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The difference the CDM makes

An analysis of the impact of the clean development
mechanism on technological change in
non-Annex I countries

Joost van Putten

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Author: Joost van Putten, 1102273

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Graduation Committee:

Professor (chairman):

Prof. Dr. Ir. Margot P.C. Weijnen, department of Infrastructure Systems & Services (Dr. Ir. Paulien M. Herder, department of Infrastructure Systems & Service, section on Energy and Industry, will act on her behalf in case of absence)

1st supervisor:

Dr. Ir. Laurens J. de Vries, department of Infrastructure Systems & Service, section on Energy and Industry

2nd supervisor:

Dr. Mark L.C. de Bruijne, department of Multi Actor Systems, section on Policy, Organization, Law and Gaming

External supervisor:

Drs. Stefan J.A. Bakker, Researcher at ECN Policy Studies, International Energy & Climate Issues team

Preface

This research has been part of completing a master degree at the Delft University of Technology at the faculty of Technology, Policy and Management in the section, Energy and Industry. It was done in participation with ECN (Energy research Centre of the Netherlands) at the International Energy and Climate Issues research group, who kindly allowed me to do an internship with them.

Although previous years of study have prepared me for my final thesis, conducting research in the manner of my final thesis was challenging and new to me. With the help of many others, this project has proven to be a valuable learning experience. I feel like I have gained an improved understanding of the concept of science and have gained increased respect for science and those that perform it. I strongly believe in science as a means to progress our common humanity and I find dedication to progress an important aspect in finding fulfilment and meaning in life. Whether I could be a scientist is something I still don't know. Maybe I will have to find another way to contribute to progress. Luckily, as I have experienced during my years as a member of the Delft city council for STIP, there are many different ways to add meaning to society.

I would like to thank all my colleagues at ECN Policy Studies for their kindness and support. In particular I would like to thank Stefan Bakker for his dedication to his task as my external supervisor at ECN, Heleen de Coninck for her involvement as unit manager and my roommates Sylvia Breukers and Andrew Higham for their support and comments.

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Joost van Putten

Abstract

In the struggle to fight global warming development and diffusion of low carbon technology as a means of achieving technological change (TC) are crucial. The Clean Development Mechanism (CDM) has grown in recent years and currently involves over 4500 projects in non-Annex I (developing) countries. As such it has become an important global instrument to influence technological change.

This study focuses on measuring the impact of the CDM on TC in non-Annex I countries. It includes a framework on TC, a causal model illustrating the way CDM influences TC in non-Annex I countries and it includes a newly developed method to measure and study the impact of CDM on TC. This method was applied to case studies in three Indian sectors: electricity, iron and steel sector and the industry producing hydro fluorocarbons.

This study has made clear that CDM is having an impact on technology diffusion and, technology development. It concludes that the impact of CDM on technology diffusion can be substantial but that it differs greatly between countries and sectors. It also concludes that CDM projects can lead to learning, R&D, spillovers and economies of scale and thus contribute to technology development. It was also found that the impact of CDM on the national innovation system is complex and not well understood.

Keywords: Clean Development Mechanism, technological change, technology diffusion, technology development, sustainable development, international climate policy, technology transfer, clean technology diffusion.

Executive summary

The development of new technology and the global diffusion of state of the art existing technology play a key role in fighting global climate change. Technological change (TC) could greatly decrease the costs of GHG mitigation actions.

The Clean Development Mechanism (CDM) has grown significantly over the past years and has become an important international policy instrument. As of 2009 the CDM project portfolio contains over 4500 projects and the value of the CER market in 2007 was about \$8.4 billion USD leading to over \$45 billion USD in project investments and it is expected to grow in the coming years.

The CDM is therefore an important global instrument. However the effects of the CDM on technological change are not yet fully understood. Therefore this research sets out to develop a method and measure “the impact of the CDM on technological change”.

For this research a new method was developed including indicators for technology diffusion, technology development and the innovation system. The developed method proves to be a useful tool in studying the effect of CDM on technological change. Applying the method helps us improve our understanding of the relation between CDM and TC in non-Annex I countries and gives us results of the impact of CDM on TC in specific sectors.

The main conclusion from the analysis is that the impact of the CDM on TC in India is considerable although the impact differs between countries and between sectors within a country. This study found that the impact is not only a result of the diffusion of technologies but that CDM also plays a role in technology development (R&D, learning, spillover and economies of scale). The impact of the CDM on the national innovation system is still little understood.

In this study the following questions were used:

- What is technological change?
- How does CDM influence TC in non-Annex I countries?
- How could the impact of CDM on TC in non-Annex I countries be measured?
- What is the impact of CDM on TC in non-Annex I countries?

These questions contain the development of a method and the application of the method to case studies. This method includes a perspective on TC, a causal model depicting the way CDM influences TC in non-Annex I countries and the development of measurable indicators to measure the impact of CDM on TC in non-Annex I countries.

First I will summarize the method that was developed and secondly I will summarize the key findings that were derived from using this method in specific case studies.

The method

In this study technological change is defined a process as consisting of technology development, technology diffusion and the national innovation system (see Figure 1-1).

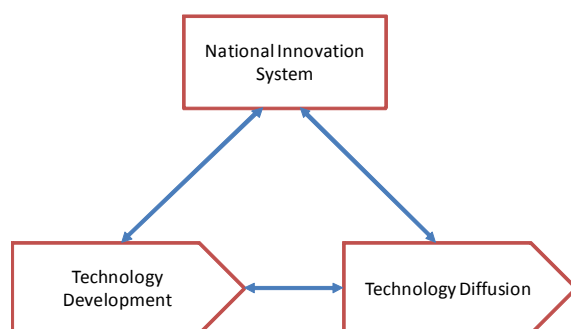


Figure 1-1 Schematic representation of the components of technological change

The national innovation system is the complete set of institutions influencing the speed and direction of technological change. Technology development is the process of improving quality and decreasing cost of technologies. Technology development is assumed to be derived from four sources: R&D, learning, spillover and economies of scale. Technology diffusion is the application of a technology in society and only through diffusion does technology affect the total production function of a society. These three aspects of technological change influence each other.

Based on the theory of technological change and a theoretical understanding of the CDM, I propose a causal model that aims to explain the way CDM might impacts technological change in non-Annex I countries (see Figure 1-2). Measuring, proving and quantifying these assumed relations is the subject of further analysis within this research.

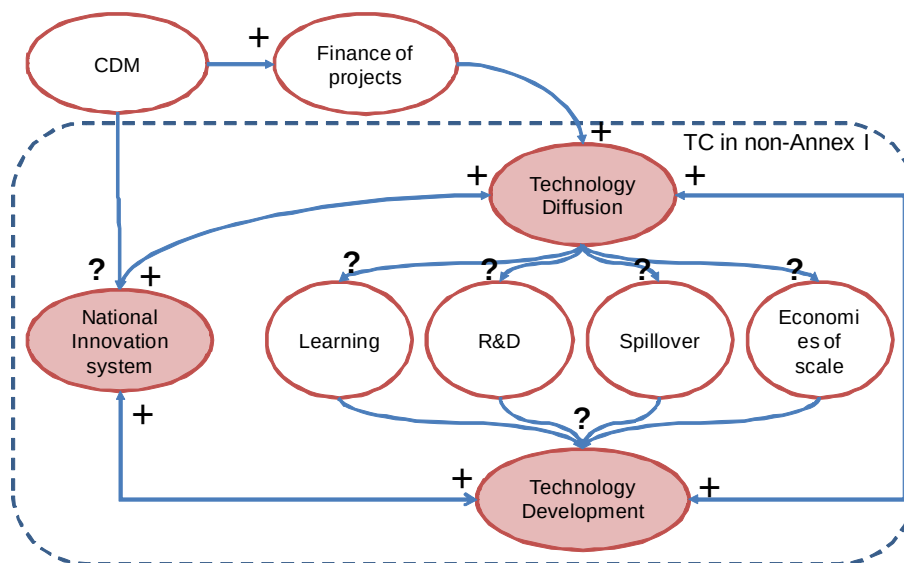


Figure 1-2 Causal relation between CDM and TC in non-Annex I countries

CDM first of all creates a financial incentive to diffuse technologies; however there is still a knowledge gap with respect to the way to measure this impact. Secondly it is expected that the diffusion of technologies under CDM will benefit R&D, learning, spillover and economies of scale in non-Annex I countries by which CDM could contribute to technology development. This relation is however still poorly studied. Thirdly the CDM is a global policy and literature suggests that it might also influence national innovation systems. However the latter has not been empirically confirmed.

Because this research is first of its kind it includes a new method to measure TC. The method includes indicators for technology diffusion, technology development and changes in the national innovation system and uses data from the CDM pipeline, national GHG emission data, PDDs and other freely available sources. The method was applied to three Indian case studies: the electricity sector, the iron and steel sector and HFC producing industries. The method has proven to be useful in studying the effect of CDM on technological change.

With respect to technology diffusion at a country and sector level I took the relation between historical GHG emissions and generated CERs as an indication of technology diffusion through the CDM. On the level of specific technologies different indicators (such as installed capacity in MW) are used.

To measure whether CDM projects led to technology development 20 PDDs were analysed. This included 6 PDDs about wind power projects, 7 PDDs on project in the iron and steel sector

and 7 PDDs on HFC mitigation. In this text analysis PDDs were screened for indicators of learning, R&D, spillover and economies of scale.

With respect to the impact of CDM on the national innovation system this research combined text analysis of PDDs with theory, literature and technology diffusion findings to improve our understanding of the impact of CDM on the national innovation system.

The results

An assessment of the CERs produced per country relative to the GHG emissions of each country indicates that CDM has a different diffusion impact on different countries (see Figure 1-3).

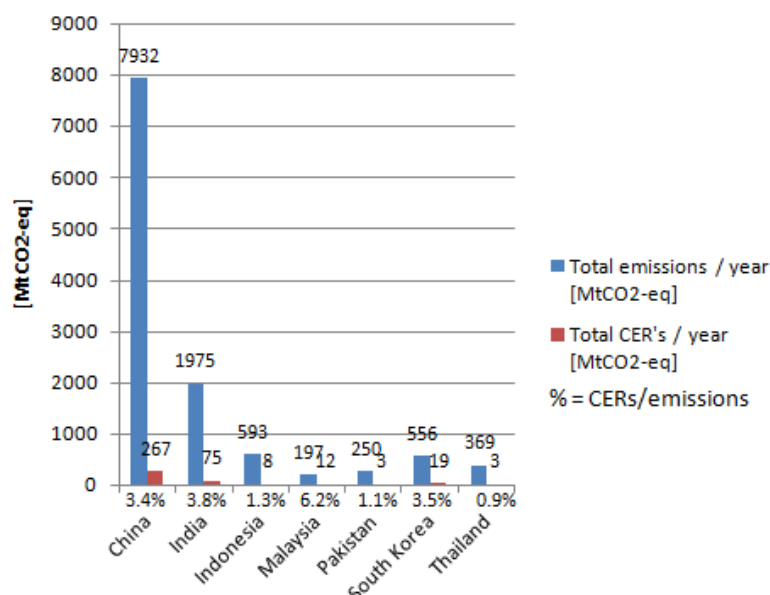


Figure 1-3 Impact CDM on total historical emissions in Asia

An assessment of the CERs produced in India on a sector level relative to the GHG emissions in 2005 of each sector (this data was not available and had to be constructed from different data sources) indicates that CDM has a different diffusion impact on different sectors within India (see Figure 1-4).

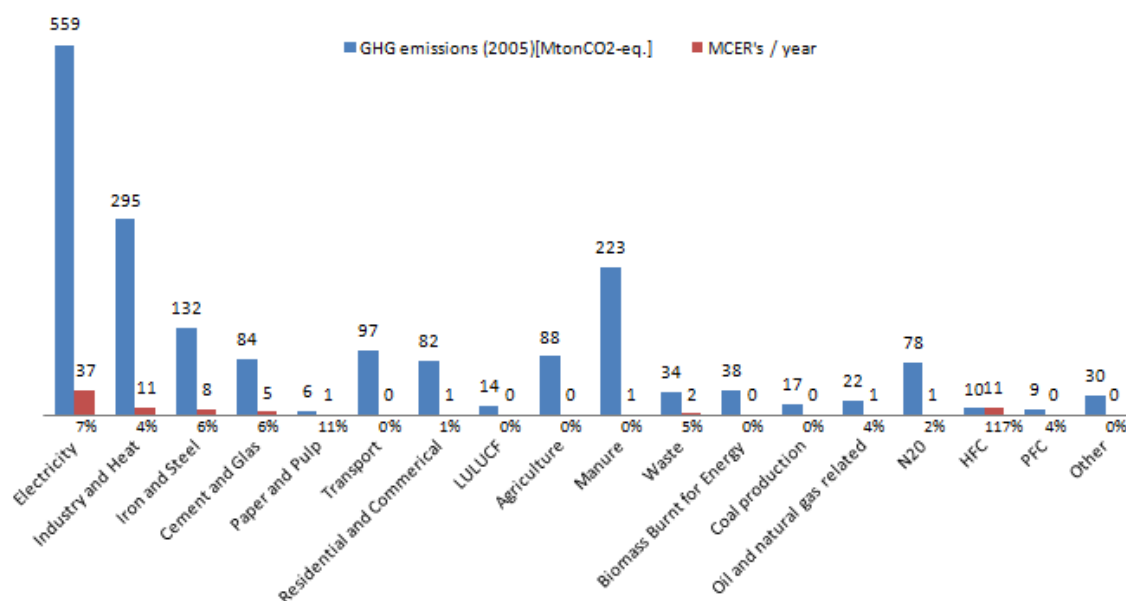


Figure 1-4 Impact assessment of CDM induced technology diffusion in India on a sector level

Within the electricity, the industry and heat, iron and steel, cement and glass, paper and pulp, waste, oil and natural gas related, HFC and PFC sectors of India, CDM had a considerable impact on technology diffusion. In the transport, residential and commercial, LULUCF, Agriculture, manure, biomass burnt for energy, coal production and N₂O producing sectors of India, CDM had no or little impact.

Apart from looking at technology diffusion by relating GHGs to the CERs per sector, this study also took a closer look into the role of CDM within specific sectors.

In the electricity sector it was found that CDM has a considerable impact on the national target for additional electricity capacity. Figure 1-5 shows that 20GW of additional capacity is planned to be installed in India using co-finance from CDM. This equals to 20% of the total planned additional capacity by 2012. Over 4 GW of this capacity is derived from wind power (see Figure 1-6).

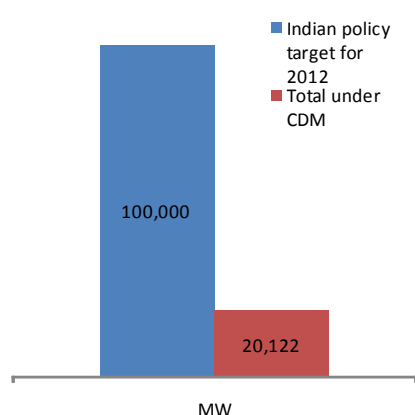


Figure 1-5 Contribution of CDM to India's additional national electricity ambition

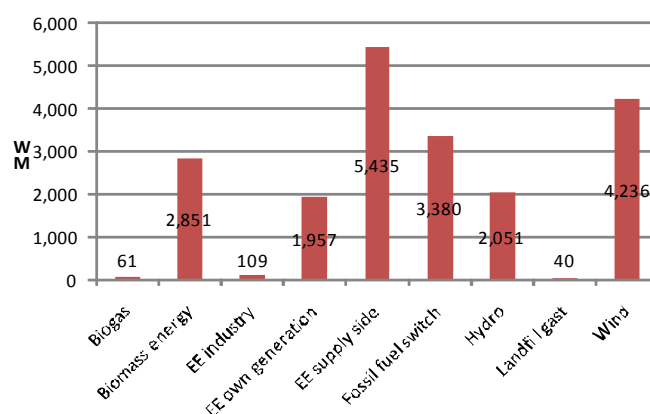


Figure 1-6 Different categories in which capacity is installed

An assessment of the total amount of wind power that was installed using co-finance through CDM relative to the total amount of wind power installed in India indicates that CDM co-financed over 40% of the total installed capacity in India, that in 2008 up to 100% of all new projects are co-financed using CDM and that between 2004 and 2007 over 4 GW of wind power was installed without using CDM as a means of co-finance (see Figure 1-7).

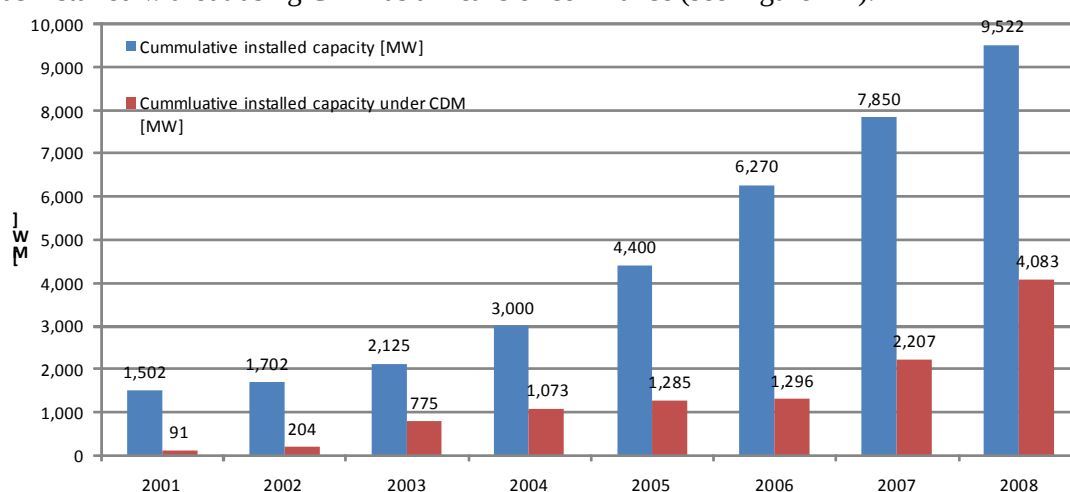


Figure 1-7 Cumulative total installed capacity and cumulative development under CDM (see Appendix I)

The CDM has a considerable impact on technology diffusion in India, but the impact differs greatly between sectors. In 2006 India emitted an estimated 1,975Mt CO₂-eq while technology diffusion by the CDM mitigated 75 Mt CO₂-eq (3.8%) measured in CERs.

An estimated 11M CERs/yr is mitigated from HFC emitting industries which equals about 100% of the sector's 2006 production (mainly due to HFC-23 destruction), the 37M CERs/yr from the electricity sector equal about 7% of the sector's 2006 emissions and the 8M CERs/yr in the iron and steel sector equal about 6% of the sector's 2006 emissions. However in other sectors such as the transport, residential & commercial and manure sectors the CDM has had almost no impact.

It is found that CDM does not only impact technology diffusion but that CDM projects may also benefit technology development. Within this research, technology development is a result of learning, R&D, spillover and economies of scale.

In the iron and steel sector the assessment indicates that CDM projects impact technology development through stimulating a combination of learning, R&D and spillover. In the electricity sector it was found that CDM aided the market expansion of domestic wind turbine manufacturers. In the HFC producing industries it was found that CDM contributed mainly to technology transfer of HFC-23 destruction technology from Europe. In the first two CDM projects using different HFC mitigation technologies CDM contributed to a combination of learning, R&D and spillover.

The method proved to be unsuitable to study the impact of CDM on the national innovation system. Different indicators of changes in the NIS and different data sources to measure these indicators will have to be used in future research.

Although literature suggests that CDM may create a perverse incentive to non-Annex I countries to take on stringent environmental policy there remains no empirical research to confirm this occurrence.

The technology diffusion data from this research does however suggest that India used to develop wind turbines without CDM co-finance from 2004-2007, but that by 2008 India has learned to use CDM in addition to domestic support in all new wind turbine projects.

The main conclusion from this research is that the CDM can have a considerable impact on TC in non-Annex I countries. The impact is primarily the result of technology diffusion; however the CDM also appears to positively influence technology development. The impact on the national innovation system is important but remains little understood.

Recommendations

About the method and its application in future research I recommend a number of improvements. This study is limited in the number of countries that were looked at and in the number of PDDs that were studied. Also the method proved to be unsuitable for studying changes in the national innovation system.

Therefore future research could apply technology diffusion analysis to a larger number of countries and increase the effort with respect to looking for explanations in the differences between sectors and countries.

With respect to measuring technology development I recommend refining the indicators and applying them to a larger number of PDDs. Due to the biased nature of PDDs I also recommend field visits to get more balanced data. These measures are needed to increase validity and improve our understanding of the causality between CDM projects and technology development.

With respect to the changes in the national innovation system I recommend using different indicators and data sources, for instance interviews with stakeholders. The current method is unsuitable and therefore a creative new approach is needed.

These recommendations aim to move the research field a step ahead. Whilst this research set a first step in measuring TC, follow up research could increasingly focus on finding explanations

for the measured differences, using these explanations to build theory and applying theory to design future policy interventions.

With respect to policy I recommend the members of the UNFCCC to consider the sectors in which CDM has had little or no impact on technology diffusion. Technology diffusion in these sectors may be achieved by either considering different (new) mechanisms apart from CDM or by improving the effectiveness of the CDM.

I also propose the idea that CDM could be used as a mechanism to stimulate the development and demonstration of innovative new technologies. This is in same line of thought with Ghana's proposal "on options for effective mechanisms and enhanced means for technology development and transfer" which includes the idea to credit "technology development, deployment, diffusion and transfer".

This could be done by awarding additional credits to CDM projects with specific technology development benefits. Awarding credits through a market based instrument could be a politically acceptable tool to secure part of the large amount of finance that is needed for low carbon technology development.

The CDM executive board could manage a list of technologies that are in need of development and demonstration assistance and changes to this list could be proposed by governments, civil society, industry representatives and the scientific community.

I also propose a new policy idea that creates a positive incentive for non-Annex I governments to install more stringent environmental policy. I propose to do this by allowing a time lag of five years between the moment new national (non-Annex I) policies are put in place and the moment these policies need to be considered in the additionality check of CDM projects. This time lag would give non-Annex I companies five years to comply with local regulation by using co-finance from CDM.

This removes the negative incentive that prohibits governments of non-Annex I countries to adopt progressive environmental policy. In return it actually gives governments the means to stimulate and encourage the diffusion of technologies under CDM. It gives them the possibility to govern and stimulate the use of CDM within their country without being negatively rewarded for doing so.

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Abbreviations

AIJ	Activities Applied Jointly
ACM	Approved Consolidated Methodology (consolidation of AMs)
AM	Approved Methodology
AMS-I	Approved Methodology Small-scale type I
BAU	Business as usual
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CCS	Carbon Capture and Storage
CER	Certified Emission Reduction (a credit derived through the CDM)
CDM	Clean Development Mechanism
COP/MOP	Conference of the Parties serving as the Meeting of the Parties
CT	Clean Technologies
DRI	Direct Reduced Iron (also called Sponge Iron)
EAF	Electric Arc Furnace
GEF	Global Environmental Facility
GoI	Government of India
GWP	Global Warming Potential
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IS	Innovation System
kgoe	kg oil equivalent
LbD	Learning-by-doing
LoI	Letter of Intent
LCT	Low Carbon Technologies
LULUCF	Land Use, Land Use Change and Forestry
NAMA	Nationally Appropriate Mitigation Action
NIS	National Innovation Systems
NSP	National Steel Policy
ODA	Official Development Aid
PUF	poly urethane foam
SC	Socio Change
SD	Sustainable Development
STC	Socio-Technical Change
TC	Technological Change
TCp	Technological Capabilities
TT	Technology Transfer
UNFCCC	United Nations Framework Convention on Climate Change
HFC	Hydrofluorocarbons

1. Introduction

This research is about the impact of the Clean Development Mechanism (CDM) on technological change (TC) in non-Annex I countries. In order to understand the importance of this research it is necessary to have some understanding of both concepts and their relation.

This research starts with the premise that there is worldwide need for TC (IPCC, 2007). This notion is strongly rooted in the current debate about climate change and energy security. Fossil fuel resources are being depleted and are becoming more expensive and there are strong indications that global warming is to a large extent human induced, i.e. caused by greenhouse gas emissions.

In order to fight climate change and at the same time allow sustainable economic growth we particularly need to change the way we organize our energy production and consumption. We need to change our behaviour and we need to change the technology that we are using.

To achieve both energy and climate security we can no longer keep depending on increasingly scarce and increasingly expensive fossil fuels alone. Our society needs to come up with new sustainable technologies that can replace unsustainable technologies, we need to start utilizing these technologies and we need to bring down the costs of these technologies. In other words we need technological change in our energy system.

Climate change and energy security are worldwide problems. We cannot solve these problems if TC occurs only in industrialized countries. We need to further develop technologies and diffuse them to both the developed and the developing world. The diffusion of technology to developing countries is of great importance in the context of the huge increase in energy use of developing countries that is bound to happen in the coming years. Not installing the best available environmental technologies while these economies are expanding rapidly would greatly increase greenhouse gas emissions in the coming decades and decrease our abilities to fight dangerous climate change.

The CDM has been designed under the Kyoto Protocol, which established emission reduction target for industrialized countries. It allows industrialized countries (Annex I countries) to comply with their reduction targets by participating in emission reduction projects in developing countries (non-Annex I countries). Reduction of emissions is often cheaper in developing countries, thus creating an incentive to participate in these kinds of projects. Apart from cost effective greenhouse gas reduction, the CDM rules prescribe that projects should contribute to sustainable development in the host countries.

Within the Kyoto protocol the CDM is the main mechanism capable of influencing TC in non-Annex I countries. Since its introduction the CDM has grown considerably. As of 2009 over 4500 projects are in the pipeline and over 1400 have been registered (UNEP/Risø, 2009).

The first commitment period of the Kyoto protocol ends in 2012 and it is unknown what will happen afterwards. In 2007 in Bali nations agreed on a roadmap to come up with a new climate agreement in Copenhagen 2009 (UNFCCC, 2008c). The concept of achieving global cooperation on technology issues is to be an important part of a new agreement.

As the CDM has so far been the most important mechanism under the Kyoto protocol to influence investment toward developing countries and since diffusion of technology towards developing countries is an important element of TC, it can be expected that CDM will be included into the discussion on stimulating TC. Nevertheless it was never studied what the real impact of the CDM on TC has been so far. Most research focused at the transaction costs of the CDM process and the amount of technology transfer (TT) that takes place under the CDM. This research aims to contribute to filling this research gap and aims to interpret the results to allow for policy conclusions and recommendations.

1.1 Research problem

The CDM is a relatively young instrument and although a lot of research has been done on CDM (595 research articles were found using this keyword on Scopus) there is still a lot unknown or disputed about the efficiency and effectiveness of CDM (McCully, 2008; Wara et al., 2008). In particular the impact of CDM on TC as a whole in non-Annex I countries has not yet been studied before.

Therefore the main research objective is to develop a method to measure the impact of CDM on TC in non-Annex I countries and apply this method in a number of case studies. Developing this method will involve defining the concept of TC and drawing up a preliminary causal model explaining the relation between CDM and TC. It will also include identifying suitable data sources and developing measurable indicators of TC.

The application of the method could improve our understanding of the impact of CDM on TC in non-Annex I countries, help to direct future research and lead to policy recommendations.

