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Understanding the CDM's contribution to technology transfer

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ABSTRACT

Developing countries are increasingly contributing to global greenhouse gas emissions and, consequently, climate change as a result of their rapid economic growth. In order to reduce their impact, the private sector needs to be engaged in the transfer of low-carbon technology to those countries. The Clean Development Mechanism (CDM) is currently the only market mechanism aimed at triggering changes in the pattern of emissions-intensive activities in developing countries and is likely to play a role in future negotiations. In this paper, we analyse how the CDM contributes to technology transfer. We first develop a framework from the literature that delineates the main factors which characterise technology transfer. Second, we apply this framework to the CDM by assessing existing empirical studies and drawing on additional expert interviews. We find that the CDM does contribute to technology transfer by lowering several technology-transfer barriers and by raising the transfer quality. On the basis of this analysis, we give preliminary policy recommendations.

1. Introduction

Industrialised countries are responsible, both historically and currently, for the majority of greenhouse gas (GHG) emissions, but developing countries are increasingly contributing to the problem because of their rapid economic growth (IEA, 2007). Access to existing technologies and technological innovations is commonly seen as a prerequisite for the reduction of emissions in developing countries (de Coninck et al., 2008). Consequently, transfer of technology will be a key pillar in any agreement on a future regime to combat climate change (UNFCCC, 2007a). While views on how to resolve this issue differ broadly, the private sector will play an important role, as it is the main source for the worldwide diffusion of technology (Heller and Shukla, 2003; Stern, 2007; UNFCCC, 2007b).

Currently, the Clean Development Mechanism (CDM) is the only market-based mechanism aimed at triggering changes in the pattern of emission-intensive activities in developing countries. It incentivises the private sector to finance emissions-reduction projects and thereby potentially contributes to the transfer of technologies previously unavailable in developing countries. It is likely that the CDM in its current or a modified form will play an important role in post-Kyoto negotiations because it is able to provide the side-payments necessary to engage developing countries (Frankel, 2007) and it can serve to link several fragmented regional trading schemes like the EU Emission Trading Scheme (EU ETS) (Jaffe and Stavins, 2007). Because of the potential future size of such a mechanism, increasing technology transfer within it could serve the dual purposes of both reducing the emissions of developing countries and changing their course of development. Hence, it is important to analyse the technology-transfer contribution of the current CDM.

While there is a large body of literature on the assessment of the CDM's overall potential for reducing emissions and on meeting two of its central criteria, additionality and host-country sustainable development (Olsen, 2007), specific literature on the CDM's technology-transfer performance is limited. Besides early conceptual work (Aslam, 2001; Millock, 2002), there have been two important streams of literature. First, some studies relate CDM activities and investment flows: for example, Niederberger and Saner (2005) conceptually analyse the CDM's potential for adding to traditional incentives of transnational corporations for foreign direct investment. Others present aggregated empirical comparisons of CDM and private investment flows but do not provide detailed analyses of technology-transfer issues (Ellis and Kamel, 2007; Ellis et al., 2007). Second, some authors undertake empirical analyses of the CDM's technology-transfer performance by analysing CDM project design documents (PDDs) (de Coninck et al., 2007; Dechezleprêtre et al., 2008; Haites et al., 2006; Pueyo Velasco, 2007; Seres, 2007). These studies find that technology transfer is occurring to some extent but that it is dependent on various parameters such as project type and involvement of foreign project participants. Although these studies are important contributions, they do not analyse the mechanisms through which

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these parameters influence technology transfer within the CDM. However, while technology transfer can be addressed in many ways, a precise understanding of the drivers and barriers of technology transfer under CDM is necessary to derive policy recommendations on how to increase technology transfer under possible future mechanisms.

In this paper, we investigate the way in which the CDM contributes to technology transfer. In Section 2, we draw on the general literature on technology transfer to develop a framework independent of the CDM that delineates the main factors that characterise technology transfer. In Section 3, we use this framework for analysing the CDM's technology-transfer performance. To do this, we reassess existing empirical evidence and additionally draw on expert interviews we conducted with various stakeholders. On the basis of this analysis, we give preliminary policy recommendations in Section 4.

2. Private-sector technology transfer

Technology transfer has been defined as "a broad set of processes covering the flows of know-how, experience and equipment" (IPCC, 2000, p. 3). In this article, we focus on private-sector technology transfer because "when considering means to enhance investment and financial flows to address climate change in the future, it is important to focus on the role of private-sector investments as they constitute the largest share of investment and financial flows" (UNFCCC, 2007b, p. 5). We focus on technology transfer from North to South because most technologies are still mainly developed and first deployed in the industrialised world (IPCC, 2007). The main channels of private-sector technology transfer are trade, licensing, and foreign direct investment (FDI). Technology transfer via international trade occurs through purchasing equipment or knowledge not commercially available in the recipient country. Licensing typically involves the purchase of production and distribution rights and the underlying technical information and know-how to exploit them. FDI can be defined as investments made by foreign entities in the productive assets of local companies, which enable the investor to influence the activities of the local firm as, for example, in joint ventures (Niederberger and Saner, 2005).

