installed wind power other than what has been introduced through CDM (BTM, 2011). Naturally, turbine supply comes through imports. This suggests, unsurprisingly, that countries without a domestic wind industry rely heavily on the standard mode of technology sourcing. On the contrary, countries with domestic firms expand the scope of technology mechanism as capabilities grow stronger.

This shows that shifting the focus to the context of developing countries' industrial structure and capability levels helps to explain why there is diversity of mechanisms in some countries rather than others. China and India stand out in terms of diversity in mechanisms because both countries are hosts to wind turbine industries and capable foreign and domestic firms. It seems that the nature of technology transfer in CDM is an effect rather than a primary cause of domestic capabilities.

Based on the preceding analysis we can thus question some inherent assumptions in the CDM literature. Much literature on CDM assumes that CDM plays an important role in technological advancement because skills and capabilities from CDM projects are redeployed in future CDM and non-CDM projects. Seres et al. (2010, 23) suggest that "transfer of technology to a CDM project creates capacity in the country that allows later projects to rely more on local knowledge and equipment". However, as suggested above, our evidence from India and China suggests that the reverse causal relationship may be more predominant. The modes of technology sourcing in wind power CDM projects in China and India is a replication of mechanisms that have already been opened up and utilised elsewhere. In extension and by hypothesis, it seems that external projects in the country created the original capacity that allowed later CDM projects to rely on these skills and capabilities.

From a certain perspective this may seem unsurprising since Hasic and Johnstone (2009) found that the CDM can only partly explain the transfer of wind technologies to developing countries and Seres et al. (2009) already noted that technology transfers is less likely in countries such as China, India and Brazil because domestic manufacturing capacity reduces the need for international flows of equipment (i.e. technology transfer in the narrow sense). However, we have taken the discussion a significant step further in this paper. We show that important technology transfer mechanisms such as foreign subsidiaries, joint ventures or license arrangements materialise in conjunction with local capacity to produce and develop wind power equipment. In other words, transfer mechanisms seem to co-evolve with domestic capabilities. Rather than becoming *less likely*, technology transfer *changes in nature* as domestic capabilities increase. This is reflected in the technology sourcing patterns of CDM wind projects in India and China.

To sum up, the analysis in Section 6 provided evidence to suggest that:

- India and China have built significant firm capabilities in the wind power field. This appears to be a result of ambitious host country policies (particularly in China) and firm level strategies and investments more than of CDM.
- Capabilities for utilising new sourcing mechanisms were created independently of CDM and have later been replicated in CDM projects.
- Transfer mechanisms have co-evolved with the maturity of the industry. The role of such external linkages did not decrease but it changed in nature and utilised a broader variety of mechanisms.

7. Conclusion and policy implications

The purpose of this study was to explore and explain the use of different mechanisms of international technology transfer in wind power CDM projects. We also sought to explore the extent to which CDM projects open up new transfer mechanisms that have not previously been utilised the host country. This final section asks how our findings relate to the existing literature, further research and climate policy.

7.1. The findings and their contribution to the literature

Our findings add value to the literature on CDM technology transfer (e.g. Dechezlepretre et al., 2008, 2009; De Coninck et al., 2007; Hasic and Johnstone, 2011; Seres et al., 2010; UNFCCC, 2011) in two main ways.

First, we specify the different mechanisms through which technology is transferred in CDM wind projects. We contribute by showing empirically that there is considerable diversity in the sources of technology. The mechanisms go beyond equipment imports (trade) and foreign direct investment which are often assumed to be the main channels (Popp, 2011; Schneider et al., 2008; Less and Mcmillan, 2005). While these are still dominant outside China and India, they are not the most important ones in the two most important host countries for wind CDM projects, China and India.

Second, we find that CDM wind power projects tend to utilise pre-existing transfer mechanisms. They typically do not open up new mechanisms of low carbon technology transfer. In turn, it is doubtful whether CDM plays the spearheading role for enhanced technology transfer which is sometimes assumed. The existing literature tend to argue that technology transfer via CDM helps to create local capacity that allows later projects to rely more on the absorbed technology and knowhow (Seres et al., 2010; UNFCCC, 2011). Our evidence questions this assumption. In fact, it turns it on its head because the most advanced skills and capabilities may have been developed independent of CDM. As explained, the diversification of mechanisms seem to relate closely to the overall maturity and capability level of the national industry, which in turn is an effect of broader circumstances, firm strategies and policy conditions.