Current literature on both CDM and on TC will serve as a starting point to build upon in this research. There is already extensive research on both fields separately. This study can build upon previous studies into the CDM, among others: studies into the effect of the CDM on technology transfer (Coninck et al., 2007a; Dechezleprêtre et al., 2008), studies about the contribution of CDM to sustainable development (IOB, 2008), specific case studies into CDM governance structures (Benecke, 2008).

This study will also build on literature on TC, among others: studies into the effects of environmental regulation (policy) on TC (Jaffe et al., 2002; Yarime, 2003; Goulder, 2004), studies about the modelling of TC (Zwaan et al., 2002; Goulder, 2004) and studies into the economics of technological change (Stoneman, 1983) and the diffusion of innovations (Rogers, 2003).

There is a need for more studies into the TC in developing countries (Gonzales 2008p867) and also for empirical studies into the impact of policy on TC (Jaffe et al., 2002).

1.1.1 Initial exploration of the concept of technological change

Technological change finds its complexity in its definition, the context in which it is used and the difficulty to measure it. After reading about the concept of TC, I found that a good introduction into the concept is given by Jaffe (2002), who based his text on Joseph Schumpeter (1942):

“Economic theories of the process of technological change can be traced to the ideas of Josef Schumpeter (1942), who distinguished three stages in the process by which a new, superior technology permeates the marketplace. Invention constitutes the first development of a scientifically or technically new product or process. Inventions may be patented, though many are not. Either way, most inventions never actually develop into an innovation, which is accomplished only when the new product or process is commercialized, that is, made available on the market. A firm can innovate without ever inventing, if it identifies a previously existing technical idea that was never commercialized, and brings a product or process based on that idea to market. The invention and innovation stages are carried out primarily in private firms through a process that is broadly characterized as “research and development” (R&D). Finally, a successful innovation gradually comes to be widely available for use in relevant applications through adoption by firms or individuals, a process labelled diffusion. The cumulative economic or environmental impact of new technology results from all three of these stages, which we refer to collectively as the process of technological change” (Jaffe et al., 2002p2).

A shorter definition is given by Pan et al (2006p751), who describes technological change simply as: *“a process of phasing-out old and phasing in new technologies”.*

I will use the above as a starting point to develop an understanding of TC and eventually to understand the relation between the CDM and TC.

1.2 Scope of this research

This study investigates the effect of CDM on TC in non-Annex I countries. How this mechanism influences the process of TC in Annex I countries would also be an interesting topic of study but is beyond the scope of this research.

This research focuses on the development of a method to measure the impact of the CDM on TC in non-Annex I countries. This is a necessity since the development of the method is a precondition to be able to actually execute large scale measurement of the impact of CDM on TC.

The application of the method is limited to a number of case studies. These case studies could help us improve the developed method and give a first impression of the impact of CDM on TC in a specific non-Annex I country. It is possible that the results of the case studies can be generalized (taking into account the limitation of inductive reasoning) to say something about the general impact of CDM on TC.

1.3 Research questions, research methods and data requirements

The main research question of this thesis is:

What is the impact of the Clean Development Mechanism on technological change?

In order to answer this question a number of sub questions need to be answered. I will discuss each of the sub questions and discuss the method that I propose to answer each sub question and the data that will be needed to answer each sub question.

1. What is the CDM?

The CDM is a complex instrument and it is essential to give a good explanation of the mechanism. This is not really a research question but due to the importance of explaining the CDM I will treat it as a research question.

This would include answers to questions such as: What are the goals of CDM? What is the history of CDM and what are its future prospects? What criticism does CDM get? How does the CDM market develop? What is the regional distribution of CDM projects?

Research method:	Literature study.
Data requirement:	Literature about the CDM.
Data sources:	Books, reports and journal articles (e.g.: UNFCCC website, Scientific databases (Scopus) through DUT library and books in the DUT library).

2. What is technological change?

This question is needed to improve our understanding of the concept of TC and to develop a useful definition of the concept that can be used in the following chapters.

Research method:	Literature study.
Data requirement:	Literature about the TC.
Data sources:	Books, reports and journal articles (e.g.: Scientific databases (Scopus) through DUT library and books in the DUT library).

3. What is the causal relation between CDM and TC in non-Annex I countries?

I will draw on theory on both CDM and TC to develop a causal model that illustrates the way CDM could influence TC in non-Annex I countries. This is needed to get a preliminary theoretical model of the relation between CDM and TC which can later be used to direct the development of indicators.

Research method:	Literature study.
Data requirement:	Literature on the CDM and on TC.
Data sources:	Books, reports and journal articles (e.g.: Scientific databases (Scopus) through DUT library and books in the DUT library).

4. How can the impact of CDM on TC in non Annex I countries be measured?

The preceding research questions will lead to the development of a perspective on TC and causal model illustrating the way CDM could impact TC non-Annex I countries. This question aims to identify possible data sources and develop indicators to measure the impact of CDM on TC.

This is likely to be challenging. Technological change is a concept that is difficult to measure. "Technological change is a phenomenon of development ... which is only traceable in its effects as a drop in its stream (Schumpeter, 1934)".

Research method:	Literature study and a brainstorm with the international policy analysis team of ECN.
Data requirement:	Literature.
Data sources:	Books, reports and journal articles (e.g.: Scientific databases (Scopus) through DUT library and books in the DUT library).

5. What is the impact of CDM on TC in non Annex I countries?

This research aims to apply the method developed under the previous question to a limited number of case studies. The application of the method will be used to test the method and to draw conclusions upon the impact of the CDM on TC in the cases studied. It is possible that some findings could be generalized to say something about the impact of CDMs on TC in non-Annex I countries in general.

Research method:	Desk research and data analysis (exact research method will depend on the outcome of the method developed in sub research question 4).
Data requirements:	e.g. Data about emission levels and projections in non-Annex I countries and specific sectors, emission reduction potentials and data about the specific characteristics of CDM projects.
Data sources:	e.g. UNEP RISOE pipeline database (includes aggregate data on all CDM projects), PDDs (each CDM project is required to write a detailed project development document containing all details about the project), Technology Needs Assessments by GEF or stakeholders from specific projects, country specific CDM potential analysis (e.g. (Adhikari et al., 2008)). IPCC, Energy Technology Perspectives, Vattenfall cost curves.

6. What can we learn from this research?

After an analysis has been conducted of a limited number of cases we may be able to draw conclusions and recommendations.

First of all we can draw key findings with respect to the applicability of the newly developed methodology. Secondly we can draw key findings with respect to the impact of CDM on TC in the specific cases that were studied. Possibly some case study findings can be generalized to say something about the general impact of CDM on TC in non-Annex I countries.

Research method:	Interpretation of results by the analyst.
Data requirements:	Data on the impact of CDM on TC in non-Annex I countries.
Data sources:	The data derived from this research in combination with discussions about the findings with experts at ECN.

1.4 Outline of the Thesis

The outline of this thesis will follow the order of the above mentioned sub questions. Chapter 2 will introduce the Clean Development Mechanism and chapter 3 will define the concept of TC. In chapter 4 the causal model of the relation between the CDM and TC in non-Annex I countries will be presented. In chapter 5 the method to study the impact of CDM on TC in non-Annex I countries will be completed with the identification of data sources and the development of indicators. In chapter 6 I will present the findings of the application of the method to a number of case studies. The results will be discussed in chapter 7 followed by conclusions and recommendations in chapter 8.

2. The Clean Development Mechanism

In 1997 the United Nations Framework Convention on Climate Change (UNFCCC) agreed on the Kyoto protocol, under which the CDM has been designed. The Kyoto protocol aims at “stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (in accordance with article 2 of the UNFCCC).

In order to achieve this goal Annex I countries (participating industrialized countries) are bound to maximum allowed emissions per year in the period 2008-2012 (emission caps). Emission reduction to (below) the maximum level allowed by the cap can be achieved in two ways: by achieving a real reduction of GHG emission domestically or by using one of three flexibility mechanisms:

- *Emission trading (article 17 of the Kyoto protocol)*: Allows Annex I countries to trade their assigned emission rights (from Annex I government to Annex I government).
- *Clean development mechanism (article 12 of the Kyoto protocol)*: Allows Annex I countries to undertake emission reduction projects in non-Annex I countries (developing countries) and use the emission reduction achieved by these projects to comply with their own national targets. The emission reductions achieved under CDM are named and traded as Certified Emission Reductions (CERs).
- *Joint Implementation (article 6 of the Kyoto protocol)*: Allows Annex I countries to undertake emission reduction projects in other Annex I countries and use the emission reduction achieved by these projects to comply with their own national targets.

2.1 The Goals of CDM

The CDM serves a dual purpose (*article 12 of the Kyoto protocol*): to assist non-Annex I countries in achieving sustainable development; and to assist Annex I countries in achieving compliance with their quantified emission targets; and in doing so, it has to contribute to the ultimate objective of the UNFCCC, i.e. preventing dangerous human interference with global climate system by reducing global GHG emissions.

Non-Annex I countries may offer cheaper GHG abatement opportunities than Annex I countries. This creates a strong financial incentive for Annex I countries to buy CERs to comply with emission reduction targets.

At the same time the criteria of sustainable development are weakly embedded in the CDM. This is because the criteria are to be determined by the host nation and host nations do not seem to have a real incentive to be strict on sustainability criteria (Sutter et al., 2007). The CDM has thus evolved towards having a strong focus on cost effective GHG reduction. In practice the goal of achieving sustainability can better be seen as an “add-on”. Interesting in this respect is Tinbergen (1960), who said that a government should have only one policy goal per policy measure.

2.2 History

In 1990 the International Panel on Climate Change (IPCC) released its first assessment report on climate change. The IPCC had been founded by the World Meteorological Organization and United Nations Environmental Programme (UNEP) to supply decision makers with objective information about climate change.

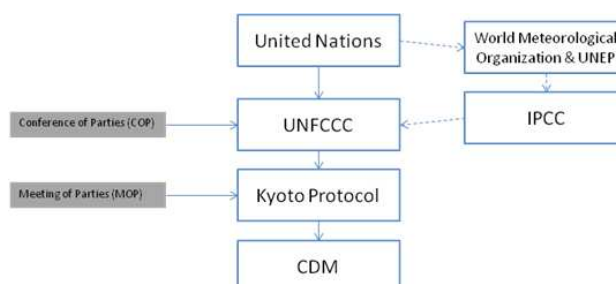


Figure 2-1 Organizational diagram

Its findings were distressing. It led to the founding of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, whose goal it is to stabilize the GHG in the atmosphere in order to prevent “prevent dangerous anthropogenic interference with the climate system” (article 2 of UNFCCC). The Kyoto protocol falls under the UNFCCC and CDM is part of the Kyoto protocol (see Figure 2-1). Official meeting of the UNFCCC are called COP and those about the Kyoto protocol are called MOP. Since the ratification of the Kyoto protocol both meetings are held at the same time (which is often referred to as COP/MOP).

CDM was included in the Kyoto protocol partly because of an initiative of the Brazilian government and other developing countries. It was the result of a complex negotiation. Important elements in the negotiations were: The interest of developing countries to attract foreign investments and the fear that developed countries might evade their obligations (Jotzo et al., 2002; Wright, 2007). In years that followed the details of the CDM were specified, especially during the Marrakesh negotiations in 2001. After the Marrakesh conference, in 2001, the Executive Board (EB) of the CDM started with provisional operations. With the Russian ratification the Kyoto protocol (aims to reduce greenhouse gases in Annex I countries by 5.2% within the period of 2008-2012) came into force on the 16th of February 2005. At the same date the first CDM project was officially registered.

2.3 Baseline and Additionality

The core concepts behind CDM are the baseline emissions and the concept of additionality. A project is additional if: “anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity” (as defined by COP/MOP). The base line is what would have happened if the CDM project would not have been undertaken.

To determine if a project is additional a business as usual scenario (BAU) has to be made, which describes the most likely scenario that would have happened without the CDM project. E.g. if the CDM would not have been there, electricity would be produced by a coal-fired power station rather than a hydro power plant. First of all the project must result in lower greenhouse gas emissions than the BAU. Secondly the project should not have happened in the absence of CDM, i.e. it should be ‘additional’.

Additionality can be proven on the bases of either an investment analysis, barrier analysis or common practice analysis (CDM EB, 2009). Determining additionality can be problematic and has led to much debate about the usefulness of CDM (see section 2.6).

2.4 The CDM Project Cycle

This section will introduce the key institutions that are relevant for project participants that are aiming to develop a CDM project. Secondly it will describe the CDM project cycle, which describes all the necessary steps to take in order to develop a CDM project and receive credits for it.

2.4.1 Key institutions

Executive Board

The Executive Board (EB) is responsible for the issuance of the CERs. They have to make sure that all credits that are issued were derived according to the right rules and procedures. This also gives them a (political) responsibility to protect the integrity of the CDM. The dilemma they face is that too easily issued CER’s might lead to credits issued that do not represent an actual emission reduction. At the same time, too strict of a stance to the issuance of CER’s might make it very difficult for market parties to participate in CDM projects.

The members of the board are appointed by the UNFCCC Conference of Parties (COP).

Designated National Authorities

Every country that participates within the Kyoto Protocol has to designate a Designated National Authority (DNA). Both the DNA of the host and Annex I country have to approve the CDM project. A DNA can set rules about what they desire within a project, for instance in relation to its contribution to sustainable development or about taxation of projects.

Designated Operational Entity

A Designated Operational Entity (DOE) is an independent third party (a company) accredited by the EB. The DOE is responsible for the Validation, Verification and Certification of projects. The DOE is hired and paid for by the project developer. The latter creates an incentive to approve and be less critical about the project they have to review.

2.4.2 The CDM Project Cycle

The CDM project cycle can be divided in a development phase (before the actual operation of the project) and the implementation phase (during the actual operation of the project) (see Figure 2-2) (this text is based on (Mizuno, 2008)).

Preparation

Prior to the preparation of a Product Design Document (PDD), the project developer informs the host country's DNA of its intentions to develop a project. This is done through a Project Idea Note (PIN) and is optional. If the DNA accepts the proposal a Letter of Intention (LoI) is signed that sets the local conditions for developing the project.

The main document that a project developer has to write is the PDD. A PDD should contain information about the project activity, the baseline methodology, the monitoring methodology, the crediting period and stakeholder comments.

Approval

The PDD has to be approved by the host DNA.

Validation and registration

The project developer chooses a DOE which has to validate the PDD. This includes checking if the PDD is correct and allowing public comment on the PDD. After the DOE decides to validate the project, a request for registration is filed with the EB.

Monitoring

Monitoring occurs after the project becomes operational. The project operator has to monitor the project GHG emissions in accordance with the monitoring plan as written down in the PDD.

Verification and Certification

Verification is an independent ex-post evaluation, performed by a DOE, of the monitored GHG reduction by the project operator. Certification is the written assurance by a DOE that a project activity achieved the reductions in GHG emissions as verified.

Issuance of CER's

After the DOE certified the GHG reduction the EB issues the CER's in accordance with the DOE findings.

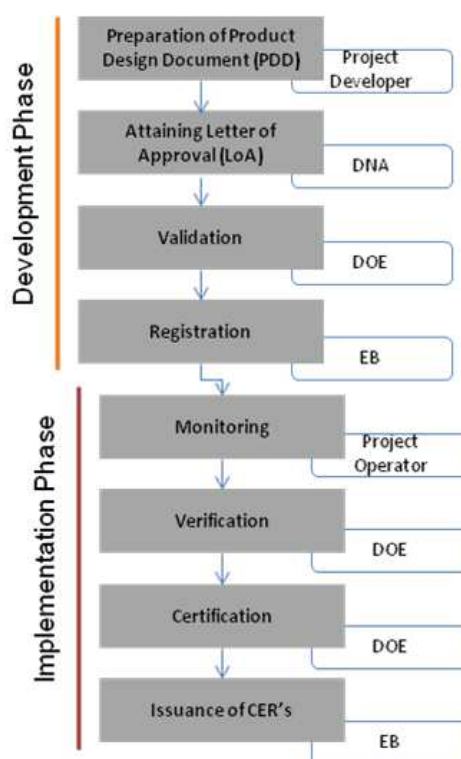


Figure 2-2 CDM project cycle (Mizuno, 2008)

2.5 CDM developments

The CDM developed more rapidly than initially expected. As of September 2008 there are 3819 CDM projects in the pipeline, of which 1152 projects have been registered by the EB, 200 are in the process of registration and 2457 are at validation stage.

The total number of available credits for the period of 2008-2012 is predicted to be about 300 million a year and this number is expected to increase to over 700 million credits per year for the period of 2013-2020 (UNEP Riso, 2008). To put this into perspective; the total CO₂-equivalent emissions of the Netherlands is just over 200 million tonnes per year.

Figure 2-3 and Figure 2-4 give an overview of the different CDM projects that are being developed and the expected CER's that will be generated because from them.

HFC & N ₂ O reduction	95	HFCs + PFCs + SF ₆ + N ₂ O
Renewables	2388	Biogas + biomass energy + geothermal + hydro + solar + tidal + wind
CH ₄ reduction & Cement & Coal mine/bed	583	Agriculture + cement + coal bed/mine + fugitive + landfill gas +
Supply-side EE	403	EE supply side+ EE own generation+Energy distribution
Fuel switch	129	Fossil fuel switch
Demand-side EE	186	EE households+EE industry+ EE service
Afforestation & Reforestation	27	Afforestation + reforestation
Transport	7	More efficient transport, biofuels are under biomass energy

Figure 2-3 Categorization of CDM projects (UNEP Riso, 2008)

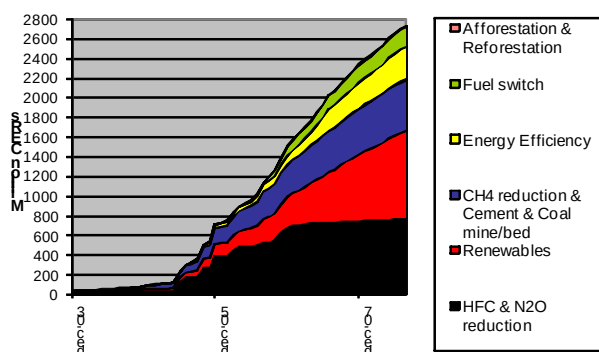


Figure 2-4 Growth of total expected accumulated 2012 CERs (UNEP Riso, 2008)

Most projects fall within the category “renewables”. Nevertheless Figure 2-4 illustrates that despite the large number of projects within “renewables”; these projects generate relatively fewer CERs than CH₄ or HFC reduction projects.

A relative small number of HFC-23 destruction projects and N₂O projects have been undertaken at the beginning of the CDM. These projects generated large amounts of credits (HFC-23 gasses have a 12,000 times stronger climate impact than CO₂) and big profits while requiring only small investments.

In the last years the number of renewables projects increased more rapidly (see Figure 2-4). Also the number of small scale projects increased. Boyd (2007) states that the number of small scale projects is about equal to the number of large scale projects. This is surprising since small scale projects were predicted to be ill favoured by investors because of the increased influence of transaction costs. Special procedures for registration of small scale projects might be part of the cause.

As can be seen from Figure 2-5 most projects are developed in China and India. About 80% of all the CER's are generated in Asia & Pacific. About 15% of the CER's are generated in Latin America. On a per capita basis the number of CER's in Latin America is higher than Asia. Af-

rica is under performing, since only about 3% of all the CER's are generated in Africa. The unequal regional distribution is an important topic of debate within the CDM discussion.

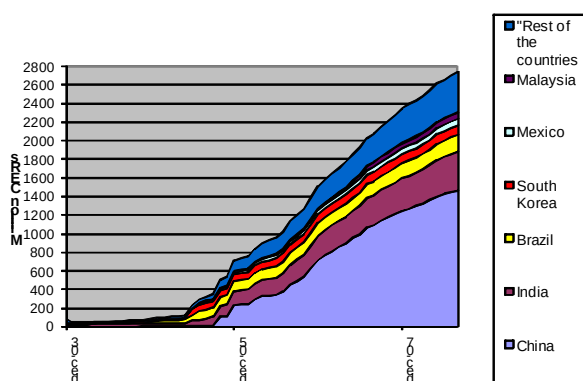


Figure 2-5 Regional distribution of CERs (UNEP Riso, 2008)

2.5.1 CDM investment flows

In order to get some understanding of the magnitude of the CDM and its relevance it is important to look at the total amount of investment that is involved in CDM projects and relate this to other investment flows.

The World Bank (Capoor et al., 2008) estimates that in 2007 about €7 billion was invested in funds purchasing credits or undertaking projects, and that this amount could go up to €9.4 billion in 2008. Taking into account a leverage factor they estimate that the CDM has generated about €24 billion of investments in clean energy in 2007.

The UNFCCC (2009) states that in 2007 total revenue of CERs amounted to \$8.4 billion USD, which led to a total project investments of \$45 billion USD.

The average market price for primary credits ranged between €8-13,- in 2007 and spot market credits traded substantial higher at about €16-17,-. The leverage factor is expected to be between 6-8 times the money from the carbon credits.

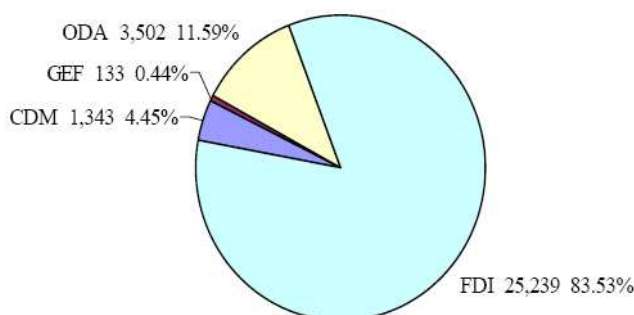


Figure 2-6 Energy and Climate Mitigation Financial Flows [\$million/yr, averaged over 2002-2004](Boyd et al., 2007, p14)

Figure 2-6 gives an overview of the different investment flows from developed to developing countries related to energy and climate mitigation in 2002-2004 (Boyd et al., 2007, p14). The energy investments from the CDM increased dramatically from an expected €1.3 in 2004 to €7 billion in 2007 and surpasses the energy related Overseas Development Assistance (ODA) and the Global Environmental Facility (GEF) (see Figure 2-6).

Foreign Direct Investment (FDI) still remains the main investment flow to developing countries. Domestic investments are even larger and are estimated to be about \$1 trillion USD (Ellis et al., 2007b).

Based on figures from the IEA and the World Bank, Boyd (2007) states that there is an energy investment demand in developing countries of \$165 billion a year in the coming years, of which there is still a funding gap of \$80 billion/yr.

Taking into account the leverage factor of CDM projects, the €24 billion (up to \$45 billion USD, depending on source) annually investments generated by the CDM could be playing an important role in supplying these funds in the coming years.

2.6 Critique on CDM as an instrument

The main critique focuses on the concept of additionality. It basically comes down to the idea that it is impossible to predict “what would have happened if the CDM project would not have been undertaken”.

The fact that currently over 90% of all Chinese wind parks are co financed through CDM credits raises the question if China would really not have taken any action building wind parks without CDM. It is dubious to believe that China would not have build wind turbines without CDM considering that the Chinese are aware of energy shortages and environmental problems themselves.

This raises the idea that some CDM projects do not actually reduce the amount of GHG in the host country. Since CDM is an offsetting mechanism and does not reduce GHG emissions, any non-additional projects would actually contribute to an increase of global GHG emissions.

Other critique focuses on a perverse incentive of the CDM. The CDM is said to reward developing countries for not taking up stringent environmental policy for strict environmental policy would render CDM projects un-additional (IEA, 2006, p225; Schneider, 2007). There seems to be little empirical evidence to support these claims.

Another perverse incentive occurs during negotiations. Through the CDM developing countries are receiving large sums of money. They are unwilling to lose this flow of income. This makes it harder in international climate negotiations to find an international solution that engages developing countries and includes binding targets for non-Annex I countries, as this may reduce CDM opportunities.

The large amount of credits by HFC-23 destruction projects also led to debate. Wara (2008) predicts the total payment for the CER's from HFC projects to be about €4.7 billion, while the total investment costs to install the technology would have been only €100 million. Wara (2008) concludes that in the case of HFC-23 destruction, other mechanisms (for instance a fund) might have been more sensible. On the other hand this might also be seen as the “low hanging fruit” that is created within any new market. It gave rise to the debate about the effectiveness of the CDM.

HFC-23 destruction projects are directly assumed to be additional (Paulsson, 2009). However interviews with stakeholders by the BBC give rise to the idea that the investment would have been made anyway (Gregory, 2008).

The large profits that could be generated by HFC-23 destruction created an incentive to increase HCFC-22 production. A decision to limit these projects to the HCFC-22 production level of 2005 countered this negative incentive.

Schneider (2007, p50) concludes that “despite the public criticism, it is unlikely that there are any perverse incentives to increase HCFC-22 production under the current rules of the CDM. However, such incentives should be carefully taken into account in the context of discussions on crediting additional production capacity”.

Also the institution and registration process created by the CDM is criticized (Michaelowa et al., 2005). Registration of a project is expensive and timely. A big bureaucracy is created to administer and monitor all the projects (high transaction costs). While on the one hand the EB has to guard the integrity of the CDM; it is at the same time pressurized by Annex I countries and

commercial project developers to speed up the registration process in order to generate sufficient cheap credits.

Project developers pay a DOE to verify their project. Also project developers pay better salaries than DOE's which drains skilled workers from DOE's to project developers. This obviously puts DOE's learning more towards the project developers than towards the EB. This raises concern about whether dubious projects are in fact skilfully guided through the registration process without actually deserving it.

2.7 Future of CDM

The most important element of a new climate agreement will be its success in engaging the USA and developing countries in the agreement. It is likely that the CDM will keep an important role in a post-2012 agreement, although changes are proposed (Schneider, 2009). These changes are currently discussed during meetings leading up to Copenhagen 2009.

Major proposed changes (they are only being discussed (UNFCCC, 2008a)):

- Include CCS, LULUCF and nuclear projects in the CDM
- Differentiate between countries and technologies, e.g.: reduce the amount of credits that can be gained through Chinese wind park projects.
- Sectoral CDM, e.g.: allow complete sectoral- or countries policies to be eligible for CDM credits.
- Sectoral Crediting + no-lose targets, e.g.: use benchmarks within sectors to judge the performance of specific industry and reward only those companies that perform better than a certain standard.
- A proposal to skip additionality tests for certain projects, e.g.: *for renewable projects*.

The CDM will be renegotiated and probably changed in Copenhagen. The exact form is yet to be determined.

3. Technological change

This chapter will introduce the concept of technological change and work towards a workable definition for within the context of this research.

3.1 Introduction

Technological change can be depicted as a droplet of water hitting the surface and the ripples that form as a result. The droplet hitting the surface represents new technology being developed and the ripples represent the effect that a new technology causes on society. After impact the circles will become wider and wider representing the diffusion of technology. Eventually the ripples will fade away and the water will be stirred by a new droplet of water hitting the surface.

Technological change has caused society to develop and improve. We changed from using rocks and bones for tools all the way to the development of the personal computer. The introduction of new technologies is often accompanied by increased production output leading to increased prosperity. It allowed new institutions to emerge and led to the decline of incumbent institutions, thereby changing the way we organize our society. Consider for example, the development of large sailing ships which led to the introduction of the first tradable stock in the Dutch VOC company or the development of power plants which led to domestic electrifications and the introduction of household appliances thus challenging traditional role patterns in family live.