In this paper, we focus on the purchase of technology via trade and transfer of technology as part of an investment, the former being by far the more common. The main agents within the technology-transfer process via trade are depicted in Fig. 1. In this case, technology providers transfer technology to enter new markets. The recipient's primary motivation to adopt new technology is driven by considerations about the company's competitive position in the local market. Therefore, recipients do not necessarily look for the most efficient technology on the world market, but rather search for technology best suited to the company's local needs and to its capacity to absorb new technology (IPCC, 2000). Public or private intermediaries can facilitate this type of transfer by providing information or access to capital. In the case of technology transfer through an investment, a firm supplies technology to a subsidiary or affiliate in the host-country to lower production costs or to improve the product quality, mostly without the involvement of intermediaries.

In general, technology providers have limited interest in the diffusion of their technology into the local economy because they hope to avoid imitation. Because of the complexity of the technology-transfer process, different factors on the macro and micro levels determine the actual flow of technology (IPCC, 2000; Worrell et al., 2001). We investigate these factors and focus on barriers that hinder technology transfer by using literature and data on environmentally sound technologies[1] (ESTs). Our framework covers three areas: barriers that can prevent technology transfer, dimensions for describing the distribution of technology transfer, and factors that determine the quality of technology transfer (Table 1).

2.1. Barriers to technology transfer

While the technology-transfer barriers listed below primarily impact the technology recipients they also affect technology providers due to their dependency on the demand of recipients. An important barrier to technology-transfer deals is the potential *lack of commercial viability*. In general, technology imported from industrialised countries is more efficient but also more expensive than technology manufactured locally, and it therefore requires higher initial investment costs. This is of particular importance for ESTs (Wilkins, 2002). Furthermore, as a result of their typically early commercialisation stage, ESTs are often considered riskier than existing commercial technologies (Ockwell et al., 2007).

Even if commercial viability allowed a deal that involved technology transfer, it might not be executed because of a *lack of information* about the investment opportunity, a lack of confidence in the information, and high transaction costs for obtaining reliable information and negotiating the deal (Worrell et al., 2001). Furthermore, since technology providers tend to lack knowledge about recipients' local needs and technological capabilities, technology available on the world market is often not appropriate, e.g. due to size differences of the required and the available technologies (Dechezleprêtre et al., 2008).

Frequently, a *lack of access to capital* hinders technology recipients from getting an investment financed (Tébar Less and McMillan, 2005). Firms might not be able to find an investor because of the insufficient infrastructure of financial markets in many developing countries or the high interest rates of up to 30–40 percent per year (Worrell et al., 2001). Moreover, investors sometimes overestimate the investment risks, thus leaving sound and theoretically profitable investment projects without the necessary funding (Wilkins, 2002).

The barriers described above are closely linked to the *institutional framework* that a country provides as described in the following examples. For instance, trade restrictions through tariffs and non-tariff barriers are limiting a technology's commercial viability. Access to capital is more restricted if investors are worried about political risks and consider enforcement of the regulatory framework as weak. With respect to lack of information, a high level of corruption complicates obtaining the right information and thus raises transaction costs. Thus, stability of the political system, sound economic policy and regulatory frameworks, legal security, trade openness, and a low level of corruption are important elements of an enabling environment suitable for attracting foreign technology (IPCC, 2000). Three issues related to the institutional framework are of particular interest: first, the literature has traditionally emphasised the importance of intellectual property rights (IPRs). However, the limited empirical evidence indicates that the effects of IPR regimes on transfer of ESTs is not a key barrier (Stern, 2007; Tébar Less and McMillan, 2005). Second, environmental policies are of particular importance since firms have few incentives to acquire ESTs if environmental regulation and enforcement is weak or if conventional energy prices are subsidised (Ockwell et al., 2007; Tébar Less and

[1] Environmentally sound technologies (ESTs) "protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes" (United Nations, 1992).

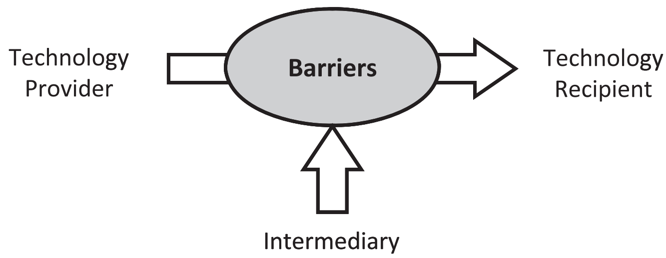

Fig. 1. Main actors involved in private-sector technology transfer.