These findings provide insights for the literature that has explored how technological capabilities of the host country influence the *quantity* of technology flows in the CDM – i.e. whether stronger host capabilities implies less or more inbound technology transfer (e.g. Dechezlepretre et al., 2008; Doranova et al., 2010). In this paper we have gone beyond this to address the relationship between the local industry and capability levels and the *nature and types* of transfer mechanisms. These mechanisms seem to start independently of CDM and co-evolve with domestic (host country) capabilities. These findings open up new issues and questions for further research.

7.2. Issues for new research

Future research should pay more careful attention to the mechanisms, processes and dynamics of 'learning' in CDM projects and the overall significance of CDM in building host country technological capabilities. Our findings stress the need to examine (a) the effectiveness of CDM for the development of capabilities for mastering and engaging creatively with climate change mitigation technologies, (b) the different processes through which this occurs and (c) how CDM projects and non-CDM compare in both of these respects. New research should seek to specify more carefully the causal mechanisms and key contingent variables involved in technological learning in and around CDM projects.

Furthermore, future research should address the complexity of the technology development process. The typology adopted for this paper does not capture the full complexity of wind power technology development as it occurs in India and China today. The five mechanisms identified in our study are mainly 'conventional' technology transfer mechanisms. However, as companies such as Suzlon and Goldwind have built own technological capabilities they are now using 'unconventional' technology transfer mechanisms (Lema and Lema, 2012). These are new technology linkages between emerging markets in China and India and OECD economies. They include (a) acquisition of innovative firms abroad, (b) investments in overseas R&D facilities and (c) joint R&D with overseas firms and technology organisations (see also Lewis, 2011). In such relationships technologies and capabilities are acquired and co-created rather than transferred. Similarly, complexity has increased as firms from OECD countries that supply to CDM projects begin to use their R&D departments in emerging markets for developing new wind technology.

As innovation is more and more globalised, the distinction between foreign and local technology becomes blurred. Ultimately, the increasing complexity means that the notion of technology transfer itself is brought into question. This is the case in China and India where technology transfer now has decreasing practical relevance. More broadly, the concept seems to have decreasing analytical relevance if one wants to examine learning and the development of the local innovation capabilities that are fundamental to ensure low carbon growth in developing countries (Ockwell et al., 2009; Bell, 2009).

To capture the technology process underlying CDM projects, future studies will need to find a new language and examine innovation as a cumulative process that combines firm-internal learning with domestic and international knowledge linkages. To do so, much guidance is likely to be found in the literature on learning and innovation in developing countries (Lall, 1993b; Bell and Pavitt, 1995; Fu et al., 2011; Bell and Figueiredo, 2012). It seems highly valuable to bring the climate/CDM and technology/learning literatures further together. Much more research is needed to further integrate the literatures conceptually and methodologically.

7.3. Implications for policy

The study also has important insights for the climate policy agenda – in the UNFCCC and for donors and developing countries preparing low carbon development strategies. The latest climate change conferences in Copenhagen, Cancun and Durban (2009–2011) laid the foundation for enhanced technology transfer and development. Our results could inform the further negotiations over CDM and potential new market mechanisms as well as the priority areas for the Technology Mechanism. Further deliberations need to keep in mind that technology creation and diffusion is multifaceted and that diversity (and hence greater impact potential on building technological capacity) seems to increase

with complementary capabilities of developing countries. Drawing on the technology literature to open the black box of technology can help to define objectives and generate more effective policy. It could be explored, for instance, whether the technology transfer component of CDM should be further elaborated and tailored to host countries with different levels of capabilities. Moreover, policy makers may give more emphasis to the combination of external sources of technology (through CDM and other mechanisms) with internal sources. This shifts the relative emphasis to domestic policies and the development of local absorptive capacity in sustainability-oriented innovations systems (Altenburg and Pegels, 2012). The learning-intensive and interactive nature of technology development and diffusion means that support for domestic technological capability building and for related international technology cooperation may prove a fruitful avenue for climate change mitigation.

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