Technological change is also a slow and continues process (see Figure 3-1). Take for instance the development of the car. Its shape, performance and costs changed a lot since its first appearance in 1894. And the development of cars is still continuing full speed as each new model outperforms the old model, either in costs or quality. As it became cheaper more people could afford one and it went from a celebrity toy to a “Volks Wagen (car of the people)”. The diffusion of new technology is often difficult and slow. Still most people worldwide cannot afford a car and even in Europe it takes years before the most advance technology used in the most expensive Mercedes cars becomes available to the general public.

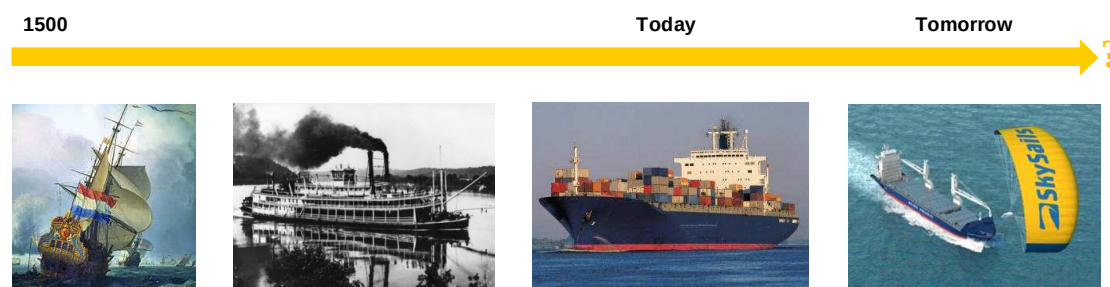


Figure 3-1 Example of technological change in shipping during the last 500 years

Whether TC is a good thing we will probably never now. The development of technology also fuels the darker side of humanity. Most notably in this respect is the development of weaponry, such as the atomic bomb or the Kalashnikov. Albert Einstein said: “I do not know what the third world war will be fought with, but the fourth world war will be fought with sticks and stones”. This is a rather dark and unpleasant outlook and should serve as a reminder to be careful.

However the dominant believe is that TC is a good thing and certainly one that is hard to avoid. As previously explained TC has been going on since the dawn of man and our current society rewards and embraces innovation. The innovating entrepreneur can make large profits and large sums of public money are spent on research and development. It seems that our quest for knowledge and exploration is an imperative that drives change and one that it is deeply rooted in our humanity.

Climate change is by many considered to be the biggest problem that the world is currently facing. The problem is closely related to the consumption of our limited natural resources. The IEA (2006p37) calls it: “twin energy related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental problems caused by consuming too much of it”.

About the solution Gore (2008) suggests: “When you connect the dots, it turns out that the real solutions to the climate crisis are the very same measures needed to renew our economy and escape the trap of ever-rising energy prices”. He refers to a “green revolution” which basically comes down to ‘change’. But what kind of change is desirable?

Ehrlich and Holdren (1971; 1972) introduced formula (1) to express the impact (I) of man on the environment. This formula can be used to analyse the solution space that is available.

$$I = P * A * T \quad (1)$$

The impact (I) is expressed as the product of the total population (P), the level of affluences (A) (wealth per person) and a technology efficiency factor (T). This formula illustrates first of all the need to limit population growth. However this has moral implications, is hard to achieve and faces the tragedy of the commons (Hardin, 1968).

Lowering affluences will require regulation, especially in the context of pollution, since nobody will want to lower consumption voluntarily and people will tend to defect agreement (Hardin, 1968).

The idea that environmental regulation inevitably leads to costs and thus an decrease in affluence is deeply rooted, although this assumption is criticized by Porter (1995) who states that environmental regulation can at the same time benefit the environment as well as increase economic competitiveness through stimulating innovation.

The latter relates to the third option which is improving the technology efficiency factor (T) by developing and utilizing more advanced technology. Improving the technology efficiency factor would lead to an improved environmental quality without lowering affluences.

It is not surprisingly that TC is said, both by politicians and scientists, to play an important role in tackling the problem of climate change. Leaders on the G8 (2008) call for “urgency of adopting appropriate measures to stimulate development and deployment of innovative technologies and practices”. Grubb (2008) states “achieving deep reductions in greenhouse gas (GHG) emissions at acceptable social cost will involve far-reaching technological change in the energy and in other sectors. Indeed, at present this seems one of the few things on which there is international agreement in relation to climate change”.

Similar calls can be heard from among others: UNFCCC (article 4.1 of the convention), IPCC, The World Bank (2008), Blair (2008), Vollebergh (2005) and Jaffe et al. (2002).

Apart from tackling climate change, TC can have a positive effect on economic development. Next to increased productivity TC can lead to the development of new markets. A country that is able to become a technology leader (eg. Finland with Nokia or Denmark with wind turbines) creates new jobs and economic opportunities (Beise et al., 2005).

Also for developing countries TC is an important element of development. Mokyr (1990, preface) states: “The difference between rich nations and poor nations is not [...] that the rich have more money than the poor, but that rich nations produce more goods and services. One reason they can do so is because their technology is better; that is, their ability to control and manipulate nature and people for productive ends is superior”.

Because of its importance it is not surprising that TC is a widely studied topic. Research is aimed at understanding the process of TC in order to influence the direction and the speed of the process. Part of the research focuses on the modelling of TC; different approaches exist to model TC. Related to this work are the identification and ranking of the causes of TC. Secondly

research is aimed at the question of “how to influence TC” (so called induced technological change). This research builds on the recognition that policy can influence the speed and direction of TC (Orr, 1976) and tries to unravel what Newell et al. (2006) calls “the black box of technological change”. The latter is important since deeper understanding of TC is needed in order to develop effective policy. Newell et al. (2006) state that this still requires extensive research on different policies and sectors from different methodological viewpoints.

3.2 Definition of TC

In section 3.3 the process of TC will be further analysed. For now I would like to make a note about the terminology that is being used to describe the process of TC. Apart from “technological change”, terms such as “technological progress”, “development” and “improvement” are used. Although each term is linguistically different, they are often used to describe the same. Their meaning, if not clearly stated in articles, is sometimes ambiguous. In this report the term TC will be used to indicate the overall process of invention, innovation and diffusion of technology and processes.

Looking at the concept of change from a higher level of aggregation one identifies “socio-technical change” and transitions. The concept of socio-technical change relates to the interdependency between the socio and the technical system in order to achieve change in a society. Socio-technical aspects include institutional arrangements, such as traditions, habits, law, policy and organizations. In order to achieve transition it is often necessary to change not only the technical system but also the social system and the processes by which they interact (Bots, ; Williamson, 1998; Geels et al., 2007a).

This study will focus on TC. The broader view of socio-technical change will serve as a reminder to put technological change in a broader perspective. Technology alone is no panacea, and tunnel vision as a result of too much focus on technology ought to be avoided.

Broadly speaking TC could be referred to as “the process of phasing-out old and phasing in new technologies” (Pan et al., 2007, p751) or more specifically: TC can occur through “...scientific innovation and invention; through the adoption and adaptation of pre-existing, but new-to-market, technologies; and through the spread of technologies across firms, individuals, and the public sector within a country” (The_World_Bank, 2008, p2).

Adapted from Jaffe et al., (2002) and Schumpeter (1942) I prefer to consider it as this:

Technological Change (TC) is the process of invention, innovation and diffusion of technologies and processes, leading to an improved performance of a technology or process and ultimately to an improved productivity of a society.¹

In the next sections I will elaborate on the meaning of TC for society, describe TC as a process, discuss the main scientific perspectives and key issues related to TC and conclude with a theoretical perspective that will be used within this thesis.

¹ I have put part of this on Wikipedia/Technological_change myself on 26st of august 2008 (as user:joost.vp).

3.3 How TC manifests itself in society

Related to the climate change the debate strongly focuses on the positive aspects of technological change. We hold high expectations that future technology will allow us to fight climate change at affordable costs (Grubb, 2008). This section will explain how TC manifests itself within our society. What are we trying to achieve with TC or what is our goal? This will be done by explaining the final result of the process of TC on our society, using the construction of wind turbines as an example.

In this thesis a broad definition of technology is used: encompassing not only the hardware but also the software and including both tacit and explicit knowledge. Technology is well defined by Metcalfe (1995): “technology is the ability to carry out productive transformations”.

The result of technological change can be depicted as occurring on three different levels of aggregation. It comes down to improved efficiency and effectiveness, or as Mokyr (1990) put it: “an improved ability to control and manipulate nature and people for productive ends”. In the following section the example of a wind turbine is used to illustrate these three different levels.

1. Δ Total Production Function:
The total production function is the function that specifies all the output of a system based on a set of inputs (Clarke et al., 2008). The change in the production function is the direct result of installing an additional wind turbine. This can be seen as the diffusion of a technology (which in this example is a wind turbine). This wind turbine increases the total electricity output of the country and it will lower the average CO₂ output per kWh of the country.
Suppose this wind turbine is a direct replacement of the same amount of electricity by a coal fired plant; in that case the wind turbine would not have increased the total kWh output of the country, it would have led to an increase in the cost price of electricity production (cost price without including externalities) and it would have led to a lower CO₂ production of the electricity sector. The latter is part of the final panacea to achieve sustainability. Eventually, if 100% sustainable technologies are available at acceptable investment costs and diffused within society, we will produce without emitting GHG's or with any other unsustainable side effects.
2. Δ Production Possibility Frontier:
The change in the production possibility frontier is a direct result of the drivers of TC (R&D, learning, spillover and economies of scale). This relates to the development of new technology, or the advancement of our technological frontier. An elaboration of these drivers will follow in section 3.7.
At least we know that in the case of our example (the wind turbine), learning will occur as a result of the construction of the wind turbine. This learning experience implies that if we build a second wind turbine, we could make this wind turbine better and or cheaper: we have gained experience. Or to state it more formally: it changes “the production possibility frontier, that is, a set of combinations of inputs and outputs that are technically feasible at a point in time” (Jaffe et. al, 2002, p 42).
To state it less formally: we have created the possibility to be able to produce differently, more efficiently. For instance we can now do the same for lower costs or at a lower CO₂ emission. A new “technological frontier” was reached, which does not mean that this technology is actually put to use. To take effect the technology must be diffused within our society.
3. Δ Possibility to Innovate (the ease and speed with which we are changing our production possibility frontier):
This indicator is harder to explain or measure. It is best explained by realizing

that the first level of technological change was about the diffusion of a wind turbine, the second was about the advancement of technology (either through learning or through other drivers of TC). This third level is about the ability to advance or learn. Basically, “learning to learn” or “learning to advance”. It is about being able and willing (as a society) to effectively set in motion the drivers of TC.

An effective innovation system is better capable of learning than an underdeveloped innovation system.

Measuring the effect of policy on the result of TC (in other words the outcome of TC) is preferential over measurement of the input, throughput or output of TC (Neij et al., 2006). However if it proves to be impossible to measure the impact of CDM on the outcome indicators of TC, different indicators will have to be found. Therefore the concept of TC will be explored in more detail.

3.4 Approaching TC as a process

The process of TC can be subdivided into a number of different phases. I will describe a classification into three phases made by Schumpeter (1942), a classification into six phases made by Grubb (2008) and a simple classification into two phases that is put forward by the IPCC (2007). I will use the latter during the remaining of this report.

The process of TC as depicted in Figure 3-2 is derived from Schumpeter (1942) and Jaffe et al. (2002). Invention, innovation and diffusion are continuous processes that influence each other. The process is in reality not always as sequential as is depicted in Figure 3-2. Invention, innovation and diffusion could happen in parallel and the outcomes of different phases influence each other.

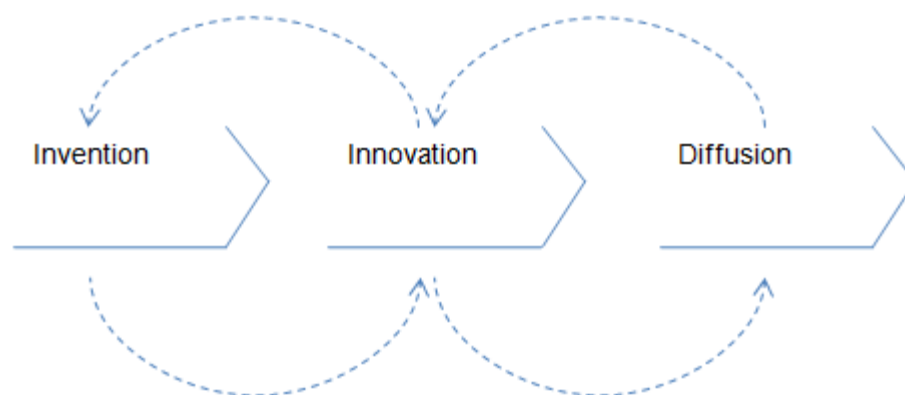


Figure 3-2 Process of TC

Invention relates to the creation of new technologies or processes. It relates to fundamental research and applied research. Invention can lead to radical new insights or breakthroughs but can also occur incrementally. What defines it is its distance from the market. A typical analogy would be with the cartoon character Gyro Gearloose (in Dutch: Willy Wortel) who does brilliant inventions but does not know how to sell them.

As an invention reaches the market the process of innovation kicks in. The technology is no longer theory but as it diffuses we start learning from our experience gained by putting the technology into practice. Innovation is a continuous process of improving the quality and lowering the costs: constantly adapting and improving the technology to please the desires of society and its customers. Innovation and diffusion is the domain of the entrepreneur. A good analogy would be with Scrooge McDuck (in Dutch: Dagobert Duck) who constantly seeks profit by improving business and outsmarting competitors.

As a technology improves or becomes cheaper it is also more easily diffused and vice versa; if a technology becomes more widely diffused often the costs and quality of the product improve (Blackman, 1999). The latter is the result of learning by doing.

Grubb (2008) divides the process of TC into six sub phases with different characteristics (see Figure 3-3). It includes the concepts of technology push and market pull. This model representation helps to distinguish among others the concepts of invention and innovation. In his model a technology starts as an idea and moves through the different phases towards a consumer ready product. During this process the technology gradually decreases in price and or increases in quality. As market pull increases the technology starts to diffuse more rapidly.

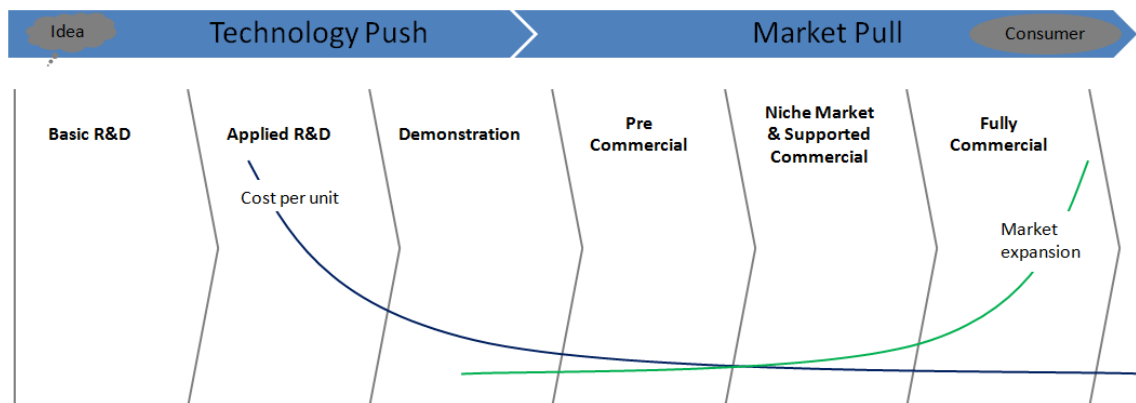


Figure 3-3 Activities for spanning the innovation chain (Grubb, 2008, p24)

The first three phases are characterized by the importance of what is referred to as technology push. Technology is improved mainly because of R&D effort. Prices decrease and the quality of the products increases. These phases correspond with what is called invention in Figure 3-2.

The last phases are characterized by the importance of market pull. The product starts to become commercialized. As the product starts to diffuse on the market (first through niche markets) the influence of learning takes effect. Learning relates to innovation occurring due to experience. These phases correspond with what is called innovation in Figure 3-2.

A popular way of describing the complete process is R,D,D&D: Research, Development, Demonstration and Diffusion.

The IPCC (2007, p152) simplifies the process of TC:

“One approach is to consider technological change as roughly a two-part process which includes:

- (1) The process of conceiving, creating, and developing new technologies or enhancing existing technologies – the process of advancing the ‘technological frontier’.
- (2) The process of diffusing or deploying these technologies.”

I will use the two-part process as a classification to structure this research.

3.5 Technology development

One of the most important elements of TC is decreasing production cost per unit and improved performance of the technology. In the beginning this phenomenon is mainly driven by R&D, when a product becomes diffused other drives, most noticeably “learning-by-doing” become involved.

Wright (1936) first introduced the concept of learning when he found that costs decrease with cumulative production. The blue line in Figure 3-3 depicts decreasing costs per unit.

The experience curve was developed by the Boston Consulting Group and states a decrease in costs the more often a task is performed and includes a wide range of drivers. An example is

given in Figure 3-4, which represents both a linear and a logarithmic representation of the decrease in costs as an effect of an increased installation of PV-modules.

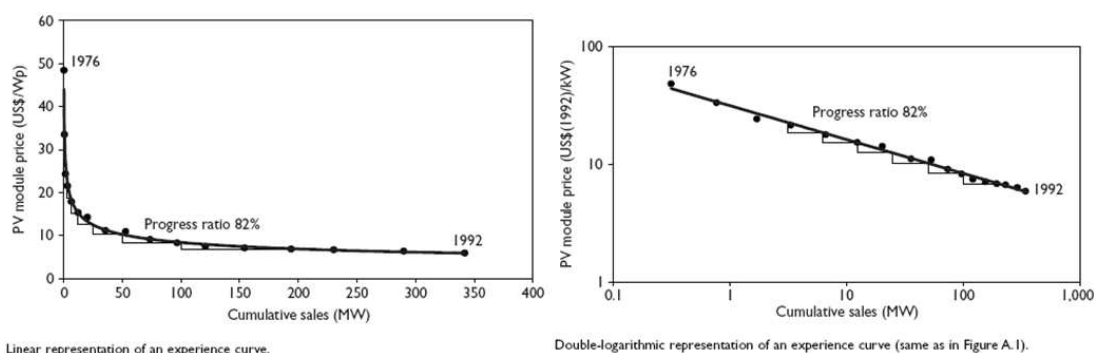


Figure 3-4 Experience Curve for Photovoltaic Modules, 1976-1992 (IEA, 2000).

3.5.1 Why do we innovate?

Jaffe et al. (2002) identifies two theories regarding the determinants of innovative activity: “The induced innovation approach” and the “evolutionary approach”. Both ideas try to answer the question; “why do firms innovate?”

The induced innovation approach is based on the concept of rational profit (utility) maximizing behaviour. Companies see R&D activities as projects that are judged on their Net Present Value. Investment decisions about R&D projects face two main problems: First the outcome of a decision is highly uncertain or in other words has a high level of variance. Secondly, Jaffe points to the effect of “spillovers”. Spillovers occur when part of the social benefit of innovation cannot be absorbed by the company but is rather “spilled” (Arrow, 1962).

The latter is considered a market failure, since the company is not able to capture all the benefits that arise due to their R&D investments. A second market failure with respect to investments in sustainability arises due to the fact that negative externalities are often not included as a market incentive. In other words: companies are not financially punished for polluting the environment (Jaffe et al., 2005).

These effects all have a negative impact on R&D based environmental investment decisions (Goulder, 2004; Beise et al., 2005). The benefits of investing in environmental innovations include the first mover advantage and the possibility to gain patents.

According to this perspective innovation is very profit motivated. Because environmental policy affects the price of environmental input, this theory accepts a relation between environmental policy and the speed and direction of technological change. This theory includes the idea that environmental regulation limits the rational profit maximization behaviour of the company.

The evolutionary perspective on the other hand doubts the rational behaviour of the firm (Jaffe et al., 2002). Rather than optimizing, a firm would more likely be satisfying, limited by bounded rationality and information. According to this perspective external constraints do not necessarily lead to profit reduction.

It even allows for what is described by Porter et al, (1995) as a win-win situation in which environmental regulation leads to a better environment and an increase in profit.

Scientific innovation is still almost exclusively a high-income activity (World Bank, 2008, p3). Instead of innovating through R&D, developing countries benefit more from the import, absorption, assimilation and the diffusion of technology (Hill, 2001, p386). Doranova (2007) states that in developing countries “the process of TC is essentially a process of learning (knowledge, skills and expertise) rather than innovation”.

However there are also thoughts that technology development in developing countries is becoming more important and that technology transfer is not only about north to south technology transfer. Developing countries can also be technology leaders, for instance Brazil (bio fuels),

China (coal gasification and hydrogen produced from coal) and South Africa (coal to synfuels) (Brewer, 2008).

3.6 Technology diffusion

The previous section specified the process of technology development. This section will elaborate on the process of technology diffusion.

Technology diffusion generally follows an s-shaped curve (see for example Figure 3-5). The process could be characterized by a takeoff phase, an acceleration phase and a stabilization phase (Rogers, 2003). During the takeoff phase a technology gains some market penetration followed by a rapid market expansion during the acceleration phase. Finally the market becomes saturated representing a stabilization phase. As can be seen in Figure 3-5 different countries experience the same pattern of diffusion, but some countries clearly advance sooner than others.

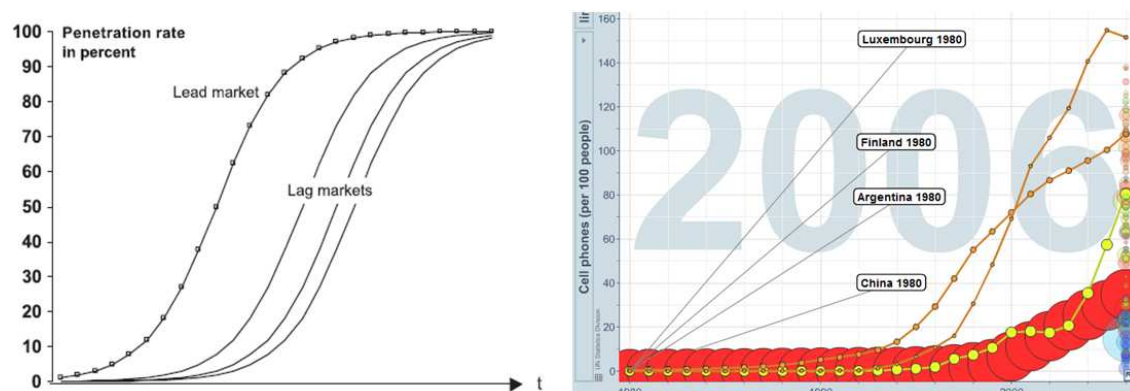


Figure 3-5 The international diffusion pattern of an innovation design (Beise et al., 2005) & Diffusion of Cell phones (Gapminder.org, 2008).

Theories on the diffusion of technology focus on the question of the apparently slow diffusion of superior technologies. Such as why are people still using old cell phones although new models outperform the old models? These theories try to explain why superior technology diffuses as it does, why it diffuses slowly and why does everybody not use the newest technology (Rogers, 2003)?

The first theory behind the diffusion of technologies is based on the idea that the decision to adopt a new technology is mainly based on the associated financial returns. An important factor prohibiting the adoption of new technologies is the fact that often the depreciation period of previous investments has not yet expired. Change prior to the depreciation date is costly and thus the benefits must be enough to overcome change prior to the depreciation date. Therefore only a limited number of companies will be willing to pay to change to a new technology. As the technology gradually decreases in price more and more companies will decide to adopt the new technology.

The second explanation focuses on the concept of information. People can only adopt a new technology if they have sufficient information about the existence of the technology. Within this theory technology spreads like a contagious disease; the more people come in contact with each other the easier the disease can spread.

3.7 What causes technological change?

In the previous section s we have gained an understanding of the reason for TC (by looking at the outcome of TC) and we have looked at TC as a process, identifying different sub-phases within both the development of new technology and the diffusion of new technology within a

society. In this section I will deal with the sources of technological change. These sources explain what is behind the continuing process of advancing the technological frontier.

Literature identifies three sources of TC (from the perspective of advancing the technological frontier): R&D, learning-by-doing (more general “learning”) and spillovers (see Table 3-1) (IPCC, 2007, p 152; Clarke et al., 2008). These are the sources directly responsible for decreasing costs and improving (environmental) performance of technologies that could be applied in real life. This does not necessarily imply direct applications of these advanced technologies in the field, as technology in the field will generally lag behind that what is possible at the uttermost technological frontier. A simple example to remind us is the introduction of new models of cars or telephones: new technology allows for better or cheaper models, but diffusion of the newest technology is not instantaneous and follows a more gradual path.

The fourth driver, economies of scale, is not technology dependent. Building two units instead of one allows costs to be shared among two instead of one unit of production thus leading to marginal cost reduction. This is an important driver for cost reduction and therefore it is included within this research.

In Table 3-1 I will elaborate on each of the four sources of technological change. I will use examples to illustrate and clarify the sources.

Table 3-1 Sources of TC (Clarke et al., 2006; IPCC, 2007, p 152)

Source:	Description (based on Clarke et al. (2006) and IPCC (2007)):
R&D	R&D is the deliberate action of spending resources aimed at acquiring knowledge. Many companies and public institutions are involved in research and development. Research leads to new knowledge and new or improved technologies. Often a distinction is made between applied and fundamental research, however both are essential and both interact with each other.
Learning (-by-Doing) (LbD)	Learning-by-Doing (LbD) occurs with the use or the production of a technology; it occurs when technology is applied and diffused within a society. The repetition of a task by an individual leads to an increased efficiency. The same holds true for companies and countries. An important element of LbD is its feedback to R&D. Experience in the field with new technologies is an important source of information that identifies the bottlenecks and problems associated with the new technology. These problems can serve as a direction for future research. Learning-by-doing is sometimes further specified in which case Learning-from-using and learning from interacting are included. These effects occur from the user's perspective and because of the interaction between the user of the new technology and the developer of the new technology. A related aspect of learning is network externalities; if more people start using a technology it becomes more attractive for new entities to start using that technology. This relates to path dependency and the reasons why superior technology faces problems taking over the incumbent technology.
Spillovers	Spillovers are advancements in one field of research, firm, sector or country have an effect on the advancement of another field of research, firm, sector or country. Examples include: the (re) introduction of (kite) sails on ocean going freighters that spilled over from a recreational kite sector to the freight sector (see Figure 3-1), improvements in the field of materials sciences (glare) that lead to costs reduction in the aerospace industry or advances in Danish wind turbine design could also improve the future designs of Indian wind turbines. The definition of spillover therefore greatly depends on the system boundaries.

Economies of scale	Economies of scale relate to a decrease in unit production cost that comes by increased production size. With an increase in production fixed costs can be shared among a larger number of production units, leading to a lower unit price. Economies of scale are a slightly different driver of TC than R&D, learning and spillover since: “Economies of scale are not a source of technological advance, but rather a characteristic of production. However, the two concepts are often intertwined, as increased production levels can bring down costs both through learning-by-doing and economies of scale” (IPCC, 2007, p154).
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3.8 Different theoretical perspectives on achieving TC

The previous sections analysed TC in a very stringent and technology orientated manner. This section will describe different theoretical perspectives and introduce key assumptions about TC. Choosing to approach TC from different theoretical perspectives or on the basis of different key assumptions leads to different methodological approaches and it leads to different solution spaces about how to influence the speed and direction of TC.

First of all I will elaborate on the relation between TC and social change, since theory strongly emphasizes the fact that it is hard to separate both, followed by a discussion on the different scientific disciplines concerned with studying socio-technical change. After that I will elaborate on the bounded rationality of actors and deal with the level of aggregation of perspective; from firm level to system level and from sector to global.