Table 1
Key parameters for assessing private-sector technology transfer

Barriers	Dimensions	Quality
Lack of commercial viability	Distribution across geographies	Type of technology
Lack of information	Distribution across technologies	Deal structure
Lack of access to capital	Distribution across firms	
Lack of institutional framework		

McMillan, 2005; Wilkins, 2002). Third, requirements for domestic ownership of ventures or the degree of local technology content influence the feasibility of technology transfer.

2.2. Dimensions of technology transfer

Private-sector technology transfer has grown significantly over the past decades (Hoekman et al., 2004). However, because of the above-mentioned barriers, the distribution of technology transfer varies across geographies, technologies, and firms.

First, with respect to the *geographical dimension*, private transfer modes favour developing countries that have achieved an advanced development status, highlighting the importance of an enabling environment with a sound institutional framework, good knowledge infrastructure, and an attractive market potential (Ellis et al., 2007). For instance, the share of total world imports of high-tech goods to low-income countries merely doubled between 1970 and 2001, while developing countries with lower-middle income increased their share sevenfold. In the case of FDI, the overall share of the former group declined significantly, while the latter denoted a rise of more than 80 percent (Hoekman et al., 2004).

Second, the *technology dimension* shows that ESTs transfer less quickly than other technologies and that there are significant differences among various ESTs (Worrell et al., 2001). Only few ESTs, i.e., mainly technologies to increase energy efficiency in automotive products or machinery equipment, benefited from a growing share in worldwide trade and investments in sectors with strong environmental impacts (WTO, 2006). In case of renewable energy technologies, wind energy has recently received more investment attention primarily as a result of its improved commercial viability, while the transfer of other renewable energy technologies to developing countries remains limited (REN21, 2007).

The *firm dimension* reveals that small and medium enterprises (SMEs) play only a minor role in technology transfer. In industrialised countries, SMEs are the firms most likely to bring about radical technological changes (Barton, 2007), but their role in the diffusion of technology to developing countries is rather limited (Marcotte and Niosi, 2005; UNCTAD, 1993). Correspondingly, in developing countries, most small firms hardly attract any international technology even though they constitute a very large part of the private economy (Lukacs, 2005). Both trends can be attributed to the fact that most barriers tend to be more striking for SMEs, especially lack of information and access to capital (Worrell et al., 2001; Yakowitz and Hanmer, 1993).

2.3. Quality of technology transfer

The quality of technology transfer can be defined as the degree to which the transfer raises the recipient's technological know-how and its capacity to use this knowledge to adopt and innovate new technologies (Mansfield, 1975). Quality can differ widely across transfers and is hard to measure because of the existence of technological spillovers that arise if the costs and benefits of technology exchange are not fully internalised by the actors involved. These spillovers are likely to represent a major share of technology-transfer benefits to recipient countries (Hoekman et al., 2004). To determine the quality of a technology-transfer deal, the type of technology and the deal structure are of major importance.

First, regarding *type of technology*, technological content varies in its complexity and its relative performance compared with state-of-the-art technology in the field (Saggi, 2004; Xu and Wang, 1999). Moreover, some technologies, especially those used in the core production process, also require extensive know-how transfer in order for them to be used properly and thus additionally contribute to developing local technological capability. However, to benefit from a higher technological content, recipients must have a sufficient financial and technical background to adopt foreign technology (IPCC, 2000).

Second, the nature of the *deal structure* influences the actors' willingness to cooperate and continually engage in information exchanges. Both continuity and collaborative behaviour increase the likelihood of transferring tacit knowledge in addition to the equipment. Thereby, they increase the recipient's capacity to adopt the technology and later innovate new technology based on it (Tébar Less and McMillan, 2005). Therefore, short-term, one-time deals are less likely to contribute to high-quality technology transfer than long term, repetitive deals. Reflecting this, the literature often refers to FDI as the most intense transfer mode because it tends to have a higher technology content, a longer duration, and more intense personal interactions (Hoekman et al., 2004; Philibert, 2005; Saggi, 2002).

3. CDM as an instrument of technology transfer

After a slow start, the CDM market has grown enormously due to greater political certainty after implementation of the Kyoto Protocol and because of the market's increasing experience with the process. As a result, there has been a steep increase from 64 projects and about 100 kt in expected certified emissions reductions (CERs) by 2012 in January 2005 to 2,647 projects and about 2.3 Gt in expected CERs in November 2007. (UNEP Risoe, 2007b). As current estimates for the compliance shortfall of countries with reduction obligations under the Kyoto Protocol are around 3.3 Gt CO_2, the CDM can, contrary to initial doubts about its potential, contribute significantly to meeting Kyoto's reduction goals (Capoor and Ambrosi, 2007). The market has attracted and created many different players from both the public and the private sector, whose objectives have included increasing awareness about the CDM and its contribution to sustainability as well as compliance by firms or countries with reduction obligations. Additionally, numerous specialised international project developers and consultants offering services in the form of project sourcing, development, and methodology writing have emerged and have recently been joined by companies offering risk management and carbon-fund management services.

The CDM's current contribution to technology transfer can be estimated by assessing empirical work based on PDD evaluations (de Coninck et al., 2007; Dechezleprêtre et al., 2008; Haites et al., 2006; Pueyo Velasco, 2007; Seres, 2007). Seres (2007) uses the most recent data and finds that 64% of expected CERs originate from projects involving technology transfer. Combining the expected 2.3 Gt in CERs with the average price of 6€ calculated from primary CDM transactions in 2005 and 2006 (Capoor and Ambrosi, 2007) suggests an investment flow of around 9 billion Euro into projects containing technology transfer. This exceeds the investment generated by the Global Environment Facility (GEF), a fund deliberately set up to promote technology transfer (Egenhofer et al., 2007), making the CDM the largest technology-transfer mechanism under the United Nations Framework Convention on Climate Change (UNFCCC). However, while the technology-transfer share—when measured in expected CERs—is fairly high, the CDM only transfers technology in 39% of its projects, pointing to a potential for further increase. Moreover, technology transfer under CDM is distributed unevenly across geographies, technologies, and firm characteristics and is more likely in the case of foreign participation (Seres, 2007), hinting at the varying importance of different actors and barriers that is also suggested by theories of technology transfer.

Therefore, we first investigate on a conceptual basis whether and how the CDM and its various actors can lower each of the technology-transfer barriers (Section 3.1). We then analyse the CDM's current distribution across geographies, technologies, and firms (Section 3.2), as well as its performance with regard to technology-transfer quality (Section 3.3). We base our analysis mainly on existing empirical studies and conceptual considerations. We support this analysis by expert interviews that we conducted before and during COP 13. In total, we conducted 21 semi-structured interviews with proponents equally representing the fields of business, academia, and policy. When preparing the interview guides, we first analysed background material of the interviewee's organisation and publications and then tailored the guide to the respective interviewee's expertise. For example, we focused questions to project developers or finance institutions around their influence on and their preferences about the technology decision in a CDM project.

3.1. The CDM'S impact on barriers

3.1.1. Lack of commercial viability

The CER price increases the revenues of any project eligible under the CDM and thus augments its attractiveness. To make the investment profitable, the carbon revenues must push the internal rate of return above a certain threshold. The magnitude of the CER price is mainly driven by international buyers of CERs, which have to meet their compliance or voluntary reduction commitments. Since European private buyers under the EU ETS dominate the market thus far (Capoor and Ambrosi, 2007), the CER price has evolved in relation to the price in the EU ETS. Because of the very volatile prices in the EU ETS and uncertainties about the CDM process and the post-2012 validity of CERs, price expectations for CERs have been diverse. These two factors, the magnitude of the expected price and the associated uncertainty, both impact technology-transfer decisions.

First, different project types exhibit different value contributions induced by CDM. CER prices do not affect the overall commercial viability of projects involving multiple revenue streams, such as renewable energy, as much as they do for projects that only exhibit a carbon revenue stream, such as landfill gas flaring or HFC destruction (Table 2). Second, the price uncertainty impacts the technology-transfer decisions because all parties, i.e., providers, recipients, and intermediaries, have varying risk-management capabilities for coping with the large and new uncertainties surrounding the increased commercial viability of a transfer deal. This uncertainty is especially high for projects whose profitability depends strongly on the CER price.

Table 2
Impact of CDM on project profitability (at $4/CER) (UNEP, 2007)

Project type	CDM impact on internal rate of return (IRR) (%)
Hydro, wind, geothermal	0.5–3.5
Crop/forest residues	3–7
Municipal solid waste	5–60
HFC destruction	+500

In our interviews, project developers and fund managers mentioned that they were most interested in projects whose CDM's contribution to commercial viability is high. Furthermore, they stated that international technology is most likely to be employed in such projects because differences in efficiency and reliability might yield large differences in revenues. However, especially in cases of high uncertainty, domestic technology might be preferred if it is cheaper and at the same time not significantly less efficient, thereby generating similar CDM revenues at comparable or smaller cost.

3.1.2. Lack of information

There are three levels of information that the CDM and its actors can influence to foster technology transfer. First, actors need to know about the CDM and its eligibility criteria in general as a prerequisite for the implementation of CDM projects and subsequent technology transfer. This awareness about CDM among potential technology recipients, intermediaries, and technology providers is being increased through various efforts of different public actors such as development organisations, host countries, and the UNFCCC's collaborating UNEP Risoe Centre.

Second, actors need to know about potential emissions-reduction opportunities and assess the profitability impact on the underlying project. As all our interviewees confirmed, knowledge about where carbon emissions occur and how they can be reduced has been increased considerably through the UNFCCC, which now makes the detailed project information, i.e., the PDDs, publicly available. The condensed information on all projects is also offered online in a spreadsheet (UNEP Risoe, 2007a) that is central to the market because it is used by many capacity-building and private organisations to learn about project opportunities and disseminate corresponding information.