3.8.1 Socio-technical change (STC)

Although this research aims at focusing on TC it becomes clear from previous research that TC and social change (SC) are closely related and interdependent. Technological systems and socio systems tend to experience some form of co-evolution. The advancement of a technological system cannot be achieved without changes in the social system; changes in economics, institutions, behaviour, culture, rules and policy are essential to the successful adoption of new technology by society (Kemp et al., 1998).

This is a more evolutionary perspective on TC, in which TC is seen as a socio-technical transition. Limited by bounded rationality and uncertainty actors satisfy instead of optimize. In evolutionary socio-economic theory routines, behaviour and the selection environment are important variables in explaining innovative behaviour and adoption of new technology. Innovation and adaption of innovations becomes less of a plan and more of a journey.

In a sociologist view technology and society are closely related in a “system that works” (Rip et al., 1998). Technology co-evolves with changes in the socio technical regime. This socio technical regime is a set of formal and informal rules that structure society and it includes aspects such as: culture, knowledge, policy, networks, markets, infrastructure and technology (Rip & Kemp, 1998). In a constant quest to reduce uncertainty society becomes locked in into dominant configurations, hesitant to challenge or change these configurations. Incumbent technologies become strongly embedded within the dominant socio technical regime. Incremental changes are possible within the regime, but challenging radical innovations are rejected by the dominant regime. New technologies have to compete with the dominant structure, are resisted and have a hard time getting through. New technologies incubate in niches from which they are able to challenge the incumbent socio technical regime (Geels, 2002; Schot et al., 2008)(see Appendix B for a visual representation).

Theory on socio-technical change takes a broad view on what is important in determining technological change and takes a less linear perspective. Apart from market instruments a more diverse set of barriers and drivers is looked at.

3.8.2 Different sciences involved in studying socio-technical change

A good overview of the different sciences involved in studying STC is given by Timmermans et al. (2008). Timmermans places transition studies into an interdisciplinary context that includes natural sciences, organizational sciences, policy sciences, political sciences, economics and sociology. Even from the unlikely angle of natural sciences we can learn about change, for instance from abrupt energy state changes such as the state change of water into ice.

Organizational sciences study among others the way organizations adopt new approaches and technologies and the role of leadership. “Both transition studies and change management emphasize the need for unfreezing, bypassing inertia, overcoming defence mechanisms, breaking down existing power structures and destabilizing the existing regime” (Timmermans et al., 2008, p396).

Policy sciences teach us about societal stability versus times of crisis and revolution. “In policy sciences the focus is on explaining sudden changes in the otherwise stable processing of issues and the related rapid change in the public policy arrangement around them (Timmermans et al., 2008, p396).

Political science includes aspects such as political elite and dominant groups and their role in either stability or change. “Political science literature emphasizes the social conflict behind transitions, their planned and intentional nature, against any emergentist flavour, the relevance of particular social groups in promoting, strengthening and taking the change, like political elites, as well as how past leaders and dominant groups in the society can make a stand against any disruptive change” (Timmermans et al., 2008, p397).

Economics approaches include evolutionary and institutional economic perspective and analysis of societal development such as changes from capitalism to socialism. “It among others emphasize the continuous interplay between groups that are bearers of changes and innovation, on one side, and the breaking strength of dominant groups, which are challenged by the novelties introduced by the firsts, on the other” (Timmermans et al., 2008, p399).

Sociology describes societal change on the level of entire societies looking specifically at interaction between different groups in society.

What can be concluded from the summary of interdisciplinary perspective on transition by Timmermans is that there are different disciplines working to explain change processes and that we can learn from each discipline to better understand the process of change and ways to influence change.

3.8.3 Rationality versus bounded rationality

In a neoclassical economic view agents make rational choices and try to maximize their utilities (Weintraub, 1993). A systematic analysis of technological change according to this perspective is mainly done by studying the input and output of a system, and policy based on that is aimed at correcting market failures.

Neoclassical economics involves studying the amounts of money spent on e.g. R&D (input), the amount of patents that are produced as a result (output) or the amount of diffusion of a given technology (output). The hypothesis is that an increase of the input variables automatically leads to an increase in output. More spending on R&D or diffusion would, for instance, lead to more technological change.

Where neo classical growth models for growth approached technological change as an endogenous factor “dropping as manna from the sky”, new growth theory tried to incorporate technological change within their models. Including this as exogenous factors resulted in argumentation for governmental innovation policy, expansion of free trade zones and improved property law (Economist.com, 2008).

From this perspective lack of technological development is caused by wrong incentives, due to market failures. The behaviour of the different actors operating in this market is perceived as being rational and profit motivated. In the case of environmental technology both market failures within environmental pollution as well as market failures in R&D and technology diffusion play a role. The existence of both calls for public interference since the market chooses an optimum that is not the most desirable from a societal perspective. To achieve the desired outcome economic incentive based policies are needed to correct both market failures (Jaffe et al., 2005):

- The first market failure: companies are not punished for the negative externalities of their activities and therefore pollute too much. The price society pays (due to the destruction of the environment) is not reflected in their internal cost structure. This is for instance the case with CO₂ emissions. Putting a price by means of a CO₂ tax, emission permits and limits to allowed pollution are possible policy options to internalize these externalities.
- The second market failure: companies might not receive the full positive externalities of their R&D activities and might therefore not invest enough. The knowledge that is gained through research programs does not only benefit the company but benefits competitors and society as a whole. Patents are one of the means of guaranteeing companies the benefit of their own research activities. Public spending on R&D is another means of countering the public good nature of knowledge.

Evolutionary and institutional economics breaks with the concept of rational actors. Instead it takes the neo-Schumpeterian standpoint that the actors are limited in their rationality (bounded rationality). According to the evolutionary economic perspectives on stimulating growth and technological change is not merely about correcting market failures. Co-evolution of technological change and social change are together responsible for increased productivity of a society. Evolutionary and institutional economics accept a world that is less predictable in which interaction occurs between technology, institutions and economics. Actors do no longer “optimize” but “satisfy” instead.

From a sociological point of view technology and society are closely related in a “system that works” (Rip et al., 1998). Technology co-evolves with changes in the socio technical regime. This socio technical regime is a set of formal and informal rules that structure society and it includes aspects such as: culture, knowledge, policy, networks, markets, infrastructure and technology (Rip & Kemp, 1998). In a constant quest to reduce uncertainty society becomes locked into dominant configurations, hesitant to challenge or change these configurations. Incumbent technologies become strongly embedded within the dominant socio technical regime. Incremental changes are possible within the regime, but challenging radical innovations are rejected by the dominant regime. New technologies have to compete with the dominant structure, receive resistance and have a hard time getting through. New technologies incubate in niches from which they are able to challenge the incumbent socio technical regime (Geels, 2002; Schot et al., 2008)(see Appendix B for a visual representation).

In evolutionary socio-economic theory technological change becomes more of a journey. The change agent (often the government) takes the role of a process manager and takes an active role in shaping the transition trajectory.

3.8.4 Firm level versus system perspective

As becomes clear from the above section, TC can be approached from a number of different perspectives. An important perspective not yet discussed is the level of aggregation: do we view TC from a firm level perspective or from a higher level of aggregation; a systems perspective.

Looking at TC from a firm level perspective acknowledges the important role that firms play in the development and diffusion of new technology. Companies are a major storage of knowledge and play an important role in knowledge dissemination. *“The development of firm-level capabilities and support systems is vital for successful assimilation of foreign technology”* (UN, 2007, p5).

As mentioned above firm-level capabilities play an important role in studying the role of firms in the process of technology development and diffusion. A simple but useful example of firm level capabilities is given by Bell (2007, pV), who identifies three levels of technological capabilities:

Operating or production capabilities

-i.e. capabilities for using knowledge that is embodied in, or closely associated with, existing production systems and facilities.

Design, engineering and associated management capabilities

-i.e. capabilities for transforming existing knowledge into new, often innovative, configurations for new or changed production systems

R&D capabilities

-i.e. capabilities for creating new knowledge and transforming it to the specifications required for application in production

Theory on technological capabilities defies the simplification that knowledge of the latest technological advances is available everywhere. What is referred to as “global learning” assumes that technological learning in region (or firm) A is also applicable to region (or firm) B. In short, if the development costs of solar power in Germany lower, the costs of installing solar panels in India decrease as well.

Theory on technological capabilities instead assumes that firms need to develop competencies in the field of new technologies before they can benefit from these advancements. In order to become innovative, firms will have to grow from purely operation and maintenance capabilities towards engineering and management capabilities and eventually develop innovative capabilities too.

3.8.5 TC from a system perspective

A system perspective breaks with the notion that the most important capabilities determining the speed and direction of technological change come from within the firm. Instead it takes the perspective that it is a relation between both the firm and the collective system that determines TC (Hekkert et al., 2007).

The system perspective does not simply see the development and diffusion of technologies as a competition between technologies, but rather as a competition between innovation systems. It gives a role to both the new technology system and the incumbent system. New technologies develop in “niches” and have to compete with the incumbent “technological regimes” (Geels et al., 2007a; Kemp et al., 2008).

The Innovation System (IS) theory was developed in the 80’s as a reaction to the neoclassical approach towards innovation. Neoclassical economic theory was thought to be insufficient in explaining the competitive character of countries and it gave insufficient input for policy development. It was too stringent. Differences in R&D spending were insufficient to explain different innovative outputs of countries.

Within innovation system theory different approaches exist. Among others, one difference between the approaches is the identification of the relevant level of aggregation: either sector, national or global level perspectives are developed.

Instead of rational agents, the concept of bounded rationality was accepted. With agents that are not fully aware of the consequences of their decisions a more evolutionary approach to technological change emerged. A picture appeared that explained the system of innovation as a set of institutions and linkages between these institutions. Correcting market failure alone was not enough to achieve an effective system of innovation: “Even if you fix all market failures, there are still all sorts of reasons why you cannot expect markets to do the right thing” (Metcalf in Sharif, 2006, p 754).

The following description of the IS concept is provided by Metcalfe (1995): “Set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which the governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills and artefacts which define new technologies”.

Instead of focusing on the input and output of the system, National Innovation System (NIS) theory puts emphasis on the underlying framework of companies, rules and contextual factors that together determine the capacity of a system to develop and diffuse technology. Although the search for performance indicators is still ongoing, the OECD (1997) identified four types of interaction and a number of indicators that together form the centre of the measurement on NIS (see Table 3-2).

Table 3-2 NIS Indicators (derived from OECD (1997))

Type	Indicators
Interactions among enterprises	R&D collaborations, informal relations, industry alliances
Interactions among enterprises, universities and public research institutions	Joint research activities, co-patents and co-publications, citations analysis, firm surveys (in which institutions are asked to attribute importance of external relations to their innovations activities), knowledge centres / clusters.
Diffusion of knowledge and technology enterprises	Adoption rates (e.g. by using firm surveys), embodied technology diffusion (inter-industry flows of R&D through purchases of technology and equipment), barriers to the adoption of technologies (such as: lack of information, finance or technical expertise).
Personal mobility (“adoption capability” of a country determined by the qualifications, overall tacit knowledge and mobility of the workforce)	Labour market statistics, informal networks among researchers (professional associations, conferences, etc)

Important element in the NIS theory is that it accepts that countries can develop themselves differently, depending on country specifications, its culture and its history. This leads national technological specialization. National policy makers could use this knowledge to design policy that takes into account specific local circumstances.

NIS theory also points to the need of innovation systems to be flexible. The speed by which markets can adapt to new technologies in general becomes more important than the speed of adopting a specific single technology. It was noticed that the speed by which markets can adapt to new technologies will increasingly depend on the capabilities of markets to adopt and use technology that was originally developed in a different market (sector or country).

Based on data about the importance of technology diffusion in Japan, the OECD (1997, p17) states that “*promoting technology diffusion ... is essential to the evolution of the overall national innovation system*”. Pointing out that in order to increase productivity a country should not be too narrowly focused on R&D expenditure and the development of new high-tech sectors, but balance it with policy promoting the diffusion of available technology.

Hekkert et al. (2007) developed an approach for evaluating TC based on the concept of innovation systems. In his article “Functions of innovation systems: A new approach for analyzing technological change” Hekkert proposes to use seven empirically identified functions of innovation systems. These functions together determine the effect of the innovation system on the speed and direction of technological change:

- The innovation system needs to stimulate entrepreneurial activities.

- It needs to stimulate knowledge development.
- It needs to stimulate the diffusion of knowledge
- It needs to “guide the search”, indicating the need for government and industry to set targets.
- It needs to stimulate market development, e.g. niche markets for pre-commercial development.
- It needs to secure sufficient resources; both financial and human capital.
- It needs to create legitimacy and counteract resistance to change.

3.9 Developing a perspective on TC

As appears from the sections above there are multiple scientific angles, different views on key issues and different approaches to define TC. In this section I will develop a framework on the TC that can be used in this thesis to develop an approach to measure the effect of CDM on TC.

Literature defines TC as a continuous process (Grubb, 2008). In this research I will make a distinction between a phase of technology development and one of technology diffusion. Technology development relates to the constant improvement of technology both in quality as well as in a decrease in costs. I will include the four sources of technological development as defined by literature: learning by doing, R&D, spillover and economies of scale (IPCC, 2007; Clarke et al., 2008). Technology diffusion is defined as the application of a technology in practise (Rogers, 2003).

In the framework on TC I will include the innovation system (national innovation system in the context of countries (NIS)), since it influences the speed and direction of TC (OECD, 1997; Sharif, 2006). The innovation system is defined as: “Set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which the governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills and artefacts which define new technologies” (Metcalf, 1995).

The literature study on TC results in the proposed framework is depicted in Figure 3-6.

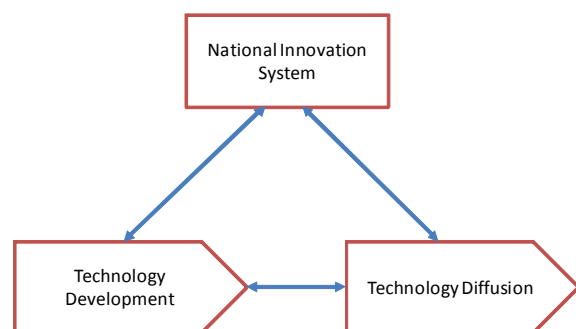


Figure 3-6 Schematic representation of the components of technological change

Technology development precedes technology diffusion (see the arrow shaped figures in Figure 3-6). As technology diffusion is an important source for learning-by-doing, technology diffusion also influences technology development. The national innovation system directs the speed and direction of technological change and in turn receives feedback from the process of technology development and diffusion (indicated by the two way arrows).

The different components of TC will be used to structure the remaining of this research. In the following chapter I will explore the relation between CDM and the different components of TC, which will be used in the next chapter to develop an approach to measure the effect of CDM on TC.

4. How CDM might influence TC in non-Annex I countries

With over 4500 projects (UNEP/Risø, 2009) generating \$45 billion USD of investments (UNFCCC, 2009) the CDM is expected to have an impact on technological change in non-Annex I countries. In this chapter I will explore the relation between CDM and TC in order to improve our understanding of what is currently still to a large extent a black box.

This chapter will contain a causal model depicting the most important relations between CDM and TC based on the framework on TC previously developed. I will discuss the factors that influence the different causal relations based on existing theory. This chapter will highlight knowledge gaps in important causal relations between CDM and TC. Based on this chapter I will, in the next chapter, develop indicators to measure these relations. Measuring these relations will help us improve our theory on the impact of the CDM.

4.1 A broad picture on the relation between CDM and TC

Prior to exploring the exact relation between CDM and TC it is important to realize that the CDM impacts a multitude of aspects and that TC in non-Annex I countries is not only influenced by CDM but by a multitude of factors (see Figure 4-1).

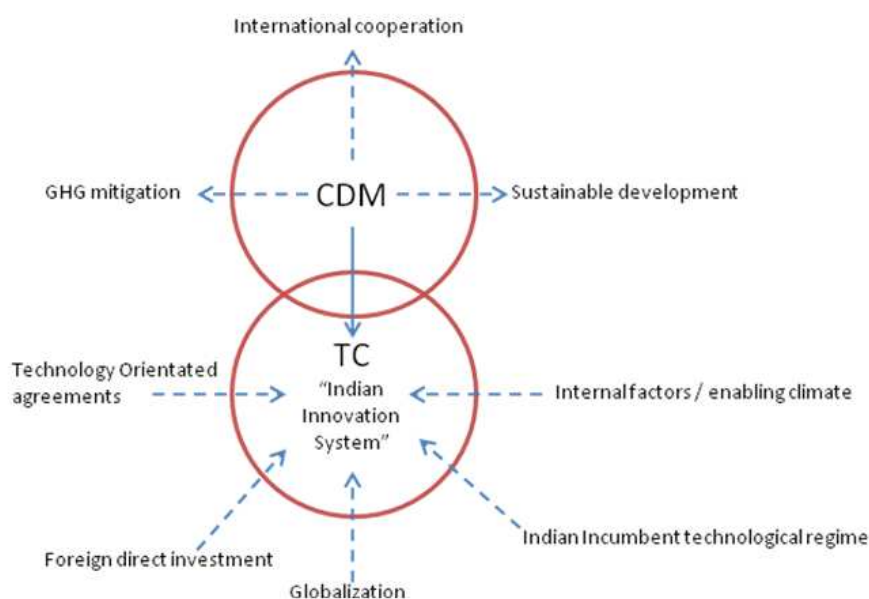


Figure 4-1 Relation between CDM and TC in non-Annex I country (e.g. India)

The CDM is an international policy instrument that has an effect on multiple issues. Not only does it affect the dual goals of the policy - GHG reduction and sustainable development - it also affects other aspects such as international cooperation and indirectly TC, as the latter is not a direct goal of CDM.

Just as CDM affects multiple issues, TC in non-Annex I countries is affected by multiple issues. Among others globalization and the removal of trade barriers (Dosi et al., 1988), high levels of foreign direct investment supported by political stability, strong rule of law and transparency (Borensztein et al., 1998; Radošević, 1999; Ellis et al., 2007b; Doranova et al., 2009), the current technological regime (Kemp et al., 1998) and the quality of the enabling environment (Bazilian et al., 2008; Thorne, 2008) influence TC in non-Annex I countries. In this research I aim to entangle the contribution of CDM.

The fact that CDM influences a range of issues and that TC in non-Annex I countries is also affected by numerous factors will have to be taken into account when distilling the relation between CDM and TC. This raises the question to what extent is CDM responsible for achieving TC in non-Annex I countries relative to other factors influencing TC (Ellis et al., 2007b).

4.2 The causal relation between CDM and TC

This section will explore the way CDM might influence TC. This relation is depicted in a causal model (see Figure 4-2) and based on theory. The relations within this causal model will be further studied within the course of this research.

Each of these relations will be discussed separately. This will include the rationale behind the causal relation or why it is expected to exist; what we already know from existing literature about the factors influencing this relation and the knowledge gaps with respect to this relation. These knowledge gaps will form the bridge between this chapter and the next chapter in which a method will be developed to further study the causal relations.

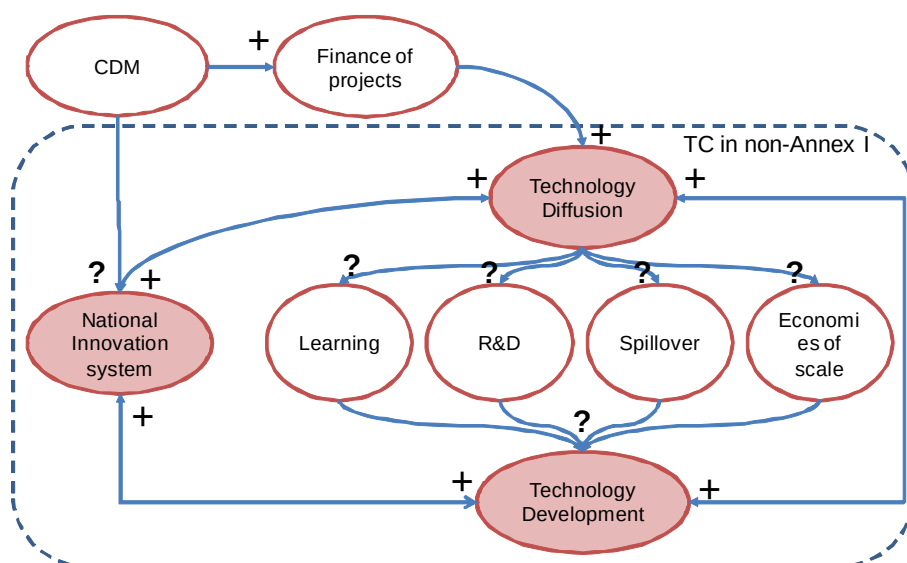


Figure 4-2 Causal relation between CDM and TC in non-Annex I countries

4.2.1 Causal relation between CDM and technology diffusion

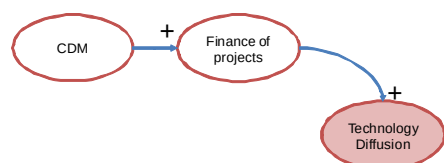


Figure 4-3 Causal relation between CDM and technology diffusion

The CDM is above all a diffusion mechanism. It co-finance projects that prove to be additional and decrease the greenhouse gasses below the baseline scenario. This relation is depicted in Figure 4-2 as CDM having a positive influence on project finance which has a positive influence on the diffusion of technology in non-Annex I countries

Within this link, the main challenge is to study to what extent CDM leads to technology diffusion and which variables influence the diffusion. In order to study what factors influence the impact of CDM on technology diffusion in non-Annex I countries we have to take the following research into account:

1. General factors influencing technology diffusion (Rogers, 2003)

2. Specific factors influencing technology diffusion of low carbon technologies (Montalvo et al., 2008)
3. Specific factors influencing technology diffusion in non-Annex I countries (World Bank, 2008)

We know that the distribution of projects between countries differs, that China holds the largest market share in CDM transaction and that the amount of transactions in Africa is catching up (Capoor et al., 2008). On a per capita basis Latin America attracts most projects and Africa least (UNEP/Risø, 2008b). There are indications that large projects are favoured over small scale projects due to lower transaction costs (Michaelowa et al., 2005; Chadwick, 2006; Ellis et al., 2007a) and I assume that CDM primarily attracts projects that have low abatement costs (Bakker et al., 2007; Ellis et al., 2007b, p19; McKinsey, 2009), thus lack of low cost reduction potential could be one explanation for the differences in diffusion between countries.

Another aspect that might impact the diffusion of projects would be the sustainable development criteria that are part of the approval process by DNAs. This might either lead to the decrease of projects that are not contributing to sustainable development or to an increase in projects that for instance score well on “technological wellbeing” (CDM.ID.0222). However among others Sutter (2003) concludes that there are no real incentives for DNAs to reject projects due to not passing their sustainability criteria.

Also interesting is the question whether CDM leads more to the diffusion of end of pipe solutions or more to the diffusion of clean energy technologies (Yarime, 2003).

There is a lack of knowledge with respect to how we can measure the impact of CDM on technology diffusion and the factors that influence the successful diffusion of technologies under CDM.

4.2.2 Causal relation between CDM and technology development

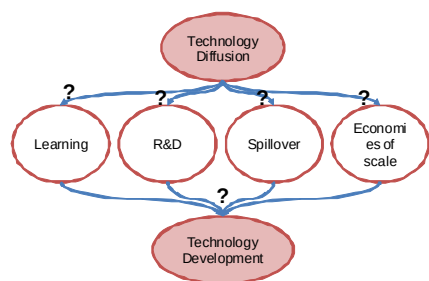


Figure 4-4 Causal relation between CDM and technology development

The second relation between CDM and TC indicates that technology diffusion caused by CDM projects could also have an impact on technology development. I put forward the hypothesis that CDM projects may carry with them characteristics that lead to learning, R&D, spillovers and economies of scale in non-Annex I countries.

This relation will still have to be explored and proven. A better understanding of this relation might be important to understanding the way CDM impact technology development in non-Annex I countries. In Table 4-1 I elaborate on the way CDM project could affect technology development. After that I will discuss what we already know about the relation between CDM and technology development and identify knowledge gaps.

Table 4-1 CDM effect on technology development

	<i>Description</i>
Learning-by-doing	Learning-by-doing is most certainly a result of a CDM project. It is in essence the result of any activity. The usefulness of the learning experience does depend on the circumstances such as whether local or foreign actors

	benefit from the learning experience and with which technologies the learning occurs (for instance whether learning occurs with advanced technologies or well known technologies).
R&D	The CDM is not a research policy, but a diffusion policy. But diffusion of technology provides important feedback for R&D. Apart from the feedback relation I expect that a CDM project could require adaptive research in order to adapt new technology to local circumstances. A third aspect is that CDM projects might implement R&D that was locally developed. Deployment of these new technologies might in turn allow for some recovery of R&D investment costs and thus stimulate R&D developments.
Spillover	Spillover refers to the extent that CDM leads to projects that are new in a sector or geographical region, but already known and used in another sector or region. This implies that a technology has spilled over from one sector or region to another sector or region.
Economies of Scale	The effect of CDM on the increase of economies of scale in non-Annex I countries depends on the amount to which CDM leads to an increase in the market for low carbon technologies in non-Annex I countries and the extent to which non-Annex I companies (or companies located in non-Annex I countries) are able to grab market share and their ability to scale up their business processes effectively.

What do we already know about the contribution of the CDM to technological development? Several authors reflect on this question by pointing out that technology development benefits of CDM projects may be part of CDMs contribution to sustainable development (Sutter, 2003; Olhoff et al., 2004; Olsen et al., 2008). A number of DNAs have included technology development orientated sustainable development criteria for CDM projects, such as among others: “project needs to contribute to technological well being” (India), “project needs to contribute to technological development” (Morocco and Brazil) or “projects should support technology transfer” (Olsen et al., 2008).

However the studies looking at the SD benefits of CDM focus on the non technological SD benefits (Olsen, 2007) and no studies were found that specifically take into account the technology development aspects.

In a recent study Olsen et al. (2008) did not take into account technology aspects in their method to measure sustainable development benefits since: “it has not been possible to come up with good indicators based on the information given in the PDDs” (Olsen et al., 2008; p2777).

Olsen (2007) concludes that according to literature CDM does not live up to its promise of SD. It does seem to function well as a market mechanism; as it does deliver cheap emission reduction credits. Important within this respect is the absence of an incentive for DNAs to be stringent on SD criteria when attracting foreign investment in CDM projects. Sutter (2003) refers to the effect of this competition as; “a race to the bottom”.

There is considerable literature on the affect of CDM on technology transfer (Haïtes et al., 2006; Paulsson, 2009)(see Appendix D for an overview of the literature). However as I will elaborate, the concept of technology transfer is not the same as technological development but only a small part of technological development.

Technology transfer is defined as the diffusion of non domestic technologies (Dechezleprêtre et al., 2009), which can includes both hardware and software. At first glance this appears to be the same as spillover. However: “the term ‘technology transfer’, which evokes technology as an object, and its transfer as a one-time transaction that maintains the dependence of the recipient, may not be adequate to reflect the process of technology diffusion and innovation (cd4cdm.org, 2003, p7)”.

Technology transfer without changing the dependence of the recipient is only a result of technology trade (Dosi et al., 1988). A technology that is transferred is only spilled over if it results in a change of local capabilities.