Third, technology recipients need to be aware of available domestic and international technologies in order to make an informed investment decision. While the above-mentioned spreadsheet gives sufficient information on the projects in terms of size, process, emissions reductions, etc., it does not provide details about the technology and its provider. International CDM project developers can partly compensate this since they have knowledge of both project opportunities in developing countries and advanced international technology. Technology transfer is very likely when international project developers cooperate with an international technology provider to replicate a certain project within and across countries.

3.1.3. Lack of access to capital

Access to capital has increased significantly as private investors have begun to regard the CDM as an investment opportunity. In contrast to the classic transfer modes FDI, licensing, and trade, CDM deal structures are best conceptualised with respect to the type and timing of deployed capital: equity, forward, and spot deals (Niederberger and Saner, 2005). First, projects can be financed entirely with equity by an international private project developer who is involved from the beginning and finances, builds, and operates the entire project on his own (i.e., build–own–operate–transfer deals). The project developer obtains full ownership of the CERs, paying the project host a fixed fee for each CER (UNEP, 2007). At the end of the lifetime of the CDM project, the project is transferred to the project host together with the trained personnel, and its operation can be continued. While this is a model with a large potential for technology transfer it has hardly been used in the CDM so far. Second, the most common contribution of CERs towards investment capital for projects is the provision of up-front payments for at least part of future CER deliveries, often under the condition of lower CER prices. This sort of finance is provided by many individual buyers, private project developers, funds, or government purchase programmes (UNEP, 2007). In case the buyers do not make up-front payments themselves but sign a contractual agreement to buy them later, the expected CERs can facilitate access to conventional project finance in the form of bank loans. Third, spot deals occur in so-called unilateral projects, where a local entity, often the project host, finances the project itself and generates issued CERs that are then sold on the spot market to an international buyer.

These different deal structures have varying impacts on technology transfer: spot deals are likely to contribute less to technology transfer from North to South. As confirmed in our interviews with international intermediaries, the earlier, the stronger, and the longer they are involved financially, the more they tend to influence the technology acquisition to increase the prospects for reliable operation. This can lead either to investing in projects with proven international technology or, even if domestic technology is employed, to assisting in the project design and thus know-how transfer. The same effect of up-front involvement is likely to be equally valid in the case where a multinational company transfers technology to a subsidiary or affiliate firm. Two further trends are very likely to occur: first, access to capital is likely to become easier over time because of the maturity of the market and the greater experience with different financing structures. Second, as a result of the strong interest of international intermediaries to devise financial structures for CDM projects, financing know-how is transferred to entities in developing countries.

3.1.4. *Lack of institutional framework*

While every country has a general institutional framework hindering or facilitating technology transfer, it has to establish CDM institutions in order to attract CDM projects. It is particularly interesting to analyse the importance of CDM institutions for the number of CDM projects and whether they increase technology transfer by influencing the institutional framework for low-carbon technologies.

First, CDM institutions mostly do not have an impact on general investment conditions such as ownership, trade restrictions, or intellectual property right regimes. The technology-transfer content of CDM projects is thus subject to those more fundamental conditions. Second, an efficient and transparent domestic CDM framework is key for attracting CDM project development (Nondek and Niederberger, 2005). Besides the approval process, national institutions can improve the CDM conditions by other measures, such as developing regional baselines, which avoids a costly data collection process for project developers. One way in which CDM institutions, i.e., the designated national authority (DNA), can try to influence the technology-transfer content of CDM projects is by promoting it as an important criterion for domestic approval of CDM projects. As Seres (2007) points out, countries have taken very different approaches in this regard. Regarding the more specific framework for investments in low-carbon technologies, the CDM can partially compensate for a lack of national environmental regulations. One way in which the CDM could be combined with domestic policy efforts is to credit entire policies or reductions on a sector level under CDM in the future (Sterk and Wittneben, 2006).

3.2. *Dimensions of technology transfer in CDM*

3.2.1. *Distribution across geographies*

Research on the geographical distribution of CDM projects tries to shed light on, among other issues, why the CDM currently does not generate projects in the least developed countries but instead yields a project distribution highly concentrated in few countries such as China, India, Brazil and Mexico (Seres, 2007). First, some studies evaluate the attractiveness of countries for hosting CDM projects by analysing both the general and the CDM-specific institutional framework (Jung, 2006; Oleschak and Springer, 2007; Point Carbon, 2007). Second, the studies focusing on PDD evaluations of technology transfer also analyse host-country characteristics, although in varying detail (Dechezleprêtre et al., 2008; Haites et al., 2006; Pueyo Velasco, 2007; Seres, 2007). We combine both sets of studies to analyse differences in host countries' CDM activities, focusing first on project numbers and second on technology-transfer content.

In Table 3, we rank the number of CDM projects undertaken in a country using two different indicators of CDM attractiveness, the composite indicator (CI) by Oleschak et al. (2007) and the ratings by the largest market-information provider (Point Carbon, 2007). The rankings are similar in that they both assess CDM institutions and general economic conditions but differ as the latter also takes into account the GHG mitigation potential of the respective countries. Both rankings exhibit a strong correlation with the number of projects in the countries analysed by Pueyo Velasco (2007). The slight differences can be traced to the GHG mitigation potential, which increases the attractiveness of larger countries like Indonesia, although its CDM and general institutions are fairly weak.

Table 3
CDM attractiveness

Country	CDM projects[a]	CI[b]	Point carbon[c]
India	596	1	2
China	397	2	1
Brazil	221	3	5
Mexico	152	4	4
Malaysia	42	15	6
Chile	31	5	3
Thailand	28	12	16
Korea	28	13	9
Indonesia	21	57	11
S. Africa	17	8	8
Peru	16	26	7
Argentina	13	11	12
Vietnam	10	22	13
Morocco	5	6	10
Egypt	5	35	15
Total	1582	–	–

[a] Pueyo Velasco (2007).
[b] Oleschak and Springer (2007).
[c] Point Carbon (2007).

In Table 4, we rank the same countries in terms of the proportion of CDM projects containing technology transfer. The ranking is very different from the one in Table 3 and, at first sight, large differences exist between the countries with regard to how much technology transfer occurs in their CDM projects. However, when taking into account project characteristics and country as variables, Seres (2007) finds in two different statistical analyses that technology transfer is significantly encouraged only by Mexico, Thailand, Vietnam, Sri Lanka, Ecuador and Honduras, and deterred by India.

Additional insights can be gained by relating the CDM technology-transfer content to various country variables that might potentially impact technology transfer. For example, if the CDM technology-transfer content is compared with an FDI index prepared by UNCTAD (2007) consisting of both actual FDI performance and FDI potential, it appears that the relative share of international technology shows a slight relation with those more fundamental investment conditions. Similarly, Pueyo Velasco (2007) analyses FDI flows and finds that they can explain 78% of the variation across countries regarding the number of CDM projects containing technology transfer. However, when controlling also for project-level variables, Dechezleprêtre et al. (2008) find that the actual share of current FDI inflows in the GDP does not impact technology transfer in CDM projects but that pre-existing capital links via subsidiaries of multinational companies and an economy's openness measured via trade do. In addition to these factors, Dechezleprêtre et al. (2008) identify the level of local technological capability as another, albeit ambiguous, influential factor: On one hand, a high technological capability facilitates the adoption of new technologies while on the other hand, it might imply that many technologies are already available locally (Dechezleprêtre et al., 2008).

In conclusion, while the performance of CDM institutions impacts the number of CDM projects, the technology-transfer content of those projects is, rather, driven by a country's general institutional framework and its capability to adopt new technologies or even produce them domestically.

Table 4
CDM, technology transfer, and FDI

Country	TT (%)[a]	Projects with TT[a]	FDI index[b]
Egypt	100	5	Above potential
Mexico*	94	142	Below potential
Indonesia	86	18	Under-performer
Morocco	80	4	Above potential
Argentina	78	10	Below potential
Malaysia	70	29	Front-runner
Thailand*	65	18	Front-runner
Vietnam*	50	5	Above potential
China	49	195	Front-runner
Korea	46	13	Below potential
Peru	38	6	Under-performer
Brazil	33	72	Below potential
S. Africa	29	5	Under-performer
Chile	17	5	Front-runner
India*	7	44	Under-performer
Total	36 (avg.)	572	–

* Countries identified by Seres (2007) as having a statistically significant positive or negative transfer impact.
[a] Pueyo Velasco (2007).
[b] UNCTAD (2007).

3.2.2. *Distribution across technologies*

While the CDM has increased investments in low-carbon technology in general, differences remain among project types in terms of quantity of CDM projects. A relatively small number of projects focusing on reducing non-CO_2 GHGs dominate the pipeline in terms of expected CERs, whereas renewable energy, mainly wind and hydropower, and energy-efficiency projects dominate in terms of number. This distribution has changed over time because the potential for projects' for generating cheap emissions reductions through destruction of industrial gases seem to have been tapped to a large extent. With respect to the technology-transfer content, the three most detailed studies (Dechezleprêtre et al., 2008; Haites et al., 2006; Seres, 2007) find that the relative share of technology transfer contained in the projects varies widely among project types (Table 5). Although the studies analyse the pipeline of CDM projects at different points in time, the results are similar for all three. The slight difference between Seres (2007) and Haites et al. (2006) on the one and Dechezleprêtre et al. (2008) on the other hand is probably due to methodological differences: while the former search PDDs for a set of keywords, the latter study analyses reading the entire PDDs and thus identifying more technology transfer. All three studies consider technology transfer to occur if either equipment, knowledge or both are transferred.