Technology transfer is most beneficial for developing countries if on the long run this technology does not only becomes diffused but actually spills over. This implies that technology transfer should in the long run decrease as local players develop capabilities to produce these technologies locally. If a decrease does not actually occur this would indicate that technology transfer merely indicates a market for western companies instead of the actual spillover of technological capabilities. Technological self reliance due to spillover would have a positive result on the countries balance of payments as more domestically produced technology can be applied (Olhoff et al., 2004, p84).

Technology transfer occurs in 30%-50% of all CDM projects (Haite et al., 2006; Coninck et al., 2007a) with most technology originating from Europe (Youngman et al., 2007).

Lower TT is witnessed in India (Seres, 2007). Lower TT might be partly explained by the size of India and its capabilities to diffuse locally produced technology (Dechezleprêtre et al., 2009). Another reason might be good technological capabilities in sectors that generally involve TT. However “strong technology capabilities are positively correlated with international transfers in China. In contrast, the technology capabilities of India seem to be rather geared towards the replication of CDM projects involving domestic technologies only” (Dechezleprêtre et al., 2009, p710). An example is the fact wind projects often involve TT (Dechezleprêtre et al., 2008), but that India has developed its own high-technological wind turbine manufacturing industry (Suzlon) and thus does not need to import the technology.

De Coninck et al. (2007) identify a trend in the development of high-technological industries in developing countries.

With respect to the transfer of technological capabilities Hansen (2008) indicates there are few incentives for companies to transfer advanced capabilities (such as engineering and management or innovative skills) to competing non-Annex I companies. The projects studied by Hansen mainly involved the transfer of basic operation and maintenance skills.

There is a knowledge gap concerning to what extent CDM projects lead to technological development and how to look at this topic in a wider fashion than only from the angle of technology transfer. The technology transfer perspective might benefit from an extended view that includes R&D, learning, spillover and economies of scale. An important part of this knowledge gap involves the question how to measure the impact of CDM on technology development.

4.2.3 Causal relation between CDM and the national innovation system

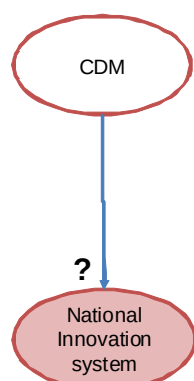


Figure 4-5 Causal relation between CDM and change of the innovation system

The third way in which CDM impacts TC could be through influencing the national innovation systems of non-Annex I countries. CDM is an international policy instrument and can be assumed to be a key policy instrument in the global innovation system, especially due to the large sums of money that flow through the CDM.

It is yet unknown in what way the CDM actually influences the national innovation system. Does it contribute to the improvement of the national innovation systems of non-Annex I countries or does strategic behaviour lead non-Annex I countries to actually weaken their own national innovation systems in order to attract more co-finance through CDM?

There are suggestions that CDM creates a perverse incentive to withhold stringent environmental policy, for stringent environmental policy would render projects non-additional under CDM rules (Lohmann, 2006, p148; Sterk et al., 2006; Halsnæs et al., 2008, p121; McCully, 2008; Wara et al., 2008). A description of the interaction between Indian electricity policy and CDM given by Babu et al. (2003), who also suggest that CDM might drive state electricity regulatory commissions “to set a pretty low Renewable Energy Portfolio Standard to promote CDM”. Literature on actor behaviour suggests that actors would behave strategically (de Bruijn et al., 1999; de Bruijn et al., 2002). There is however no empirical evidence in literature on CDM to support the claims of the perverse incentive. These are questions that still need to be studied.

There is a lack of knowledge with regard to what extent the CDM influences the national innovation system, if the perverse incentive is occurring and how to approach these questions.

5. How to measure the impact of the CDM on TC

In this chapter I will elaborate on existing research (section 5.1) and secondly I will develop a method for studying TC within the context of this research (section 5.2).

5.1 Existing methods for measuring TC

There is a lot of research both on TC and on CDM. A selection of relevant and important research fields for the context of this study had to be made. Therefore I will structure this section by first discussing research on TC and following with a discussion on CDM research. This section is structured as follows:

Studies related to TC:

- Studying TC within mainstream economics
- Studying TC from an evolutionary economic perspective

Studies related to CDM:

- Studies into the effect of CDM on sustainable development
- Studies into the effect of CDM on technology transfer

With respect to the studies related to TC, I would like to recall that previously, in section 3.8, I have given an overview of the different sciences involved in studying TC. This led to a view on technological change that is applicable in this research context. This technological view includes aspects from both economic and social sciences. In the following sections of this section I will elaborate on the methods that are used in economic and social science to study TC.

5.1.1 Mainstream economics theory

For an introduction of mainstream economic theory I refer to section 3.8. Common methods used for studying the effect of policy on TC within mainstream economics are: econometric analysis of meta-data about TC, which uses macroeconomic proxies for TC such as R&D spending, patents, citations or diffusion (see Appendix D).

However doing this research in developing countries might be difficult due to limited data availability.

5.1.2 Evolutionary socio economical theories

A more evolutionary perspective on TC, in which TC is seen as a socio technical transition is derived from evolutionary economics in combination with sociology. Limited by bounded rationality and uncertainty, actors satisfy instead of optimize. In evolutionary socio-economic theory routines, behaviour and the selection environment are important variables in explaining innovative behaviour and adoption of new technology. Innovation and adoption of innovations becomes less of a plan and more of a journey.

Methods used for measuring and studying technological change include case studies, interviews and historical storylines (narrative plots). These analyses try to identify recurring patterns and use these to strengthen theories about the importance of different elements that shape and structure these development and diffusion journeys (Rip et al., 1998; Geels et al., 2007b; Hekkert et al., 2007; Verbong et al., 2008).

Compared to mainstream economics, evolutionary socio economic theory takes a broad view on what is important in determining technological change. It takes a less linear perspective. Apart from market instruments a more diverse set of barriers and drivers is looked at. Evolutionary socio-economical studies are very focused on the dynamics of technologies and their systems over time, and tend to not analyse a single policy but rather a single technology over time.

5.1.3 Studies on the impact of CDM on sustainable development

As TC is by some authors mentioned as a SD benefit of CDM it is relevant to take a look into studies that analyse the effect of CDM on SD (see section 4.2.2).

A variety of studies has been conducted aimed at analyzing the impact of the CDM on sustainable development (one of the two official goals of the CDM). A review article by Olson (2007) provides a good overview of the different studies.

With respect to the methodologies used to study the SD benefits of CDM it becomes clear that checklists and multi criteria analysis are most often used (Olsen, 2007). Criteria are developed, scored and weighted; examples include the SouthSouthNorth matrix and the Gold Standard, both developed by NGOs and the SD criteria used by DNAs to determine the national SD benefits of CDM projects.

Sutter (2003) developed a method called multi-attribute assessment methodology (MATA-CDM), which includes that the criteria are weighted by project participants. To allow project participants to weigh the criteria Sutter used questionnaires that ought to be filled in and returned by the project participants. Unfortunately in his study only 4 out of 16 project developers responded to his call (Sutter et al., 2007).

Two examples of SD criteria related to technology:

- Technological self reliance (including project replicability, hard currency liability, skills development, institutional capacity, technology transfer) (Kenber, 2003).
- “Contribution to training and technological development: Assess the degree of technological innovation of the project and the technologies used in activities comparable to those called for in the project. The project should lead to the possibility of reproduction of the technologies used, taking account of their demonstration effect, and evaluating the origin of the equipment, the existence of royalties and technology licenses and the need for international technical assistance”(Olhoff et al., 2004). These are the criteria (on technology) used by the Brazilian DNA to check the sustainability of projects with respect to technological sustainability.

Studying the SD benefits of CDM projects that are mentioned in documents (PDD, LoI, and Validation reports) is in some cases combined with site visits, interviews and questionnaires to determine how well the project scored on the developed sustainability criteria in practise. Gupta (2008) mentions that the assessment of projects purely on the PDDs is difficult and that much more information can be gained through site visits.

In a recent article Olsen and Fenhann (2008) propose a method for analyzing SD benefits based on taxonomy. They perform text analysis of PDDs based on 13 SD criteria and score yes/no if these criteria are mentioned in the PDDs. They propose an international standard of SD assessment by DOEs, based on taxonomy, and additional to the checks performed by DNAs.

Their method however does not take into account technology aspects since: “it has not been possible to come up with good indicators based on the information given in the PDDs” (Olson, 2008; p2777).

5.1.4 Studies on the impact on CDM on technology transfer

The second relevant part of CDM impact studies focuses on studying the effect of CDM on technology transfer. A recent article by Schneider (2008) gives a good overview of the research that has been performed in recent years. Most authors that have studied TT under CDM have used PDDs as their main data source (Haïtes et al., 2006; Coninck et al., 2007a; Seres, 2007; Dechezleprêtre et al., 2008). In some cases the project developers were contacted when data from the PDDs was insufficient. They used regression analysis to determine the main dependent variables determining technology transfer.

The main findings from these studies (see Appendix D for a full review of the findings) include the fact that larger projects and the involvement of foreign partners increases the occurrence of technology transfer.

One limitation to the method using PDDs is that this method only tells whether technology transfer is mentioned in the PDD or not. It does not give quantitative judgement to the value or weight given to the different kinds of technologies transferred. An example of the limitations is given by Haites (2006, p342): "technology transfer is claimed for some projects with very simple technology (e.g. solar cookers); while no technology transfer is claimed in other projects where it might be expected (e.g. wind power)".

An exception to the above mentioned studies is a study by Hansen (2008) in which he analysis Malaysian CDM cases through field work and interviews to get an improved understanding of the process behind technology transfer of firm related technological capabilities. This study brings to the attention the unwillingness of the technology supplying company to transfer valuable advanced technological capabilities to (competing) non-Annex I companies.

An article by Schneider (2008) uses existing empirical analysis on technology transfer and expert interviews to increase the understanding of the barriers of TT under CDM. By analyzing CDM's influence on the barriers (commercial viability, lacking information, access to information and institutional framework), Schneider recommends policymakers to further reduce the transaction costs of the CDM and to pay attention to the need of receiving countries to improve their institutional framework and not to rely on CDM only for technology transfer. Schneider recommends further studies into the different technologies and the quality (what kind of technology and under what deal structure does TT take place) of their transfer and the strategic behaviour of actors involved in CDM projects.

5.2 Research method used in this report

The research method applied in Chapter 6 is based on the insights gained on CDM (chapter 2), the perspective on TC that was developed in chapter 3, the interconnection between CDM and TC (chapter 4), the research already performed related to measuring TC and research on the impact of the CDM on various aspects (section 5.1).

The method developed for this research contains three aspects.

First of all the distinction between three different aspects of technological change and their measurement (see section 3.9)

- Technology diffusion
- Technology development
- Change in the innovation system

Secondly the different indicators and the data that are required to measure each aspect of technological change induced by CDM. This includes:

- Data from the CDM pipeline database
- Global and national greenhouse gas emission data
- Project design documents (all data gathered from the systematic analysis of PDDs will be placed in an excel database).
- Literature and freely available data

Thirdly it contains the application and testing of the method in a number of case studies. These case studies will be used to see if the method is suitable and to draw conclusions about the impact of CDM on TC within the case studies.

5.2.1 Measuring technology diffusion

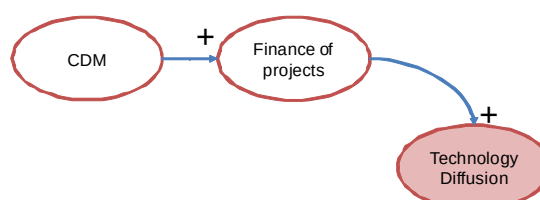


Figure 5-1 Causal relation between CDM and technology diffusion

With respect to the relation between CDM and the diffusion of technology (see Figure 5-1), four measurable indicators were developed (see Table 5-1). I will use global data on greenhouse gas emission per year per country and relate those to the CERs generated per country per year to measure general technology diffusion caused by CDM. Secondly I will choose a specific country and look at the GHG emissions per sector per year and relate those to the CERs generated in each sector per year. Based on this analysis I will choose three specific case studies. For these case studies I will look at the level of diffusion of specific technologies and also look for indicators of technology development and change in the innovation system (see the next section s) within a number of PDDs.

Table 5-1 Variables and indicators of technology diffusion

<i>Variable</i>	<i>Indicators</i>	<i>Measurement</i>
1. To what extent did the project(s) lead to the diffusion of technologies?	• Current level of diffusion • Potential for diffusion • Role of CDM in diffusion • Encourages further diffusion	-General:[CERs/GHG emission] -Additional diffusion data: [depends on data availability] [depends on data availability] [depends on data availability] [#PDDs mentioning indicator]

In order to study this relation I will use available data on historical GHG emissions on a country and sector level. This GHG emission data can be placed in proportion to the amount of CERs that are generated in a specific country and sector. This indicates on a general level the amount of diffusion within a country or sector.

Specific data on the diffusion of specific technologies within the different case studies would result in more detailed information about the effect of CDM on the diffusion of specific technologies. That finding data about the extent of diffusion of a technology in a non-Annex I country will prove to be a challenge is already mentioned by Mathur (2007) in his proposal for a diffusion-innovation based approach to additionality.

In order to put this information into perspective this research will also study the potential for diffusion and the role of CDM in the current level of diffusion of specific technologies. The exact measurement will be dependent on the specific cases studied and the technologies that are used within this sector.

Within PDDs I will look whether the PDDs mention that the project encourages further diffusion of the technology.

5.2.2 Measuring technology development

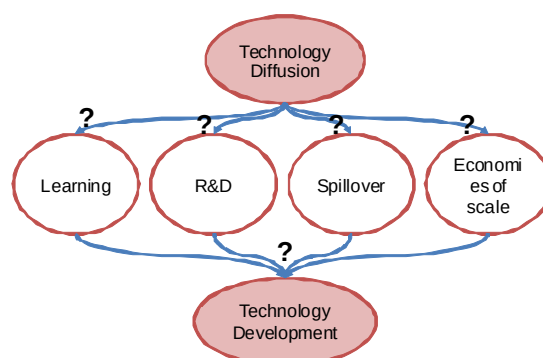


Figure 5-2 Causal relation between CDM and technology development

With respect to the question whether CDM also encourages technology development (see Figure 5-2) this research will take a closer look into the PDDs. The question is whether CDM projects carry with them the benefits of technology development complementary to their impact on technology diffusion. For each variable of technology development (learning, R&D, spillover and economies of scale) indicators were developed and made measurable (see Table 5-2).

I assume that the CDM project would not have happened in the absence of CDM (I assume that the projects are truly additional) and that the benefits of these projects such as learning, R&D, spillovers and economies of scale would not have happened either had the CDM project not been undertaken. This causal relation is open for discussion for it might be that the technology development benefits would have happened in the absence of CDM finance and are merely a co aspect of projects and not necessarily the result of the project.

Table 5-2 Variables and indicators of technology development

<i>Variables</i>	<i>Indicators</i>	<i>Measurement</i>
2. To what extent did the project(s) deliver learning experience?	• Involvement of domestic actors • Technology's level of maturity • Contribution to skill building • Custom or novel design	[#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator]
3. To what extent did the project(s) stimulate R&D?	• Connection to R&D project • Adaptive research performed • Feedback to R&D	[#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator]

4. To what extent did the project(s) lead to spillovers?	• Hardware or software transferred • First in the world • First in India • First in State • First in Sector	[#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator]
5. To what extent did the project(s) contribute to improved economies of scale?	• Scaling up of national industry	[Data about the size of the LCT technology's market and market development]

In order to learn from projects one has to be actively involved in the project. I will therefore look at whether the PDDs give us information about the different actors involved in the CDM project and their different roles. This way it may become clear from the PDDs whether the learning effect of the execution of a project goes to a non-Annex I company, Annex I company/institution or combination of both.

The indicator about the technology's level of maturity relates to the question whether the learning effect is derived by using an already well understood technology or whether the learning effect relates to learning occurring from the projects using novel technology (Olhoff et al., 2004, p62).

I will also look at whether a project mentions contributing to skill building and if the project mentions using novel or custom made designs.

With respect to R&D I will analyse whether there are CDM projects that mention a relation to a previous research project in their PDD. If this is the case the execution of the CDM project could be seen as a possibility of both rent extraction and deployment of a novel technology and thus considered to stimulate R&D.

Secondly I will consider whether PDDs mention that the project included adaptive research. This research is important to adapt alien technology to local circumstances, for instances due to specific plant design, different climate or different feedstock characteristics.

Thirdly I will look whether the project PDDs mention a feedback from the project to R&D projects.

With respect to spillover, PDDs will be scanned to see if they mention the transfer of hardware (technology) or software (skills and knowledge). PDDs will also be scanned to check whether the PDDs mentions whether projects are first of its kind, either first in the world, first in India, first in the state or first within the sector.

In order to get an impression of the effect of CDM on increased economy of scale I propose to use market data. The market size for a technology can be measured in terms of units sold or installed each year in combination with the price of the unit (market= #units * price per unit). An increase in the market combined with a market share for domestic companies, would imply that local production capacity would increase, leading to economies of scale. More detailed information on a company level is outside the scope of this research. However company specific information about costs would be useful, although I do expect this kind of information to be difficult to acquire since companies might consider this information as confidential.

5.2.3 Measuring change in the innovation system

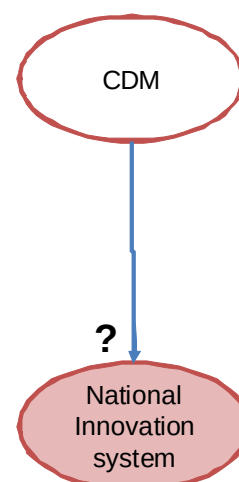


Figure 5-3 Possible causal relation between CDM and change of the innovation system

Measuring the impact of the CDM on the national innovation system (see Figure 5-3) is likely to be difficult (Sharif, 2006). I will try to look for indicators of change in the innovation system within the PDDs (see Table 5-3). Apart from screening PDDs I will also reflect on other research that mentions this relation. I will do this in the discussion chapter.

Table 5-3 Variables and indicators of change in the innovation system

<i>Variable</i>	<i>Indicators</i>	<i>Measurement</i>
6. Did the CDM project contribute to strengthening the receiving countries innovation system?	• Policy implications • Infrastructure adjustments • Corporate responsibility • Support collaboration • Connection with other industry	[#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator] [#PDDs mentioning indicator]

Within the PDDs I will check to see if the PDDs mention that the projects have an impact on local policy, whether the project lead to adjustments of the current infrastructure, whether it improved corporate responsibility, whether it supported collaboration between different institutions and whether it improved the relations between different industries (OECD, 1997).

6. Empirical results from the case studies

In this chapter I will present results of technology diffusion assessments between countries. Based on that assessment, one country will be selected. A more detailed studying will be done on the industry sectors of that specific country CDM had a large impact. Three of these sectors will be analysed in more detail (analysing technology diffusion, technology development and change in the national innovation system). The results of these case studies will be presented in this chapter.

6.1 Impact of CDM on technology diffusion in different countries

The global technology diffusion impact assessment of Asian countries is based on data from UNEP/Risø (2008a) and Höhne (2008). The emission levels are based on the emission levels of 2006 as stated by Höhne (2008) and focuses on the largest GHG emitters ($>135\text{MtCO}_2\text{-eq/y}$ in 2006) of Asia. The CERs per country are based on the CDM pipeline database of UNEP/Risø (2008a). Figure 6-1 shows the impact assessment for the selected Asian countries (see also Appendix C for an analysis of Latin America).

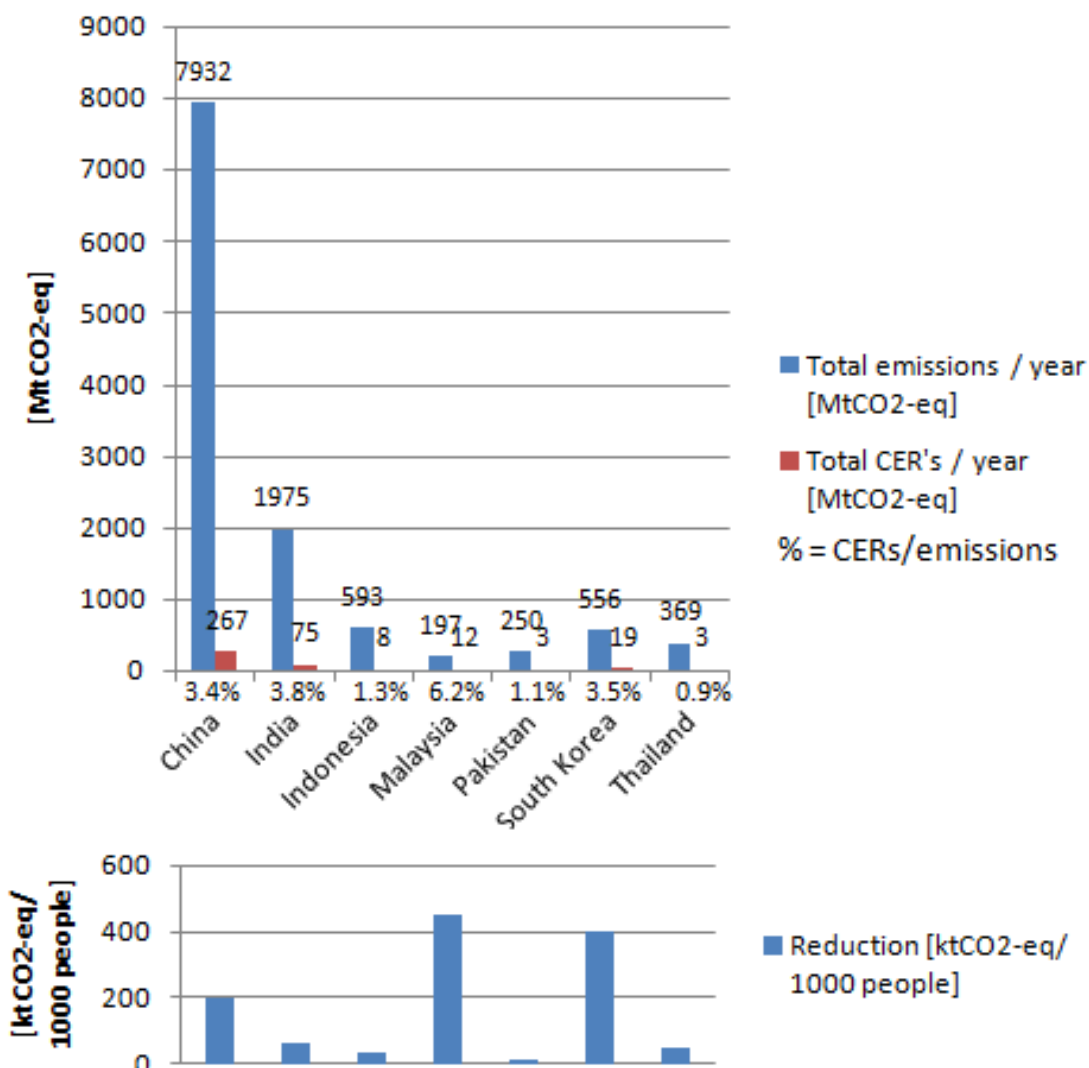


Figure 6-1 Global impact assessment: Asia

China draws attention with the largest number of GHGs, a high level of CERs related to their total emission (3.4%) and a high number credits per capita (200ktCO₂-eq/1000people). Apart from China (and not taking account of the small countries): India, Malaysia and South Korea have a large number of CERs compared to their emissions. This indicates a relatively large impact within their sectors. India scores lower on a per capita basis than China, Malaysia and South Korea. This may be (partly) related to a lower per capita emission level.

The impact assessment that focuses on Latin America (see Appendix C) indicates large impact measured in CERs/emissions in Chile, Brazil, Nicaragua and Panama.

For the sector-specific impacts study a single country has been selected since the data on the sector specific GHG emission data in relation to CERs is not readily available for each country. Thus this data has to be constructed using multiple sources which is time consuming. Based on the global impact assessment India was chosen for further study. The main reasons for choosing India are:

- The large number of CDM projects (over 1000 CDM projects are currently in the Indian pipeline).
- There is a large range of different projects undertaken in India
- Data availability on GHG emissions in India
- The fact that official literature is in English

6.2 Impact of CDM on technology diffusion in different sectors in India

After the assessment of the impact of CDM on technology diffusion in different countries I performed an assessment of the impact of CDM on technology diffusion within different sectors in India. The global impact assessment gave insight into which countries were more heavily impacted by CDM; the country level impact assessment was performed to give more insight into the impact of the CDM on the sectoral level (see Figure 6-2).

No consistent data of recent emission levels on a sector level in India was found in a single source. The data had to be estimated and reconstructed from different sources. The data from the International Energy Agency (IEA, 2008) was used to get the CO₂ emissions from fuel combustion in 2005, the National Communication (GoI, 2004) was used to extrapolate the CO₂ emissions by the process industry from 1995 to 2005 based on a 37% increase in CO₂ emissions from fuel combustion over the same period. Data from non CO₂ gasses was derived from Garg (2006) (see Appendix E for details).

The pipeline (UNEP/Risø, 2008a) provided information about the CERs per year (see also Appendix E). The categorisation used in the above mentioned documents is different from the categorisation used in the CDM pipeline. A combination between both had to be made, taking into account the accuracy and the relevance of the new categorisation that was used in Figure 6-2.

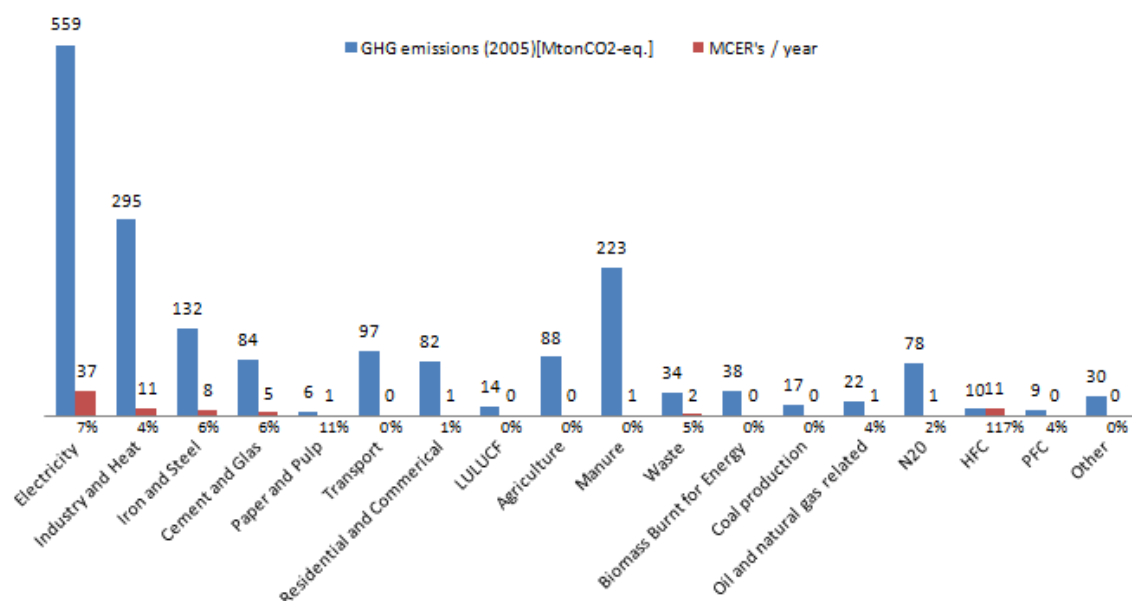


Figure 6-2 Country technology diffusion impact assessment: India (see also Appendix E)

Figure 6-2 shows big differences between the impacts of CDM on technology diffusion between sectors. The relative impact of the different sectors and notes about possible explanations are presented in Table 6-1. The impact is categorised based on the percentage of CERs generated relative to the level of GHG emission in the sector.

Table 6-1 Relative impact between sectors in India

Impact	Sectors	Notes
Around 100% (high)	HFC destruction	This was to be expected, since HFC-23 destruc- tion CDM projects are relatively simple and highly profitable. What remains
Between 2-11% (medium)	- Electricity sector - Industry and Heat sector - Iron and Steel sector - Cement and Glass sector - Paper and Pulp sector - Waste Sector - Oil and Natural gas related - N2O	Possible explanations for the differences between the sectors might be due to different characteris- tics of the sectors: such as whether the sector is highly international, whether domestic policies encourage CDM within the sector, the availability of large low cost abatement opportunities, the ex- istence of good methodologies or the existence of strong national knowledge and technological ca- pabilities. It would also be interesting to see whether there are differences between Indian sectors and the same sector in other countries
Between 0-1% (low)	- Manure - Transport - Residential and Commer- cial - LULUCF - Agriculture - Biomass burnt for energy in the domestic sector - Coal production	Possible explanations could be the lack of suitable methodologies or the lack of low cost abatement opportunities.

The impact assessment (see Figure 6-2) shows that CDM has a different impact on technology diffusion within different sectors. Table 6-1 notes the importance of different characteristics of sectors as an explanation of the differences.

I propose to study the impact of CDM on TC in more detail by looking at sector specific case studies. These case studies will take different sectors and study them in more detail to:

1. improve our understanding of technology diffusion under CDM within that sector
2. study the technology development benefits of CDM projects
3. study the effects of CDM on the national innovation system

In consultation with experts it was decided to study the following sectors, for the following reasons:

1. Electricity sector, with a large impact and a range of different technologies that can be applied this sector is especially interesting. Still many rural areas do not have electricity and electrification is an important goal in Indian politics.
2. Iron and Steel sector: The iron and Steel sector is a well defined sector and operates in a global market. In recent years the industry grew a lot due to increased demand in developing countries. Only recently, due to the financial crisis, did the sector see a sharp decrease in demand.
3. HFC producing industry: This sector is controversial and still part of debate as to whether certain projects should be eligible for credits. Relatively simple technological measures resulted in the generation of large amount of credits and profit. A more specific look at the technological change that took place in this sector might prove useful to the ongoing debate.

After each analysis I will present major findings about the technological change that took place within the sector. I will also reflect upon the experience of using the method that was developed for this study.

6.3 Case 1: Electricity sector

In this section I will analyse technological change in the Indian electricity sector in more detail. The focus of the analysis will be on the wind sector.

I will proceed with an introduction to the Indian energy sector. After that I will analyse the wind sector. The structure of the analysis will follow the six variables of technological change (see section 5.2). I will end the analysis with a summary of the key findings.

PDD selection

For the analysis of the Indian electricity sector I selected 14 Indian CDM projects from the CDM pipeline. I took PPDs from a number of different sectors to get a general picture of the differences and look into one specific technology into more detail (wind).

- 14 PDD were studied
 - o 6 Wind projects
 - o 2 Hydro projects
 - o 3 Energy Efficiency projects
 - o 3 Biomass Projects

6.3.1 Introduction into the Indian energy sector

India is a large country, faced with an enormous electricity demand challenge. Many people in India do not have access to electricity, especially in rural areas (about 400 million are deprived of electricity (IEA, 2007a)). With a current installed capacity of 146 GW the country needs to increase this capacity by 100 GW to 255GW by 2015 and up to 522GW in 2030 to meet demand (IEA, 2007a). The GoI even targets a capacity increase up to 800GW by 2030 (GoI, 2006). The price of energy is the major determinant in choosing energy technologies, since providing cheap energy to the masses is the current priority of the Indian government (GoI, 2006). To meet this demand India will need to invest approximately \$1.25 trillion, of which three quarters in the electricity infrastructure (IEA, 2007a). This additional capacity is expected to be mainly derived from coal in combination with nuclear and hydropower (IEA, 2007a). Seeking clean coal combustion technologies is therefore of great importance.

The country has a strong focus on large-scale power projects of over 1000MW thermal or 500MW hydropower (9 project sites for 4000MW thermal each have been identified (GoI, 2007)). These mega projects share the promise of large amounts of cheap electricity. With a low GDP per capita and a still relatively small carbon footprint per capita Indian policy has a strong focus on economic development and believes that mainly “the west” is responsible for realizing GHG emission reductions.

There is also a lot to gain in India from improved energy efficiency using available technologies. India consumes 0.16kg of oil equivalent (kgoe) per dollar of GDP which is lower than in China (0.23kgoe) or US (0.22kgoe) but higher than Denmark (0.13kgoe) or Brazil (0.15kgoe) (GoI, 2006). According to the government of India this indicates that there are possibilities of increasing energy efficiency. For instance energy efficiency of power generation could be improved from an average of 30.5% to 34% by building modern efficiency plants of 36-40% efficiency (GoI, 2006).

By 2012 it is expected that India will generate about 10GW from renewable energy (PDD, 2005). By 2030 the GoI (2006) plans to supply 5-6% of the India energy mix from renewable sources.

Globally, electricity firms generally spend 2% of their turnover on R&D, while in India large energy companies spend only about 0.2% (GoI, 2006). The government recognizes the need to boost R&D. Priority areas named by the government are (GoI, 2006):

- Coal technologies for efficiency improvements (coal is named as a focus area)
- In-situ gasification

- IGCC and Carbon Sequestration
- Solar power
- Bio fuels; bio-diesel and bio-ethanol
- Biomass gasification; plantations, wood gasification, community based bio-gas plants

The government's actions to fight climate change can be summarized as follows (GoI, 2006):

- Energy efficiency measures in all sectors
- Investment in mass transportation
- Supporting policy for renewables
- Development of hydropower and nuclear
- Development of clean coal technologies
- R&D on climate friendly technologies

Although the central government steers national development activities, energy supply is a decentralized state responsibility. The energy sector in India is dominated by state owned firms, with an increasing move towards more privatization since the 90's, mainly to attract much needed investments (IEA, 2006). There are large differences between the different states in India; the BNP of Goa is about ten times that of Bihar, a much more populated state. India has five different regional grids for electricity, with underdeveloped interconnections. Realizing the needed regulatory reforms and private investment is a big challenge. The Indian Electricity Act 2003 paved the way for the needed reforms, including improved access to the transportation and distribution networks, removal of certain license requirements, anti-electricity theft measures, removal of cross subsidies, power trading and improved regulatory responsibilities (CDM EB, 2005).

6.3.2 Impact of CDM on of the Indian electricity sector

In this section I will use the methodology developed in chapter 5 to discuss the impact of the Clean Development Mechanism on technological change in the Indian electricity sector.

The results of the analysis are focused on one specific sub-sector: the wind sector. This allows a thorough analysis of the wind sector and creates a better opportunity to evaluate the methodology. The results of the analysis of the wind sector are presented in three different stages. First I will deal with findings related to technology diffusion, secondly to the findings relate to learning, R&D, spillover and economies of scale and thirdly with the findings related to the impact on the innovation system. After the analysis of the wind sector I will present a selection of the findings from the other PDDs analysed.

Technology Diffusion

Wind power is on the rise in India. Over the past years the installed capacity has been exponentially growing (see Figure 6-3). As of 2009 there is over 9.5GW of installed capacity within India (Thewindpower.net, 2008).

The earliest CDM projects started generating credits from the 1st of April 2000, since then the number of Indian wind turbine projects within the pipeline has grown to 226 (UNEP/Risø, 2008a). Of the 226 projects, 73 Project use methodology ACM2 (“grid-connected electricity generation for renewable sources”), the other 143 use AMS-I.D (“small scale method: renewable electricity generation for a grid”). The CDM projects add up to 4.2GW, with a total installed capacity of 4,083MW at the end of 2008.

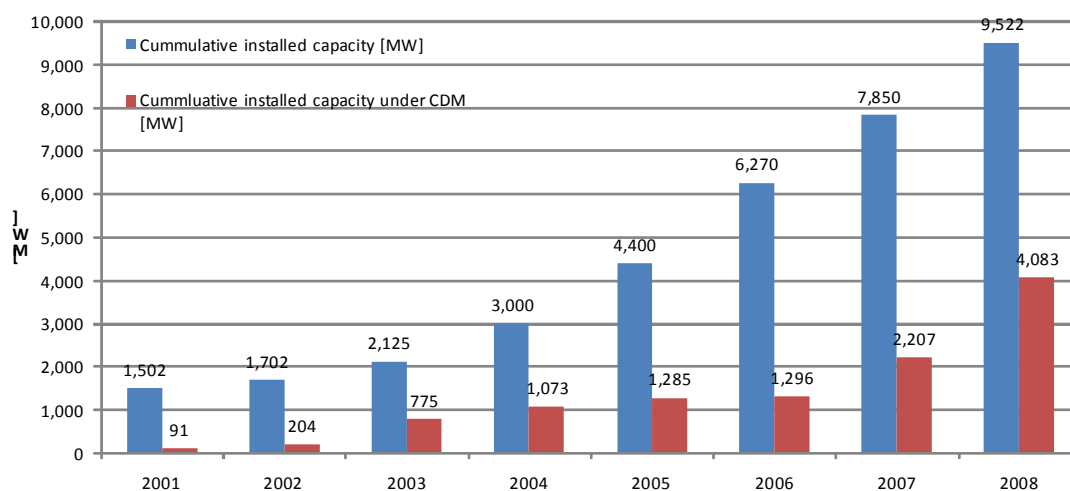


Figure 6-3 Cumulative total installed capacity and cumulative development under CDM (see Appendix F)

By the end of 2008 the CDM contributed to 43% of the total installed capacity of India (see Figure 6-3 and Appendix F). In 2007 the CDM played a role in 58% of all MW installed capacity and in 2008 it contributed to over 100% of all installed capacity (see Figure 6-4 and Appendix F). The latter could be explained by the different data sets that might contribute some projects to different years.

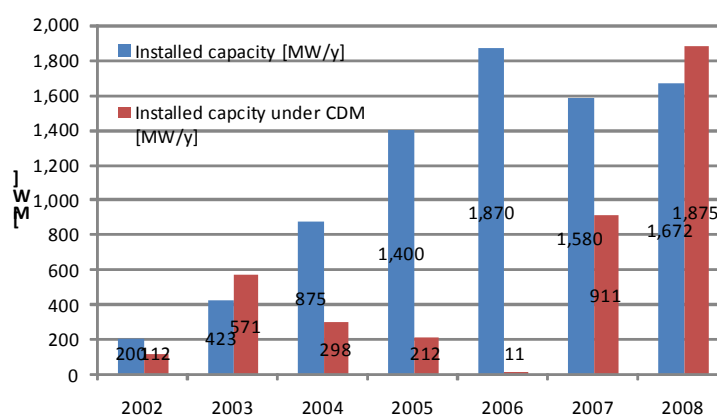


Figure 6-4 Yearly capacity instalments

In 2003 most capacity that was installed received CDM funding. Between 2003 and 2007 this number decreased significantly although the expansion of wind power continued (Figure 6-4). There is only one project in the CDM pipeline that has 2006 as the starting date of its credits. In 2008 the number of projects receiving CDM credits rose and in 2008 most projects received CDM credits. PDD 0991p25 (registered in 2007) specifically mentions that 97% of wind projects developed at that time in Tamil Nadu are co-financed by CDM. This gives rise to the impression that since 2002 a number of wind turbine projects were implemented without CDM co-financing, but that this practice is becoming scarcer in 2007 and 2008 and that currently most new projects are co-financed through CDM.

The diffusion of wind power differs between the different states of India (see Figure 6-5 and Appendix G). This analysis is based on the gross potential and technical potential (MNRE, 2005), the installed wind turbine capacity at the end of 2008 (InWEA, 2009) and the installed capacity under CDM (UNEP/Risø, 2008a). The technical potential for wind power is limited to 20% of the total grid power capacity of 2004 (MNRE, 2005). Since the total capacity of the Indian network is expected to increase, the technical feasible potential for wind power is expected to rise as well, until it equals the gross potential. Tamil Nadu had the largest installed capacity as of March 2008, followed by Maharashtra and Gujarat. Most CDM projects were developed in Tamil Nadu, followed by Maharashtra and Karnataka.

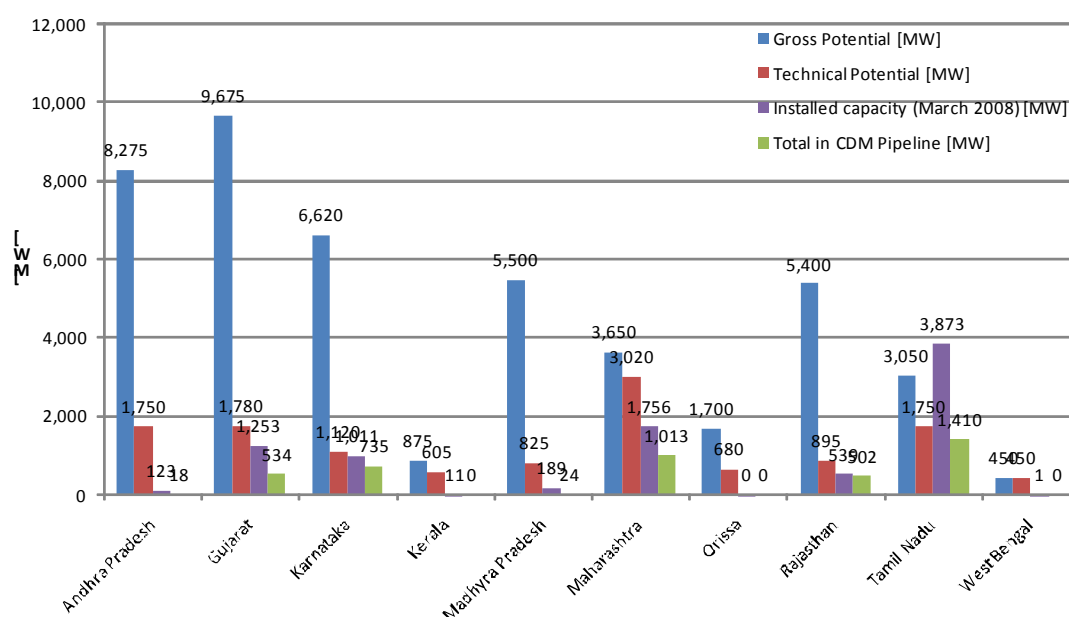


Figure 6-5 Diffusion analysis: wind power in different states of India

There is a total gross potential of 45GW in India (see Figure 6-6), of which 13GW is technically feasible taking into account a maximum of 20% grid penetration and the power production of 2004 (see Appendix G). The largest gross potentials are located in Gujarat and Andhra Pradesh (see Figure 6-5).

The contribution of wind power to the total national electricity coverage is 2% in India, relative to 4.5% in the Netherlands and 20% in Denmark as of the end of 2008 (WSH, 2009).

Based on the fact that there is still a very large unused potential for wind power and that the amount of wind power connected to the grid is still only 2%, it can be expected that there will be a continuation of new wind power projects in India.

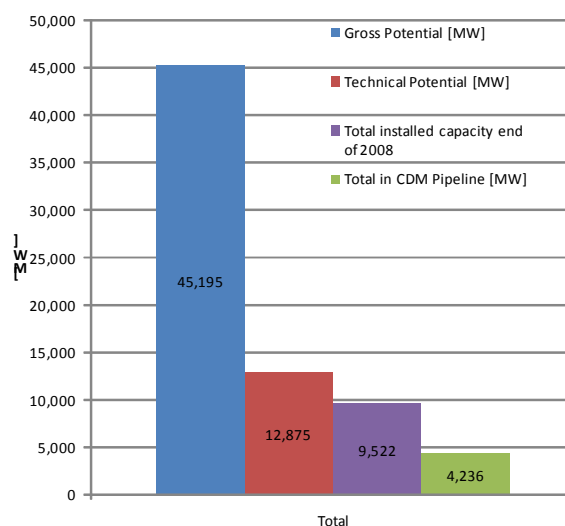


Figure 6-6 Diffusion analysis: wind power in India (see Appendix F for the references)

In sum, CDM plays a role in the diffusion of wind power in India, assuming a large share of the projects to be additional. There appears to be a trend of an increasing number of wind turbine projects that are being co-financed by CDM. The summary of this analysis is presented in Table 6-2.

Table 6-2 Summary of findings related to the diffusion of wind power projects in India

Diffusion (see also Appendix F and Appendix G)	
Current level of diffusion	43% of the total installed wind power capacity of India is co-financed by CDM
Potential for diffusion	There is a gross potential for wind power of 45GW and an installed capacity of 9.2GW, of which 4.1GW is co-financed by CDM.
Role of CDM in realising diffusion	From 2007 to 2008 the amount of new wind projects being developed that includes CDM co-finance moved up to 100%.
Encouragement for further diffusion	The PDDs do not mention that these projects would encourage similar projects.

Technology Development

To judge the role of CDM in technology development I will take a look at learning, R&D, spillovers and economies of scale.

Companies learn as a result of being involved in projects. To understand what impact these project have on learning within India it is interesting to see whether Indian or non-Indian firms benefit from the development of the projects. Figure 6-7 presents the results of linguistic studies into the number of times the 10 largest companies were named related to CDM projects in India and China respectively (see Appendix I for an explanation about this method).

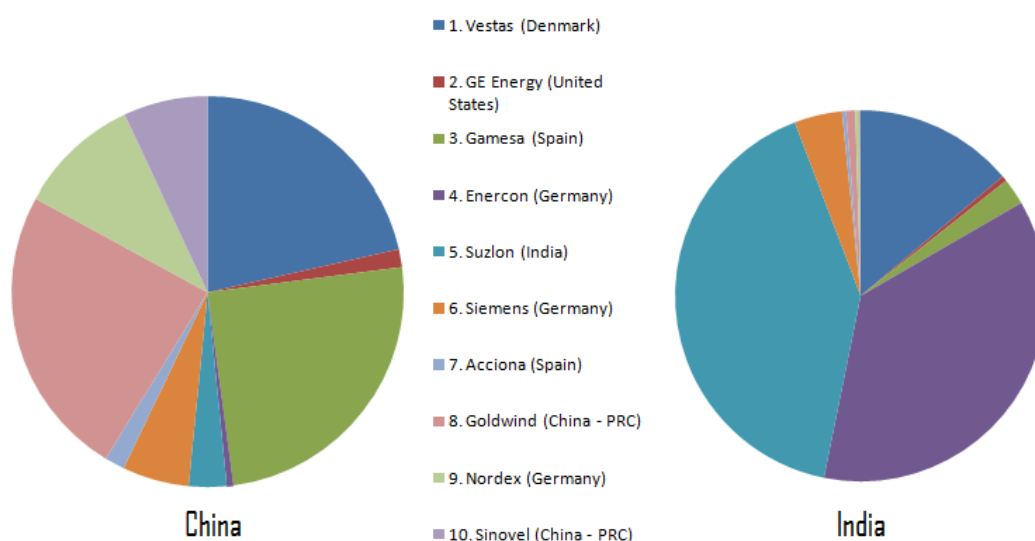


Figure 6-7 Indication of market shares of turbine manufacturers in China and India based on linguistic study (see Appendix I)

This analysis shows the presence of Suzlon in India. Suzlon is an Indian company that recently bought a number of European wind power research and development firms. Its presence helps to establish India as a leader manufacturer of wind turbines. The analysis also shows the presence of Chinese companies active on the Chinese market and a presence in both India and China of European firms, mainly Vestas (Denmark), Gamesa (Spain) and Enercon (Germany).

The R&D in the wind sector is still mainly carried out in Europe and US. From the analysis it becomes clear that India has grown to one of the leading global companies in the production of wind energy solutions (Suzlon) and that this company has recently acquired western R&D companies. In this manner Suzlon has gained innovative capabilities.

Most of the hardware is developed in India because both Suzlon as well as other wind power companies have manufacturing facilities in India.

The findings related to technology development and the role CDM plays within this development are summarized in Table 6-3.

Table 6-3 Technology development related to CDM in the Indian wind sector

Learning	
Local or foreign actors involved	• PDDs make reference to the vendors of wind turbines. Among these vendors Suzlon (Indian), Vestas (Danish) and Enercon (Germany) are often mentioned. • Suzlon has recently acquired a number of European research and development companies (Suzlon, 2009). This increased the ability of Suzlon to innovate and develop new and improved wind turbine designs.
Development stage of technology used	• Wind energy is a well developed technology in a commercial stage. • One PDD mentions that the project installed new turbine models (CDM.ID.1333).
R&D	
Part of R&D project	• No specific references are made to R&D projects.
Adaptive research performed	• One project mentions a technical barrier due to the pioneering nature of the project due to non-compliance of local and foreign parts. (CDM.ID.0658)
Feedback to R&D	• -
Spillover	
Hard-ware/software transferred	• By acquiring Dutch, German and Danish wind R&D companies Suzlon strengthened its innovative capabilities. Because of these acquisitions Suzlon is better capable of innovating its products and developing new ones. Because CDM plays a role in the diffusion of wind turbines in India, it might have contributed to generating the finance needed to make these acquisitions. • Enercon (Germany) has opened up manufacturing facilities in India (CDM.ID.0120)
First in India/World /State or Industry	• Projects are not mentioned as being first of its kind. Wind farms are a well known commercial technology, also in India.
Economies of scale	
Up scaling of national industry	• The large involvement of Suzlon and its growth are an indication of the fact that the Indian Wind Industry is scaling up. The fact that most new wind farms in India are co-financed by CDM is an indication that CDM is contributing to the market expansion.

Innovation System

This analysis found that possible changes in the innovation system (“set of institutions that contribute to the development and diffusion of technology” (Metcalfe, 1995)), as a result of CDM, are difficult to find by studying PDDs.

One aspect that was found when studying the PDDs were that 4 out of 6 wind PDDs studied made a statement about state or national wind power policy and that in each case it was clearly stated that wind power is inadequately supported by state or national policy to render the projects feasible. It is unsurprising that PDDs state that domestic wind power policy is insufficient to stimulate the development of wind power projects, since projects need to pass the additionality check.

Mandatory laws and regulation are part of the first step of determining additionality of a project. In the first step of determining additionality alternatives to the proposed project have to be identified that are in line with regulations and law (CDM EB, 2009). Strict environmental laws and regulation would thus automatically render projects not-additional. The second step involves investment analysis, to determine if the project would actually be executed without CDM revenues, which involves taking into account local stimulation measures.

The GoI and states have their own stimulation packages to stimulate the development of wind power. These include sales tax, feed in tariffs and policy targets (CDM.ID.1333). It however becomes clear from the PDDs that wind projects claim that the stimulation measures of the states are unreliable or insufficient to stimulate wind power projects on their own.

However diffusion analysis suggests that before 2007 India developed wind power projects without the CDM, but has learned to use CDM in addition to domestic support (see Figure 6-3 & Figure 6-4).

The findings related to the effect of CDM on the innovation system are summarized in Table 6-4.

Table 6-4 The impact of CDM wind power projects on the innovation system

<i>Innovation system</i>	
Policy implications	• Four projects studied claim that state policy prior to 2001 was more favourable to wind power than current policy (CDM.ID.0120&1333&0451&1362). • One PDD mentions that government wind policy is in place but that it is irregular and of non-conductive nature (CDM.ID.0658).
Infrastructure adjustments	• -
Corporate responsibility	• -
Support collaboration	• One very large project (468 MW, CDM.ID.1362) was initiated by an industrial association representing spinning mills (clothing industry). The PDD makes reference to the fact that this project worked very closely with public institutions and it helped encourage its members to participate in this project.
Connection with other industry	• In project CDM.ID.1362 wind parks are combined with planting Jatropha trees that can be used to produce bio oils.

6.3.3 Noticeable findings from the other PDDs that were analysed

The other PDDs that were studied will not be dealt with within the structured framework, as the main focus of this case study was the wind sector. Analysing these PDDs did however lead to some interesting findings.

Electricity generation under CDM

India plans to develop 100GW of additional capacity by 2012 of which 10GW is planned to be derived from renewable energy sources (PDD, 2005).

From the analysis of the CDM pipeline database it becomes clear that all CDM project in India (all project except the rejected and the withdrawn projects) add up to 20GW (see Figure 6-8).

Figure 6-9 depicts the different categories in which these GWs are realised. Energy Efficiency supply side projects are involved in the installation of an additional 5.4GW installed capacity. Within this category there is one mega project that proposes to generate credits by installing supercritical turbines up to 4GW of 43% efficiency instead of the more expensive and common practise method of using subcritical technology of 31% efficiency (this project claims to be first of its kind in India using supercritical technology).

Projects in the category biomass energy contain mainly projects that use bagasse or agricultural residues to generate electricity. Projects in the category fossil fuel switch are mainly derived from 6 power plants that switched to natural gas. The lion's share of MW generated by projects in the EE own generation comes from projects in the iron and steel or coke oven industries. The biomass energy sector, hydro sector and the wind sector (the main renewable energy sources categories) together add up to about 9GW of installed capacity.

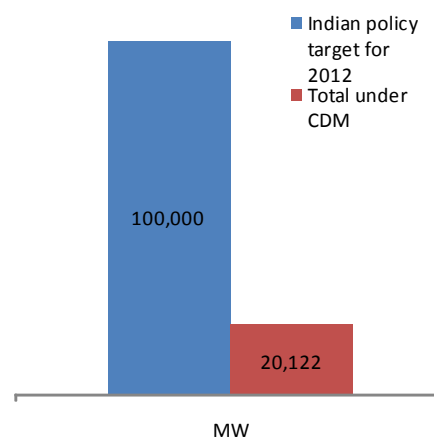


Figure 6-8 Contribution of CDM to India's national electricity ambition

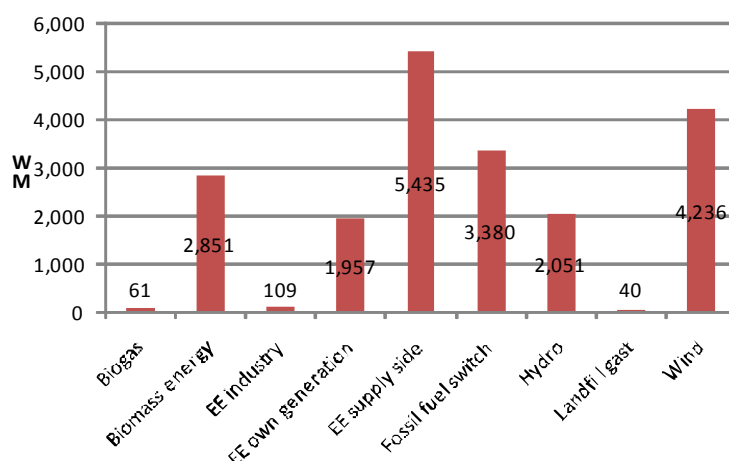


Figure 6-9 Different categories in which MWs from CDM projects are installed

The analysis thus shows that CDM is involved in up to 20% (20GW) of the current policy target of adding 100GW by 2012 and up to 90% of the renewables target of 10GW by 2012.

This however has to be seen in the context of the long term target of the GoI of increasing the installed capacity up to 800GW (including 5-6% (~40GW) renewables) by 2030 (GoI, 2006). This analysis shows that the CDM has a considerable impact on the electricity sector of India.