For this variation in technology-transfer share among different project types, we suggest three explanations: first, the CDM impacts the commercial viability differently for various project types as a result of the differences in carbon value contribution

Table 5
Technology transfer in different CDM project types identified by left: Dechezleprêtre et al. (2008), center: Haites et al. (2006) right: Seres (2007)

Project type	Number of projects			Average project size (kt CO_2/y)			Projects with technology transfer: No. of projects in %			Projects with technology transfer: Expected CERs in %		
Agriculture[a]	104	91	170	43	53	44	70	81	94	n.a.	82	89
Biogas[a]	14	32	127	45	54	64	29	38	57	n.a.	57	58
Biomass energy	141	194	438	56	56	61	19	21	25	n.a.	38	44
Energy efficiency (Industry)	65	109	239	112	77	103	25	14	25	n.a.	18	45
Energy efficiency (own generation)	n.a.	n.a.	112	n.a.	n.a.	176	n.a.	n.a.	42	n.a.	n.a.	62
Fossil fuel switch	14	32	72	34	54	328	43	6	36	n.a.	8	77
HFC, N_2O, PFC	19	16	61	4147	4742	2047	100	87	95	n.a.	88	93
Hydro	112	145	500	50	61	81	22	15	9	n.a.	19	9
Landfill gas	51	74	170	279	252	202	80	65	67	n.a.	64	69
Solar	4	5	7	11	11	26	100	80	57	n.a.	99	30
Wind	80	99	260	84	72	81	63	41	57	n.a.	62	73
Others	40	57	137	190	198	329	35	25	31	n.a.	19	36
Total	644	854	2293	208	175	164	43	34	39	84	66	64

[a] Agriculture and biogas projects seem to have been classified differently by Dechezleprêtre et al. (2008) than by Haites et al. (2006) and Seres (2007).

(e.g., non-CO_2 projects like landfill gas and agriculture). Second, technologies exhibit varying degrees of sophistication and respond differently to the level of technological capability within the host countries. Results from Dechezleprêtre et al. (2008) confirm that a high technological capability favours transfers in the energy sector and in the chemical industry, while it has a negative impact on projects in agriculture. Third, international intermediaries reported in our interviews that end-of-pipe technologies such as methane recovery from wastewater exhibit a higher probability that international participants initiate the project idea and propose a technology. In contrast to projects in core processes such as energy efficiency, where local firms often know opportunities and local solution providers themselves, end-of-pipe projects have no value to the implementing firm except generating carbon revenues and thus have rarely caught firms' attention. This is supported by Dechezleprêtre et al. (2008) who find that the four different broad categories of projects, namely end-of-pipe, new unit, input switch, and change in the production process, exhibit different degrees of technology transfer: while end-of-pipe projects are most likely to involve technology transfer (69% of projects), changes in the production process are least likely to involve technology transfer (20%).

3.2.3. *Distribution across firms*

In contrast to the technology-transfer literature, the CDM literature has focused almost exclusively on project size instead of firm size when assessing technology transfer. Several studies indicate that project size strongly impacts the technology-transfer probability (Dechezleprêtre et al., 2008; Haites et al., 2006; Pueyo Velasco, 2007; Seres, 2007). Seres (2007) finds that 44% of large projects contain technology transfer whereas small-scale projects involve technology transfer in only 33% of the cases. The major reason is the decreased commercial viability due to CDM-specific and general transaction costs, which impact smaller projects more, even though transaction costs for small-scale projects have already been reduced (UNFCCC, 2001).

Second, to our knowledge, no study has analysed firm size or other firm characteristics as determinants for technology transfer under the CDM. Recent empirical research in the Indian pulp and paper industry suggests that mostly big firms are using the CDM. Furthermore, it seems that firms of different sizes pursue different types of CDM projects, which is likely to lead to differences in technology transfer (Hoffmann, 2007). Among other reasons, this might be due to varying endowments of capital, networks, and skills.

While the discussion above sheds some light on the recipients, it is equally interesting to analyse the influence of other firms participating in the transfer process. Dechezleprêtre et al. (2008) find that subsidiaries of companies from Annex I countries are likely to implement CDM projects involving technology transfer. Furthermore, the existence of a credit buyer, i.e. an entity from an Annex I country, also favours technology transfer. These findings support the hypothesis that deal structures relying on strong up-front capital links to Annex I entities increase the likelihood of technology transfer.

3.3. *Quality of technology transfer under CDM*

Regarding the *type of technology*, CDM projects focused in the beginning mainly on end-of-pipe non-CO_2 technologies, as for example HFC and N_2O destruction. PDD data suggests that such projects do not only transfer equipment but also involve significant amounts of knowledge transfer (Seres. 2007). However, the knowledge transfer indicated might have been overstated in order to improve the project's apparent contribution to sustainable development and thus facilitate registration (Dechezleprêtre et al., 2008). In addition, the technology content of such end-of-pipe projects is considered to be relatively low, as they are not situated in a firms' core production processes and often embody only a limited amount of technological know-how. In contrast, other technologies like renewable energy and energy-efficiency projects require the improvement of local skills and the diffusion of technical knowledge into the local economy and, consequently, thereby contribute much more to a recipient country's know-how.