An R&D project

One project (CDM.ID.0400) had a strong connection with R&D activities. The energy efficiency project aimed to reduce the steam consumption of a stripper reboiler (type of heat exchanger) at a combined refinery, chemistry and power producing industrial complex. Interestingly this project has a clear relation with R&D activities. The project states: “The project activity is the result of in-house R&D and involved a process simulation and innovative measures to make changes in the established process technology supplied by world’s renowned technology supplier M/s UOP.” (CDM.ID.0400, PDD, p3).

The project won a prize (by the Petroleum Conservation Research Association) for being innovative. The PDD state that this innovation could be diffused to similar plants around the world, leading to “worldwide benefit”.

This project indicates that CDM might influence R&D decisions. This project allowed the demonstration and implementation of a new process technology which application might have worldwide benefits.

Biomass sector

3 PDDs related to biomass were studied. Interestingly all three of them claimed to be demonstration projects. The projects referred to adaptive research that needed to be performed to make the projects a success and two of the projects claimed to be first of its kind in India. PDD.ID.0668 claimed to be a demonstration project and first of its kind in India. It also stated that the technology was well established in India thus no technology transfer was needed.

These findings suggest a different technological dynamics in the biomass sector than in the wind sector. In the biomass sector the projects more often claim to be first of its kind or a demonstration projects.

According to data about the potential for energy generated from biomass and the current installed potential there is still a large undeveloped potential. There is a potential for 16GW (MNRE, 2008) of which 0.5GW (PDD, 2005) was installed in 2004 and 3GW is currently being installed under the CDM (UNEP/Risø, 2008a). This implies that the CDM increased the diffusion of biomass for energy projects from 3% of the potential to 22% of the potential (see Appendix H).

In short it appears that different sectors face different challenges and experience different dynamics.

6.3.4 Key findings from the analysis

The CDM has a considerable impact within the Indian electricity sector with respect to technology diffusion. CDM is involved in 20% of the additional electricity capacity instalments target up to 2012, and fulfils 90% of the Indian renewables target of 2012. Within the wind energy sector CDM is used for co-financing over 43% of the total installed capacity by the end of 2008 and between 2007 and 2008 the number of new wind power projects using CDM for co-financing went up to 100%.

And there is still a lot of additional potential. India targets to dramatically increase its energy consumption mainly through the installation of mega (coal) projects and there is still a large capacity for additional project in among others the application of wind, biomass or super critical technology.

With respect to the development of technology the analysis showed that within the wind energy sector India is developing a strong global player: Suzlon. The company is estimated to be involved in over 40% of Indian CDM wind power projects; because India has a strong local player it is able to let a national companies benefit from the learning experience derived from the increased diffusion of wind power. Suzlon has grown to be one of the leading global wind energy companies. However this decreases the amount of technology transfer, since technology is derived from local companies instead of being acquired from Annex I country companies. But rather than being perceived as negative it could be perceived as positive in the case of wind energy, since it implies strong domestic technological capabilities. By acquiring western R&D companies the company has increased its innovative capabilities.

One energy efficiency project was encountered that had a clear relation to an R&D project. The project claimed to implement a first of its kind technology that was developed in-house and would have a global benefit. Within the biomass sector a number of projects claimed to be demonstration projects and to be first of its kind. None of the projects analysed in the wind sector made such claims. This finding indicates that CDM might have different effects on technology development depending on which specific sector is analysed.

The method appears to be limited in gaining insight into the subtle impact of the CDM on the national innovation system, however some observations are interesting.

The analysis shows that most projects in the wind sector claim that current national policy is insufficient to develop wind power projects without CDM co-finance, which may not be surprising in the light of the additionality test. Some PDDs mention that wind power policy used to be more favorable in previous years. What however is striking is that from the diffusion analysis it became clear that India has been able to develop large capacities of additional wind power without CDM co-finance. It is only since 2008 that 100% of all additional installed capacity uses co-finance from CDM.

Diffusion analysis suggests that before 2007 India developed wind power projects without the CDM, but has learned to use CDM in addition to domestic support (see Figure 6-3 & Figure 6-8).

6.4 Case 2: Iron and steel sector

This section will present the second case study. First the sector will be introduced. Secondly the results will be presented followed by the key findings.

6.4.1 Introduction into the Indian iron and steel sector

According to the IPCC the iron and steel sector contributes 3-4% of global greenhouse gas emissions alone. The emissions are expected to grow in the coming years due to increased production activities worldwide (Christmas, 2008). There is an international desire to push towards more efficient and environmental steel production.

The technological dynamics of the Iron and Steel industry:

There are two main methods applied for making steel. The first is based on using a Blast Furnace (BF) in combination with a Basic Oxygen Furnace (BOF). This process is often called integrated steelmaking. This technique uses raw materials such as iron ore, limestone and coke. The blast furnace produces pig ore, which is fed into the basic oxygen furnace to produce steel. The second method uses an Electric Arc Furnace (EAF). This technique primarily uses scrap metal as a feedstock, but Direct Reduced Iron (DRI) (also called sponge iron) can also be used as a feedstock. The scrap based method is often referred to as the mini mills.

The BF/BOF combination is mainly used for producing large quantities. The EAF technique has lower investments costs and is more often used to produce smaller quantities, either to supply a local market or to create specific products. The more scrap metal is recycled within a country; the better is its overall energy efficiency when measured over the total chain.

Increased environmental performance within the sector can be achieved by the diffusion of existing technology and the development of new technology and practices. According to the World Steel Association a lot of advancements have already been implemented, among them: enhanced energy efficiency, improved recycling, improved use of by-products and better environmental protection techniques. To further enhance the performance of the sector three areas for improvement are named: through the products of the steel industry (for instance strong light weight metals improve the performance of cars and wind turbines), technology transfer and the development of breakthrough technologies (worldsteel.org, 2009).

There are many ways to improve the environmental performance of plants. Methods include the recovery of thermal energy, recycling of materials, continuous casting, improved burner technology, producing energy from waste BOF gasses etc (APP, 2007). The handbook on state of the art technologies for the Iron and Steel sector names over 70 different technologies and processes (APP, 2007). To what extent plants use pollution prevention methods depends largely on economic conditions and environmental regulatory obligations. The potential for environmental improvements using these technologies lays mainly application of these technologies in developing countries that have not yet applied these technologies (worldsteel.org, 2009). Modern plants are already optimized for energy efficiency.

An additional significant decrease in the CO₂/tonne steel within modern plants that are already equipped with state of the art technology can only be achieved by radical new breakthrough technologies. Promising breakthroughs mentioned by the World Steel Association include the recycling of blast furnace top gas, carbon capture and storage, direct reduction with oxygen and using electricity from renewable sources or biomass.

The steel sector faces important technological challenges. There are many different combinations of technologies that can be applied to produce steel and new technologies and improvements are still being developed and discovered. The application of these technologies greatly depends on economic conditions and the tightness of environmental pollution restrictions.

The steel industry is a global Industry. In recent years the industry has grown, mainly due to economic development in developing countries. The present financial crisis has hit the sector hard. The World Steel Association has spoken out for a global sector approach to reduce greenhouse gasses within the sector (worldsteel, 2007).

Development of the Indian iron and steel sector

India is the fifth largest steel producer in the world, with an output of 53Mt in 2007 (of a total of 1,344Mt) (worldsteel.org, 2008). China is by far the largest producer with an output of 489Mt in 2007. Production in India rose from 22Mt per year in 1995 and 27Mt in 2001 to 53 Mt in 2007. With a steel use of 43 kg per capita in 2007 India still falls far below the world average of 194 kg per capita. In recent years India has experienced a large growth in production. Interestingly India has developed a clear leading role in the production of sponge iron (intermediate product with 90-97% pure iron). With a production of 18Mt in 2007, out of a global production of 65Mt, India was by far the largest producer of sponge iron. India uses mainly coal to produce sponge iron, which is a very emission intensive process (IEA, 2008). Sponge iron can be used in EAF to replace scrap metal and the government stimulated the construction of sponge iron plants due to scarcity of scrap and coking coal (which is not needed when using an EAF instead of a BF and BOF). The production of sponge iron was stimulated by the government by among others de-licensing, and financial support (Electrotherm, 2009).

After independence (1947) the Iron and Steel sector was earmarked for state control. Anno 2009 still a large part of the sector is in public control and run by the Ministry of Steel. It was not until the 90s that due to globalization the sector was liberalized and deregulated, which led to the emerging of a private sector, rapid growth in the steel sector and greater excess to modern technology (GoI, 2008). After a slowdown during the Asian financial crisis at the end of the 90s, the sector experienced a boom from 2002 onwards. In 2005 the Government of India (GoI) announced a National Steel Policy (NSP) to steer the growth of the sector. The NSP aimed at production of 110Mt by 2020, but recent estimations expect production to reach nearly 124Mt by 2012 (GoI, 2008). These estimations were before the financial crisis. The financial crisis led to a sharp decrease in the price of steel and the long term effects of the crisis still remain to be seen. Related to CDM the Ministry of Steel makes it clear that it “is pursuing all other Iron & Steel companies to avail this (refers to CDM) opportunity” (GoI, 2008p56).

As of September 2008 CDM pipeline database includes 164 projects in the Iron and Steel sector, of which 95 are in India.

6.4.2 Impact of the CDM on the Indian iron and steel sector

In this section I will use the methodology developed in chapter 5 to discuss the impact of the Clean Development Mechanism on technological change in the Indian iron and steel sector.

The results are presented in three different stages. First I will deal with findings related to the diffusion, secondly to the findings related to technology development (learning, R&D, spillover and economies of scale) and thirdly with the findings related to the impact on the innovation system.

The PDDs selected for this case study were all the seven Iron and Steel related CDM projects in the province of Karnataka. This was done to get a complete picture of the dynamics in one province.

Technology diffusion

Yearly GHG emissions within the Indian Iron and Steel sector are estimated to be 132 MtCO₂-eq in 2005 (see Figure 6-2). The IEA (2008) estimates that best available technologies would allow a reduction of about 25 Mt CO₂ /yr in India in 2005. The total CERs generated within this sector amount to 8 MtCO₂-eq/yr within the first period of the CDM (UNEP/Risø, 2008a).

According to the Worldsteel association the global average CO₂ emission per tonne steel is 1.7 tCO₂-eq /t steel (Worldsteel, 2008). With a production of 46Mt steel and GHG emissions of 132 Mt CO₂-eq in 2005, the Indian average is estimated to be 2.9 tCO₂-eq /t steel. The 8Mt reduction gained by CDM would equal a decrease of 0.18 tCO₂-eq /t steel. This indicates that there are still many possibilities to lower the GHG emissions in India.

Table 6-5 gives an overview of the status and the methodologies the projects that are currently undertaken under CDM to lower the GHG emissions of the sector. This data does not include 7 projects that are undertaken in coke ovens, since the CERs derived from coke ovens was not included within the Iron and Steel sector during technology diffusion analysis of India (Figure 6-2).

Table 6-5 Status and methodologies of the projects in the Indian Iron and Steel sector (UNEP/Risø, 2008a)

Status	1st period ktCO ₂ e/yr	Methodologies
Registered	34	3.291
At Validation	51	4.271
Request Review	7	565
Under review	3	236
total	95	8.362
		AMS-I.C.+AMS-I.D.+AMS-III.Q.
		1
ACM12 = GHG reductions for waste gas or waste heat or waste pressure based energy system (ACM4 is replaced by ACM12)		
ACM2 = Grid-connected electricity generation for renewable sources (no biomass)		
AM66 = GHG emission reduction through waste heat utilization for pre-heating of raw material in sponge iron manufacturing process		
AMS-II.D.= Energy efficiency and fuel switching measures for industrial facilities		
AMS-III.Q.= Waste gas based energy systems		
AMS-I.C. = Thermal energy for the user		
AMS-I.D. = Renewable electricity generation for a grid		

The 95 project will together generate 8 MCERs annually till 2012. The most common methodology used is ACM12 (see Table 6-5). ACM4 has later been replaced by ACM12. The ACM12 methodology can be applied in projects that generate electricity by using waste gas, heat or pressure.

Table 6-6 presents a summary of the findings related to the impact of CDM on technology diffusion in the iron and steel sector of Karnataka. Unfortunately no publically available data was found about the total number of steel plants in Karnataka or the diffusion of technology without CDM co-finance. This makes it difficult to assess the contribution of CDM on the total diffusion.

Table 6-6 Summary of findings related to the diffusion of technology in the iron and steel sector

Diffusion	
Current level of diffusion	5 out of all the steel plants in Karnataka use BF gas to generate electricity (CDM.ID.0222). 4 out of 7 pig iron manufactures in Karnataka is involved in power generation (CDM.ID.3914). - Low penetration of captive power plants in the sponge iron industry (CDM.ID.3260).
Potential for diffusion	There are 20 sponge iron plants in Karnataka and the current diffusion of waste gas utilization processes is low (CDM.ID.3260).
Role of CDM in realising diffusion	waste gas utilization is on the rise due to CDM (CDM.ID.0387)
Encouragement for further diffusion	5 out of 7 projects mention that the project will encourage further diffusion of the technologies that were used in the project.

Technology development

To assess technology development I will look at learning, R&D, spillover and economies of scale.

With respect to learning this analysis shows that CDM projects in the iron and steel sector involve both Indian firms as well as suppliers from the USA and Europe. The technologies applied include both novel and existing technologies and the designs that are used are often custom designed or novel. 6 out of 7 projects that were studied mentioned that the project contributed to skill building. This often involved training the staff to be able to work with the new technology or design.

This analysis found one example of a project that mentioned that the project was preceded by in house R&D. The R&D “resulted in the development of a heating zone around the burner of the boiler to facilitate in complete burning of the waste gas” without the need for supporting fuels (CDM.ID.3755, p21). This R&D was of Indian origin and the project was executed by Indian partners (CDM.ID.3755). Furthermore two projects mentioned the technological challenge of adopting the technology to the local circumstances.

Two projects that were analysed mention that the projects are first in the world to implement the technology and three other projects analysed mention that they are the first of its kind in India. These findings suggest that CDM projects within the iron and steel sector could also be impacting the technology development of the iron and steel sectors by stimulating learning, R&D and spillover through projects that have an experimental character and stimulate the development and demonstration of technology. This is an interesting finding since the CDM was not intentionally designed to facilitate technology development.

The findings related to technology development and the role CDM plays within this development are summarised in Table 6-7.

Table 6-7 Summary of findings related to technological development in the iron and steel sector CDM projects

Learning	
Local or foreign actors involved	3 out of 7 projects include information about the nationality of the actors involved with supplying the technology and knowledge. One mentions using European technology customized to Indian practices, one mentions being supplied, designed and developed completely by Alstrom (USA) and a third project mentions only Indian project partners and technology suppliers (this project also applies first time in the world, in house R&D).
Development stage of technology used	One PDD mentions that the project installs “novel pre-heater technology”. Apart from this project two projects mention being the first in the world to install their technology, which would indicate that that technology is in a development stage too. So 3 out of 7 projects are using advanced technology in other words technology that is still in its demonstration phase (see Figure 3-3).
Skill building	6 out of 7 projects mention that they will contribute to skill building
Custom design	3 out of 7 projects make reference to the fact that a custom or novel design is applied within the project
R&D	
Part of R&D project	1 out of 7 projects refers to in house R&D. This project is the first in the world to apply this R&D (CDM.ID.3755)
Adaptive research performed	2 out of 7 projects mention the difficulty of adopting the technology to local circumstances.
Feedback to R&D	-

Spillover	
Hard-ware/software transferred	• See “local or foreign actors involved”
First in India/World /State or Industry	• 2 out of the 7 projects mention being first in the world with the application of new processes or technologies. • 3 out of the 7 projects mention being first in India (not including the 2 projects that mention being first in the world). Of these 3 projects 1 also mentions its novel design and one other mentions trials and modification made during the absorption and stabilization of the technology.
Economies of scale	
Up scaling of national industry	• -

Innovation system

Changes in the innovation system as a result of CDM are difficult to find by studying PDDs. Two PDDs mention that the firms involved have international alliances, but no references were found about new relation forged as a result of the CDM projects.

4 Out of 7 PDDs mention that current regulation in India does not obliges the companies to apply technology to use the energy that is still remaining in the blast furnace gasses. However the analysis of PDDs does not tell us how CDM influences domestic regulation.

The findings related to the innovation system and the role CDM plays within changes of this system are summarised in Table 6-7.

Table 6-8 Findings from PDDs about the innovation system in the iron and steel sector

Innovation system	
Policy implications	• 4 out of 7 PDDs mention that there is no regulation that obliges the companies to apply the technology.
Infrastructure adjustments	• -
Corporate responsibility	• -
Support collaboration	• 2 PDDs mention that their firms have international alliances.
Industrial ecology	• One PDD mentions that the fly ash produced will be used in cement manufacturing

6.4.3 Key findings

The 95 iron and steel related CDM projects in India could have a significant impact on the diffusion of technologies to reduce emissions in the Indian iron and steel sector. Yearly GHG emissions within the Indian Iron and Steel sector are estimated to be 132 MtCO₂-eq in 2005 (see Figure 6-2). The IEA (2008) estimates that best available technologies would allow a reduction of about 25 Mt CO₂ /yr in India in 2005. The total CERs generated within this sector amount to 8.3 MtCO₂-eq/yr within the first period of the CDM (UNEP/Risø, 2008a).

Of the 95 iron and steel related CDM projects 86 are about energy recovery from waste heat, gas or pressure, 8 projects are about fuel switch and 1 about preheating raw material.

A key finding from this analysis about technology development is the seemingly experimental character of iron and steel sector projects. 2 out of 7 projects claimed to be first of its kind in the world of which one projects was preceded by an in-house R&D project and three other project

claimed to be first of their kind in India. The analysis also found three projects that contained novel or custom designs and references to two projects that claimed that adaptive research had been performed in order to install the new technology. All but one of the PDDs studied mentioned the skill building activities that would be needed to train their staff.

This finding shows that CDM can support project with an experimental character. These projects could in turn aid in the development and demonstration of novel technologies that could have a global benefit.

The method appears to be limited in gaining insight into the subtle impact of the CDM on the national innovation system. 4 Out of 7 PDDs mention current regulation does not oblige the companies to apply the technologies applied by the CDM projects. However from studying PDDs it does not become clear how CDM influences this development of regulation.

6.5 Case 3: HFC producing industry

This section will analyse TC as a result of CDM in the HFC producing industry (here defined as the sector in which hydrofluorocarbons are produced, directly or indirectly). First I will introduce the sector. Secondly I will present the results from the analysis. Thirdly I will draw key conclusions.

6.5.1 Introduction into the HFC producing industry

HFC is a collective name for a group of different gasses. These gases mainly used as refrigerant and are used as an alternative to CFCs; since CFCs are ozone depleting and they are being phased out under the Montreal Protocol. Some of these gasses have a very strong global warming potential (GWP) (see Figure 6-10).

Emissions	GWP	1990	1995	2000	2005	CAGR (%)
HFC-134a	1300	–	–	285	1437	38
HFC-152a	190	–	1	2	6	23
HFC-227ea	3800	–	61	137	271	16
HFC-23	11700	873	2004	4936	9500	17
Total HFCs		873	2066	5361	11214	19

Figure 6-10 Indian HFC emissions in ktCO₂-eq/yr (Garg, 2006)

Since the HFC gasses (CFC substitutes) have high global warming potential, the quest for sustainable alternatives is ongoing. Directions for development include (IPCC, 2005, p12):

- Not-in-kind technologies that produce the same result but do not use HFCs
- Increased use (and development of) alternative substances with a lower GWP
- End-of-life recovery, recycling and destruction of the substances
- Reduced use and better containment of the substances in equipment

HFC-23 has the largest GWP and the destruction of 1 tonne HFC-23 equals the reduction of 11,700 t CO₂-eq. HFC-23 is a by product of HCFC-22, which is used in air conditioners. The technology used for mitigating HFC-23 is thermal oxidation. Thermal oxidation technology is very effective in destroying HFC-23. It burns the HFC-23 waste stream using oxygen and a little bit of hydrogen to fuel the reaction. Most western countries stopped using HCFC-22 altogether and developing countries are supposed to phase out HCFC-22 by 2040. There is a search going on for the best replacement of HCFC-22 (alternatives include HFC-134a and HC-290 (Devotta et al., 2001)).

HFC-134a can also be replaced by other substances. There are numerous alternatives being developed, but their application and suitability depends on the specific circumstances. A recent methodology under CDM (AMS-III.N) switches HFC-134a for Pentane at Poly Urethane Foam manufacturing plants. Currently only two of these projects (both in India) are under validation. Other methodologies to replace HFC-134a in specific situations are also proposed (see Table 6-9).

Socio- economical dynamics

Since HFCs have a very large GWP it is unsurprising that we want to mitigate these gases. However the CDM has resulted in controversy due to perverse incentives that occurs due to HFC-23 destruction projects.

The destruction of HFC-23 by thermal oxidation is relatively cheap and can be done for as little as US\$0.2/tCO₂-eq (IPCC, 2005, p15), while generating large amount of credits. Since the market prices of CERs are far higher, the generated income from the destruction of HFC-23 may be higher than the income generated from the production of HCFC-22 (Schneider, 2007). HFC-23

destruction leads to windfall profits giving companies with CDM projects competitive advantages. It would even become economically feasible to produce HCFC-22 just for the sake of generating credits by destructing the HFC-23 waste gas².

The first CDM project to be submitted and accepted was an HFC-23 destruction project. As can be seen from Figure 2-4 in the beginning of the CDM a large part of the CERs were generated from a relatively small number of HFC-23 destruction projects.

To prevent the perverse incentive it was decided that newly built plants cannot submit CDM projects. The discussion what to do with new plants is still ongoing.

This discussion is also influenced by the fact that HCFC-22 is part of the Montreal Protocol (about the mitigation of ozone depleting gasses), under which non-Annex I countries are obliged to phase out HCFC-22 production by 2040.

Methodologies used under CDM

Under CDM there are three approved HFC mitigation methodologies of which the most commonly used is about HFC-23 burning (UNEP/Risø, 2008a). The other two are still new. One is a small scale methodology about avoiding HFC emissions by replacing HFC in poly urethane foam manufacturing (PUF) and the other is about switching refrigerants in refrigerators.

As of august 2008 there are 20 HFC-23 destruction projects (of which 5 in India). HFC-23 destruction accounts for 99% of the emissions reduction in the Indian HFC producing industry (see Figure 2-4). Two PUF projects (both in India) and one (also in India) about manufacturing and servicing refrigerators are the only two other HFC mitigating projects approved.

Table 6-9 HFC methodologies (UNEP/Risø, 2008a)

	Description	Number	GHG reduction/yr	Host country
Approved methodology	Burning HFC23 from HCFC22 production	AM1		
Approved small scale methodology	N. Avoidance of HFC emissions in rigid Poly Urethane Foam (PUF) manufacturing	AMS-III.N.		
Approved methodology	Manufacturing and servicing of refrigerators and freezers using low GWP refrigerant (from HFC-134a to hydrocarbons)	AM0071		
Proposed new small scale methodology	Integrated Refrigerator Energy Efficiency and Recovery of HFC-134a	SSC-NM12	3 ktCO2	Brazil
Proposed new small scale methodology	Natural refrigerants in after market mobile air-conditioning systems (MACs)	SSC-NM13	22 ktCo2	Iran

The proposed new methodologies all deal with the more efficient use of HFC-134a or the use of alternatives. This is a good development since there is a range of possibilities to develop and apply alternatives for HFCs.

The newly proposed methodology “Natural refrigerants in after market mobile air conditioning systems (MACs)” offers an interesting perspective on the development of technology. The PDD that accompanies the proposed new methodology proposes to use a refrigerant (to replace HFC-134a) that is a non-incumbent technology. The new refrigerant (that uses a mixture of propane and isobutene) that is proposed to replace HFC-134a is used in a number of Australian states but is illegal in other Australian states and the USA. The refrigerant is highly flammable but did not result in any accidents (IPCC, 2005). If the project would be executed it would create a new market for the non-incumbent technology. The diffusion of this technology on new market may lead to learning experiences that could help to develop and improve the technology.

² http://cdm.unfccc.int/public_inputs/inputam0001/Comment_AM0001_Schwank_081004.pdf

6.5.2 Impact of the CDM on Indian HFC producing industry

In this section I will use the methodology developed in chapter 5 to discuss the impact of the Clean Development Mechanism on technological change in the Indian HFC producing industry. The results are presented in three different stages. First I will deal with findings related to the diffusion, secondly to the findings related to technology development (learning, R&D, spillover and economies of scale) and thirdly with the findings related to the impact on the innovation system.

Technology Diffusion

With respect to technology diffusion it becomes clear from the analysis that most HFC projects that were taken up under CDM were HFC-23 destruction projects. These projects have had a profound impact on the CDM due to the large amount of credits generated.

The diffusion of alternative HFC mitigation projects has only recently started with two small scale projects under AMS-III.N and the approval of methodology AM0071.

Table 6-10 gives an overview of different HFC emissions and the amount of CERs that were realised in India by mitigating these emissions.

Table 6-10 HFC emissions and CERs

	Emissions in 2005 [kt CO ₂ -eq] (Garg, 2006)	CERs/yr up to 2012 [kt CO ₂ -eq/yr] (UNEP/Risø, 2008a)
HFC-23	9,500	11,032
HFC-134a	1,437	46
HFC-227ea	271	0
HFC-152a	6	0

With respect to the potential for diffusion it becomes clear that for HFC-23 projects the potential lays with newly build plants. However currently these cannot apply for credits due to the perverse incentive that occurs from HFC-23 destruction projects.

Taking into account the Montreal Protocol restrictions on the use of HCFC-22s Bakker et al, (2007) estimate the global potential of CERs from HFC-23 mitigation from HCFC-22 production of 119.2 MtCO₂-eq in 2020, of which 17 Mt from new to build plant.

Since other HFC mitigation projects are scarce and new methodologies have just recently been approved and proposed it can be expected that there is still a potential for diffusion of these projects.

The findings related to technology diffusion and the role CDM plays within this development are summarised in Table 6-11.

Table 6-11 Summary of findings related to diffusion of HFC projects

Diffusion	
Current level of diffusion	• The diffusion of HFC-23 destruction projects (using methodology AM1) went very quick (see Figure 6-10). The HFC-23 projects in the CDM pipeline for India add up to 11MtCO₂e/yr, which is more than the estimated 9,5Mt emitted in 2005 (Garg, 2006). • The diffusion of projects for other HFC gasses is just starting (see Figure 6-10). Two small scale projects for HFC-134a abatement have been submitted in India. Three new methodologies are submitted (see Table 6-9).

Potential for diffusion	• The current potential for HFC-23 destruction projects lies in newly build plants. However it was decided that due to the perverse incentive new plants cannot take part in CDM activities. A specific solution to counter the perverse incentive and phase out HCFC-22 will have to be found. • There is still potential for the diffusion of projects in HFC-134a mitigation. Currently only one methodology is approved, 3 new ones are in the process of approval.
Role of CDM in realising diffusion	• The CDM has had a large role in the diffusion of the oxidation technology for HFC-23 destruction. However it had a perverse incentive and stimulated the production of HCFC-22, that is actually in the process of being phased out by 2040.
Encouragement for further diffusion	• 1 out of 2 AMS-III.N projects (ID.CDM4079) claims that the project will help promote the use of pentane over HFC-134a.

Technology development

The technology for the HFC-23 destruction projects has all been transferred from Annex I countries. All project mention skill building but that relates mainly to the basic operation and maintenance skills.