In terms of the *deal structure*, CDM projects with equity or forward deals represent long-term investments, as CER generation might last up to 10 years after registration and realisation of the project. International CER buyers, mostly CDM project developers or private companies (Dechezleprêtre et al., 2008), often need the CERs with high certainty in order to deliver according to contracts signed with their clients or to comply with their regulatory or voluntary targets. Therefore, it is in their own interest to make sure that the project reliably delivers as many CERs as possible. International intermediaries reported in our interviews that they have an incentive to assist in the project design in order to optimise the project from the beginning, for example by suggesting a technology provider or proposing technical modifications to the project. Thus, whether or not international technology is used in the project, the design can be optimised through knowledge transfer at the start of the project. Furthermore, intermediaries stated that, in order to ensure that the projected amount of CERs is delivered over the long term, they establish implementation teams to monitor the project constantly. A side benefit of this monitoring assistance is that intermediaries become aware of operational problems and consequently can suggest modifications in technology or management of the project. This long-term collaborative quality management between international intermediaries and project hosts or local engineering companies may result in intensive knowledge exchange and network building that have the potential to enhance the innovative capabilities of host-country firms.

4. Conclusions

Our study confirms that the CDM contributes to technology transfer in terms of both equipment and know-how, and it demonstrates that CDM is currently the strongest mechanism for technology transfer under the UNFCCC. However, its performance varies considerably along the dimensions of geography, technology, and project size. Three key findings concerning the CDM's role in contributing to technology transfer emerged mainly from an assessment of the existing empirical literature under our framework and were supported in the expert interviews. We now discuss these key findings and make preliminary policy recommendations related to each.

First, the CDM increases the *commercial viability* of low-carbon technology transfer by setting a price on carbon. Therefore, a high and stable carbon price would be desirable for the future if technology transfer is to be increased under the CDM or a similar mechanism. To this end, policy-makers have to contemplate on the one hand emission-reduction targets for industrially advanced countries and their possible access to CDM credits and, on the other hand, how to reduce transaction costs of the mechanism, possibly by introducing sector-based approaches or similar measures. Second, the actors created as a result of the CDM reduce the barriers of *lacking information* and *access to capital*. With regard to further reducing the lack of information, the UNFCCC could improve the way data are generated and presented from the extensive number of projects. With a requirement for more information on the technological specification and the name of the technology supplier and/or technical project developer in the PDDs, as well as for information on key problems occurring during operation in the monitoring reports, a unique database could be created. If coupled with data on project performance in terms of issued versus projected CERs, this could serve as valuable information for private actors to reduce search costs for choosing the proper technology and its provider. Furthermore, it could serve as a basis for a better risk assessment of different technologies, thereby increasing access to capital. Such a database would also be valuable for policy-makers to continuously assess the CDM's technology-transfer performance and thereby identify capacity-building needs. Third, the CDM does not improve the *institutional framework* of receiving countries, which is considered vital to attracting international technology. Therefore, international and domestic policy-makers need to complement the CDM by fostering host-country-specific improvements in investment conditions for key technologies and not only rely on CDM.

In addition to the above results, we identified two further aspects regarding how common CDM *deal structures* increase the *quality* of technology transfer under CDM. Equity and forward deals with international intermediaries can trigger, first, assistance in project design and, second, long-term collaborative quality management, as long-term CER generation incentivises international intermediaries to assist in both the design phase and the operation phase. Therefore, it is crucial for the design of any future mechanism to maintain such incentives for long-term involvement of organisations that transfer knowledge, especially the private sector in industrialised countries. In order to further improve the quality of technology transfer under the CDM, one possibility would be to limit the eligibility to project types that potentially yield significant technological spillovers, such as renewable energy and energy efficiency, necessary for changing the development path of developing countries.

In order to give more detailed policy as well as business recommendations, more empirical research is needed to improve the data currently available. First, a detailed study of technologies and their differences should yield further insights into their respective commercial viabilities and the quality of technology transfer involved. It is especially interesting to analyse the financial sensitivity of different technologies towards parameters such as carbon price, baseline, electricity price and discount rate. Second, detailed analyses of country characteristics should identify country-specific variables responsible for the differences between countries in attracting technology through the CDM such as technology-related policies like feed-in laws. Third, another area for future research concerns the strategic behaviour of private actors. Besides the analysis of technology providers and recipients, research should be undertaken on intermediaries by first increasing the transparency of existing and newly created business models before proceeding to study their influence on the technology decision and the quality of technology transfer in more detail.

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