The new HFC (134a) mitigation projects mention that the first of these projects required large R&D costs to adapt the technology (ID.CDM4079) although the technology used for this project was already well established in the developed world.

The potential of CDM to contribute to the development of new alternative technologies in the quest to replace HFCs lies with the development of more different HFC mitigation projects (apart from HFC-23 destruction).

The CDM project in Iran that accompanies the newly proposed methodology SSC-NM13 proposed to replace a refrigerant in car air conditioners with a more sustainable alternative. This alternative is still a niche application for it only used in some cars in Australia. This project might help the technology further develop and prove (or disprove) itself.

The findings related to technology diffusion and the role CDM plays within this development are summarised in Table 6-12.

Table 6-12 Summary of findings related to technology development in HFC producing industry

Learning	
Local or foreign actors involved	• It becomes clear from the PDDs studied that the technology that is applied in the Indian HFC-23 destruction projects comes from Europe and Japan. The learning effects related to improving the technology are thus mainly gained by western companies. • In case of the HFC-134a destruction projects the PDDs do not give a clear picture apart from mentioning that the technology is sourced from well established vendors and is well established in the developed countries.
Development stage of technology used	• Both the technology applied for the destruction of HFC-23 and that of replacing HFC-134a by pentane are well established technologies in the developed world. This is clearly mentioned in all PDDs.
Skill building	• All projects mention that specialized training and skill building is part of the project. This mainly relates to operation and maintenance skills.
Custom design	• -
R&D	
Part of R&D pro-	• -

ject	
Adaptive research performed	One PDD (ID.CDM4079) mentions large R&D costs involved in adapting the technology of replacing HFC-134a by pentane.
Feedback to R&D	-
Spillover	
Hardware/ software transferred	- All the HFC-23 destruction project use technology from developed countries - The technology used for HFC-134a mitigation is sourced from “well established vendors and running successful in developed countries” (ID.CDM3884).
First in India/World /State or Industry	Both HFC-23 destruction and HFC-134a mitigation through the use of pentane in continuous PUF manufacturing had not been done in India prior to CDM.
Economies of scale	
Up scaling of national industry	-

Innovation system

The empirical findings from the PDDs do not give much insight into the impact of the CDM on the innovation system. We do know from literature about the discussion related to the perverse incentive that is caused by CDM and that occurred in the HCFC-22 sector (Schneider, 2007). The findings related to the impact on the innovation system summarised in Table 6-13.

Table 6-13 Impact on the HFC innovation system

Innovation system	
Policy implications	- There is currently no regulation restricting the emission of HFC-23 in India. The perverse incentive of the CDM (lowering HCFC-22 prices thus stimulating its market power and increasing the levels of HFC-23) also negatively affects the need to phase out HCFC-22 by 2040. - With respect to PUF production there are no restrictions to using HFC within this process
Infrastructure adjustments	-
Corporate responsibility	2 out of 7 PDDs mention the social and environmental commitment of the project company.
Support collaboration	One PDD (ID.CDM0484) makes reference to the fact that the company maintains relations with educational research institutions. This could be an example of collaboration between a company and a research institution. It does however not become clear from the PDD if this is more than merely a charity financial support.
Industrial ecology	From the PDDs it becomes clear that HFC-23 could also be used as a feedstock in additional processes. However there is no demand within India for HFC-23 as a feedstock.

6.5.3 Key findings

The CDM has led to the widespread (100%) diffusion of HFC-23 destruction technology in India. Additional potential for HFC-23 reduction exists in new to build plants. Due to controversy over HFC-23 destruction, new plants are currently not eligible for CDM revenues. A suitable approach to align the Kyoto protocol and the Montreal protocol will have to be developed.

The development of different projects in HFC mitigation (other than HFC-23 destruction) is just recently taking off. New methodologies have been proposed. This could be a promising development, especially for the development and diffusion of alternative substances.

All projects in the HFC producing industry contain technology transfer and the build up of operation and maintenance skills. One of the two HFC-134a mitigation projects claims that adaptive research was performed. No linkage with R&D projects was found in the PDDs.

Technological change within the HFC producing industry in India has mainly been due to the diffusion of HFC-23 destruction technology and the associated transfer of operation and maintenance skills. The technologies used were well developed; there are no indications that the technologies installed were innovative or experimental. HFC destruction is an end-of-pipe technology. The real technological challenge is to develop and diffuse clean alternative technologies for the use of HFCs. With the development of new methodologies under CDM, the diffusion of alternative substances to replace HFC seems to be just starting.

The method appears to be limited in gaining insight into the subtle impact of the CDM on the national innovation system. From literature we know that the CDM created a perverse incentive to increase HCFC-22 production which is the reason why currently only emission reduction from historical production levels are eligible for credits (Schneider, 2007). However this analysis did not produce any new findings with respect to the way CDM impacts the national innovation system.

7. Discussion

In this section I will discuss the usefulness of the methodology and the findings from the three case studies. The findings from the case studies will be related to each other and existing literature on CDM and TC.

This research set out to study the impact of the CDM on TC. The first aim of this research was to unravel the concept of TC and the way CDM would impact TC. Secondly this report aimed to develop a method to measure the impact of TC. This method was applied to three case studies. The findings from these case studies serve to:

- Improve our understanding of the way CDM results in TC
- Validate the method that was developed
- Judge the impact of CDM on TC in the three case studies and possibly to generalize these findings in order make recommendations

7.1 Discussion of the methodology

Part of the research in this study was to develop a method to measure the effect of CDM on TC in non-Annex I countries and apply this method in a number of case studies. The first step taken during the development of the method was to come up with a definition of TC and a causal model of the relation between CDM and TC.

The second step involved the identification of data sources and the development of measurable indicators that could be used to analyse the relation between CDM and TC.

The method developed in this research serves two purposes, first of all to strengthen the theoretical causal model with empirical findings and secondly to assess the effect of CDM on TC in non-Annex I countries.

The framework of TC, in which TC is divided into technology diffusion, technology development and the innovation system proved to be a useful classification. Also the sub-classification of technology development into learning, R&D, spillover and economies of scale proved to be useful. This led to 6 variables for which indicators were derived.

Next I will discuss the usability of the indicators that were developed to measure each of the 6 variables and the way this method set out to gather data. I will first discuss technology diffusion, secondly technology development and thirdly the change of the innovation system. Afterwards I will discuss the application of the methodology and end with conclusions

I will evaluate the variables used for this study based on two questions:

1. Was data available about this variable?
2. What was the quality of this data?

7.1.1 Measuring technology diffusion

With respect to the indicators of technology diffusion this method proved to be able to gather sufficient data on technology diffusion. The CDM pipeline database (UNEP/Risø, 2008a) gives an excellent account of diffusion under CDM. To put this diffusion into perspective it has to be related to other data such as diffusion without CDM and data about the potential for diffusion. Accurate data about diffusion without CDM and about the potential for further diffusion of technologies is more difficult to find.

Among others it would be desirable if non-Annex I countries would have more up to date GHG inventories.

The evaluation of measuring technology diffusion is summarized in Table 7-1.

Table 7-1 Evaluating measuring technology diffusion

<i>Indicator</i>	<i>Measurement</i>	<i>Data availability</i>	<i>Data quality</i>
Current level of diffusion	-General: [CERs/GHG emission] -Additional diffusion data: [depends on data availability]	General: The CDM pipeline database supplies excellent data about the diffusion of CDM projects. Data on GHG emissions of countries was old (more recent data was by EcoFys was found, but not yet included, see (Höhne et al., 2008)). Data on sector emissions in non-Annex I countries is difficult to find and/or has to be constructed from different sources. Addition data about diffusion of specific technologies is more difficult to find and not always readily available.	Data quality of the CDM pipeline database is excellent. Data from literature and governmental sources is scarcer and of lower quality.
Potential for diffusion	[depends on data availability]	Data about the potential for diffusion of a certain technology can be obtained from grey literature, or estimations based on benchmarks with other countries	In some cases data about diffusion potential is available (for instance for wind) but in other cases this data is more difficult to obtain (iron and steel) in which case more aggregate data and benchmarks can be used.
Role of CDM in realising diffusion	[depends on data availability]	This indicator is based on the information of the current level of diffusion and the potential for diffusion.	-
Encouragement for further diffusion	[#PDDs mentioning indicator]	PDDs often mention that they encourage future projects	-

7.1.2 Measuring technology development

The indicators that were developed to study the impact of CDM on technology development were useful. This method looked at specific indicators and whether they were mentioned in the PDDs. It is not a mandatory requirement to mention these indicators in PDDs. It can be concluded that these relations were actually found within the PDDs (see Table 7-2). However PDDs are documents written by the project proponent and have the tendency to show a rosy picture of the project. The data acquired from looking for indicators in the PDDs remains qualitative.

The evaluation of measuring technology development is summarized in Table 7-2.

Table 7-2 Evaluating measuring technology development

<i>Indicator</i>	<i>Measurement</i>	<i>Data availability</i>	<i>Data quality</i>
Learning			
Local or foreign actors involved	[#PDDs mentioning indicator]	Limited data availability from PDDs.	If this data is mentioned in PDDs it can be assumed to be correct.
Development stage of technology used	[#PDDs mentioning indicator]	Limited data availability from PDDs. External sources can be used to judge the development stage of	PDDs do not regularly mention the development stage of the technology used.

		a technology	
Skill building	[#PDDs mentioning indicator]	PDDs often mention whether a project contributes to skill building.	PDDs give a rosy picture and SD benefits are not validated by the DOE
Custom design	[#PDDs mentioning indicator]	PDDs often mention whether a technology applied in the project is custom designed.	Without expert judgement it is hard to really judge the level of customization.

R&D

Part of R&D project	[#PDDs mentioning indicator]	A number of PDDs mentioned that the CDM project was preceded by a recent R&D project.	Based on the PDDs only it is impossible to really judge the novelty of the research that is mentioned in the context of the CDM project.
Adaptive research performed	[#PDDs mentioning indicator]	This indicator is often literally mentioned in PDDs	Based on the PDDs it is impossible to really judge the novelty of the adaptive research that is mentioned in the context of the CDM project.
Feedback to R&D	[#PDDs mentioning indicator]	The PDDs and freely available data do not give any information about the feedback from CDM projects and R&D	-

Spillover

Hardware/software transferred	[#PDDs mentioning indicator]	Limited data availability from PDDs. It is sometimes mentioned.	It becomes more difficult when local dealers or manufactures are used
First in India/World /State or Industry	[#PDDs mentioning indicator]	This indicator is mentioned in PDDs. I have got the impression that when a project is the first to use the technology in a specific context that they most often say so.	The quality of this data is good. It often mentioned and there are no specific reasons to believe that these statements would be incorrect.

Economies of scale

Up scaling of national industry	[Market data]	This information is not available from PDDs. Another way to look at it is by looking at the market size expansion of domestic producers of technology.	-
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It can be concluded that the indicators are useful and that PDDs give information about the indicators. However the PDDs are not required to mention the indicators, thus judging solely on the basis of PDDs means that some indicators might be occurring in practise, but are not measured by studying PDDs.

Data on up scaling of industry is difficult to find. It is also difficult to state a causal relation between an increase in market size and the CDM.

7.1.3 Measuring change in the national innovation system

With respect to the innovation system it has to be concluded that PPDs do not give information that can be used to unravel this relation and thus it can be concluded that the method is unsuitable in determining the impact of CDM on the national innovation system.

The PDDs are focused on a specific project and do not make reference to the relations between the project and its institutional context, although the innovation system indicators are focused on the linkages between companies, government, research and education.

The analysis did however found that PDDs often mentioned local policy as being insufficient to render the project feasible, which is at first impression unsurprising for the CDM project would otherwise not pass the additionality test.

The evaluation of measuring change in the national innovation system is summarized in Table 7-3

Table 7-3 Evaluating measuring change in the national innovation system

<i>Indicator</i>	<i>Measurement</i>	<i>Data availability</i>	<i>Data quality</i>
Policy implications	[#PDDs mentioning indicator]	PDDs mention the local and national policy and why it is unfavourable towards the project proposed under CDM.	The quality of the data is fine, but it is just not the right information.
Infrastructure adjustments	[#PDDs mentioning indicator]	Insufficient information available from PDDs	-
Corporate responsibility	[#PDDs mentioning indicator]	Insufficient information available from PDDs	-
Support collaboration	[#PDDs mentioning indicator]	Insufficient information available from PDDs	-
Industrial ecology	[#PDDs mentioning indicator]	Insufficient information available from PDDs	-

In the end the method proved to be unsuitable to study the impact of CDM on the national innovation system. Different indicators of changes in the NIS and different data sources to measure these indicators will have to be used in future research. Some creativity will be required.

7.1.4 Ways to improve the method for future research

There are a number of limitations to this study:

- The sector analysis was only performed for India; some sectors might do well under CDM in different countries.
- Only a limited number of PDDs were studied
- PDDs have limitations, they are not required to mention the indicators used in this study and the information written down in the PDDs if biased.

For future research the following directions would be interesting:

- On technology diffusion:
 - Perform sector level impact assessments for more countries to improve our understanding of the different impacts of CDM on different sectors.
 - Improve our understanding of the factors that determine the successful technological diffusion in different countries and sectors by CDM
 - In order to explain diffusion it would be interesting to combine technology diffusion data of all non-Annex I countries with country dependent variables (such as GDP, technology indexes, etc) and use regression analysis to find the factors that influence this relation.
- On technology development
 - Look at different sectors and extend the number of PDDs within each sector
 - Combine PDD text analysis with field visits and interviews with stakeholders

- o Keep refining the indicators for technology development. For instance by more clearly defining the text indicators or by introducing scales (such as advanced technology=1 modern technology=2 and commercial technology=3).
- On change of the national innovation system
 - o Use interviews with local politicians, policy makers, NGOs and industrial representatives to improve our understanding of the way CDM influences national innovation systems. Were stringent policies hindered due to CDM or were successful local policies designed to enhance the potential of CDM?

To improve this method I recommend using field interviews with stakeholders to improve the understanding of the relation between CDM and technology development and the innovation system. The current analysis gives a rough first indication of this relation, but this method is unable to get a detailed picture of the subtle way in which this relation occurs.

I recommend doing empirical studies on the impact of CDM on the innovation system. This would probably need a radical new creative method, since this method is ill suited. Such a study would need to focus on the new linkages that are formed because of CDM, the way CDM challenges and stimulates the current dominant regime and the perverse incentives that arise due to CDM.

I recommend striving for an analysis based on outcome indicators of TC, such as changes in the total production function or the change in the production possibility frontier. This would however require improved macro data. A first step would be regression analysis between the GHG development trend in non-Annex I countries correlated to the CER generation trends in non-Annex I countries.

I recommend carrying out a text analysis of PDD documents that only focuses on a smaller number of indicators of technology development, for instance starting with “R&D” and “first of its kind” but then taking a larger sample size and use statistic data analysis. Maybe these indicators can be included within the taxonomy framework that is being developed by Olson et al, (“new methodology for sustainability assessment based on text analysis of the project design documents submitted for validation”) (2008).

I conclude that the method developed is usable but imperfect. It proved to be impossible to quantify the impact of CDM on TC. We can’t say: “the impact of CDM on TC is 0.85”. But the method did help us to structure the analysis of the impact of CDM on TC and improve our understanding and measurement of this relation.

Its weakness is at the same time its strength. On the one hand it is a rough method that improves our understanding of the relation between CDM and TC but only to a limited extent and on the other hand it is a relatively easy to use method that does not require extensive resources.

Another interesting way to find out more about the role of CDM in technological change in non-Annex I countries would be to take a number of technologies in a number of different countries and describe the innovation journeys that these technologies have experienced over the years (see section 5.1.2 Evolutionary socio economical theories). If this were done in a number of different non-Annex I countries it might lead to interesting findings with respect to the way CDM influences innovation journeys in non-Annex I countries.

7.2 Discussion of the results

This section discusses the results from the case studies and links the results with theory. It discusses whether assumed relations between CDM and TC should be confirmed or denied.

7.2.1 CDM's role in technology diffusion

It can be confirmed that technology diffusion occurs due to CDM. However, impact assessment revealed that there are differences between the impacts of CDM within different sectors (see Figure 6-2). The exact reasons behind the differentiated impact do not become apparent from this study but some hypothesis about possible explanations can be made.

An important suspected explanations could be the availability of cheap reduction potential in certain sectors and the lack of cheap abatement potential in others (Bakker et al., 2007; McKinsey, 2009).

Another explanation could be that certain sectors lack good CDM methodologies. This could be due to the nature of certain sectors. Abatement opportunities in the residential sector are for instance far more fragmented than large abatement opportunities available in iron and steel plants. Interestingly under CDM there appear to be an increasing number of small scale projects even while these projects have a higher burden of the high transaction costs under CDM (Boyd et al., 2007; Ellis et al., 2007a).

A third explanation is more evolutionary. It could be that certain sectors score better because a non-Annex I country had better locally available technological capabilities within that sector. Another similar explanation would be that specific historical (colonial) or cultural (language) linkages between an Annex I country with specific technological capabilities and a non-Annex I country increase in CDM projects in a specific sector. Also political motivations to favour certain projects might play a role in the difference in the spread of projects.

An explanation behind the differentiated impact of CDM between countries might be because some countries have a more stable policy and investment framework and that these countries are also appearing to be attracting more CDM projects (Ellis et al., 2007a; Ellis et al., 2007b)

7.2.2 CDM's role in technology development and bridging the valley of death

Developing countries are generally seen to lag behind with respect to innovation and development of technologies. Their industrial focus is on adoption of foreign technology instead of pushing the "global technology frontier" (UNCTAD, 2007). According to the World Bank, most technological development still occurs in OECD countries and there are scientists who say that this is going to stay this way (Cimoli et al., 2003). However there is also evidence that developing countries are becoming technology leaders, for instance Brazil (bio fuels), China (coal gasification and hydrogen produced from coal) and South Africa (coal to synfuels) (Brewer, 2008). If the latter is true then technology transfer is not only about north to south technology transfer but also about south to south and south to north.

This study found that in the iron and steel sector there were many CDM projects that scored well on the technology development indicators. One reason might be that there are many innovative technologies available and that it makes business sense to acquire the most advanced technologies when developing CDM projects.

The diffusion of these innovations into non-Annex I countries might be stimulated by the fact that most expansion of the iron and steel production capacity is taking place in emerging economies (IEA, 2007b; Worldsteel, 2008) and because installing new technology in novel plants is often less expensive than retrofitting existing ones.

Another explanation might be that because of the size and complexity of iron and steel plants a project would most often be a tailor made project, simply because there are little non tailor made projects in the sector.

To what extent CDM is responsible for the execution of these project remains difficult to tell. But taking into account the premises that each project is truly additional one could say that the CDM does play a role in the development of those projects.

7.2.3 Enhancing CDM's contribution to technological development

This study confirmed that technological development benefits can be part of the sustainable development co-benefits of CDM projects. It is hard to say that these properties are the sole result of the CDM. Whether there is a cause and effect relation between CDM and the indicators that were measured. But let's assume that CDM projects play a role in technology development. Would it be possible and useful to enhance the CDM to support more technology development?

There is a global need for technology finance. As was calculated by the IEA and the UNFCCC that a considerable amount of learning investments are needed for technology development and diffusion (IEA, 2000; IEA, 2008; UNFCCC, 2009). Between \$2.8 and \$7 trillion USD globally according to the IEA (2008) and up to 1 trillion USD is needed up to 2030 (of which up to \$500 billion USD would be needed in developing countries) according to the UNFCCC.

Achieving international cooperation to achieve sufficient finance is difficult and currently ongoing. Ghana's proposal "on options for effective mechanisms and enhanced means for technology development and transfer" includes the idea to credit "technology development, deployment, diffusion and transfer" (UNFCCC, 2008b).

A possible way to support technology development would be by awarding additional credits to CDM projects with specific technology development benefits. Awarding additional credits to projects with technology development benefits does however touch upon the discussion on the environmental integrity of the CDM for it would award carbon credits without immediate CO₂ reduction. Technology development would however in the long term benefit CO₂ reduction initiatives. Also awarding credits through a market based instrument instead of subsidies might be a more politically acceptable tool to secure finance for technology development.

CDM is currently an environmental policy. However there is discussion about positive effect of technology policy on the environment (Coninck et al., 2007b; del Río González, 2009, p870). Technology policy and environmental policy could be complementary and the CDM has the flexibility to incorporate both.

7.2.4 Why the discussion should be broader than technology transfer

Technology transfer plays an important role in the current debate about international cooperation for climate change mitigation (Coninck et al., 2007b; Schneider et al., 2008). However technology transfer is only an aspect of technology change (see section 4.2.2).

If we measure more technology transfer this does not necessarily mean that this constitutes a good development since it also implies that the technology is not locally available. This is especially the case in India, which thanks to its sheer size, among other features, contains a lot of locally available technologies. If sufficient local suppliers are available, such as in the case of wind power, CDM might prove a tool to create market for non-Annex I companies.

Technology transfer is defined as the diffusion of non-domestic technologies. Spillover is an improved capacity to carry out productive transformations due to activities undertaken in an unrelated sector or geographical region (based on Metcalfe (1995) and the IPCC (2007)). A spillover occurs when a technology that used to be bought abroad eventually leads to the development of local capacities in which case the technology need not be bought any more. Buying technology from a different region is probably good for a country as long as there is a balance between import and export of technologies and as long as importing technologies also contributes to improvement of local capabilities.

7.2.5 What does it mean for TC that CDM divides the world in two?

In this section I will discuss the implications of dividing the world into Annex I and non-Annex I.

The Kyoto protocol stimulated the market for low carbon technologies. It put a price on carbon and by creating tight caps, the carbon price rose. As the price rises more types of abatement become feasible. As can be seen in Figure 7-1 a higher price per abated CO₂-eq makes an increasingly larger range of abatement options economically feasible.

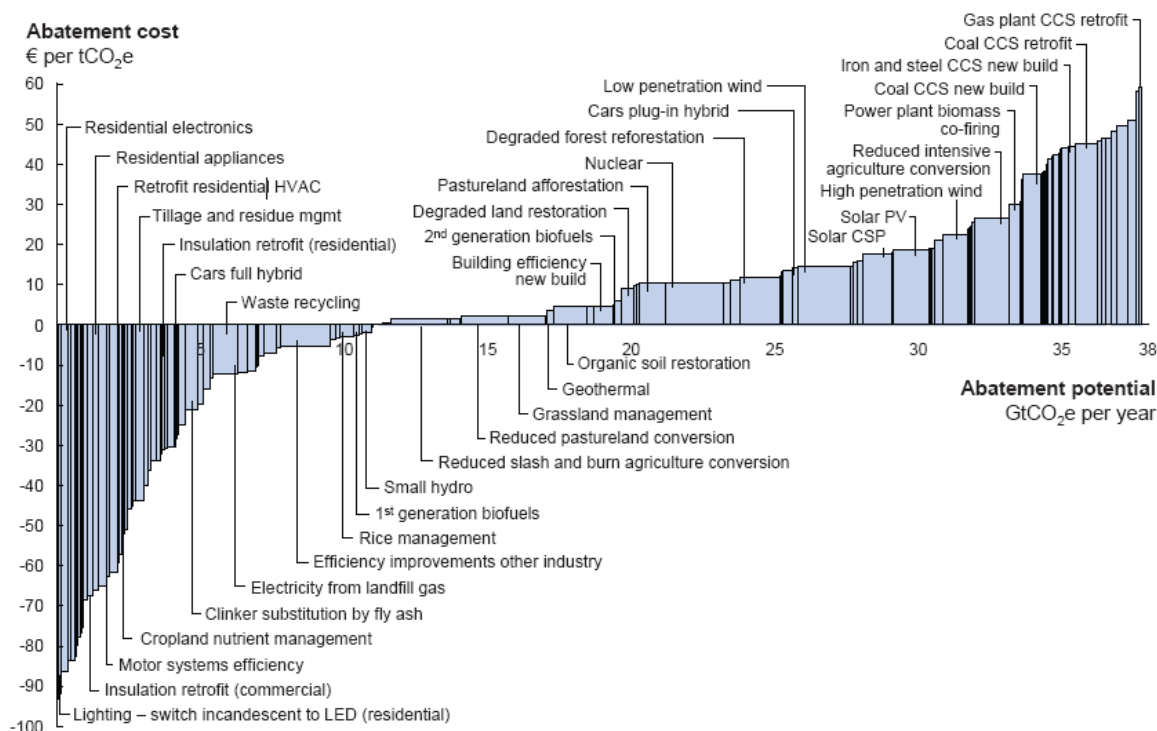


Figure 7-1 McKinsey Global Abatement Cost Curve (McKinsey, 2009)

The CDM allows for more economic flexibility between the available abatement options of Annex I and non-Annex I countries. Non-Annex I countries with large low cost abatement options could lower the burden of Annex I countries with little low cost abatement potential.

This implies that the CDM leads to an increase in the diffusion of (relatively) low cost abatement technologies in non-Annex I countries at the cost of a reduction in the diffusion of (relatively) high cost abatement options in Annex I countries.

CDM thus takes the pressure of the abatement responsibility in Annex I countries and might lower the need to be creative and implement (relatively) high cost advanced technologies in Annex I countries. This might have a negative influence on technology development and innovation of high cost abatement options in Annex I countries (see also (Lund, 2006)).

However it does lead to lower abatement costs which have an influence on the political will to reduce emission reductions. Probably a lower emission price will make it easier for governments to commit to more stringent emission reduction targets in coming international rounds of negotiation.

In an article Barreto (2004) models the effect of different emission trading scenarios on the spillover of learning by doing in a global model. He assumes global learning, which implies that learning in Annex I regions (and decreasing investment costs as a result of learning) creates an

equal spillover to non-Annex I countries. Even in a world without emission trading, learning in Annex I countries thus still affects the deployment of low carbon technologies in non-Annex I regions.

In his model Barreto finds that without global emission trading (basically no CDM), GHG levels in non-Annex I countries are reduced below that of other scenarios (BAU, trading between Annex I countries, global trading). This is due to the fact that without global emission trading, Annex I countries have to increase the deployment of low carbon technologies which positively affects learning in Annex I regions. The effects of learning are spilled to non-Annex I regions and have a more positive effect than when they would be included in a global emission scheme. The outcomes of this model depend heavily on the weight of different effects: such as the effects on the size of the Annex I and non-Annex I LCT markets under different trading scenarios, the amount of spillover that really takes place between Annex I and non-Annex I regions. Also this model does not take into account the effect on rising CO₂ abatement costs of different scenarios, which must have an effect on the political will to set ambitious emission targets. It does however give interesting insight into different trade scenarios. And it helps make us aware that policy on a global level affects technological change in both Annex I and non-Annex I countries.

Another interesting study is one by Gagelmann (2005) about the impact of CO₂ emission trading within Europe. Gagelmann tries to find out the effect of emission trading on innovation. His literature study mainly cast doubts on the superiority of emission trading over other policy instruments and tells us that although emission trading seems to be an effective way to comply with emission reduction targets, its effects on innovation are not clear. Taking a more evolutionary perspective, he points out that emission trading appeared to be a politically acceptable compromise. And in that sense it induced more innovation than when no agreement would have been reached. Lund (2006) concludes that as a result of Kyoto's flexibility mechanisms Denmark has decreased its effort to deploy innovative technologies leading to less innovative activities within Denmark. Instead Denmark buys credits abroad.

To conclude this section I would like to remind that the effect of global emission trading through CDM on technological change is the sum of the effect in Annex I regions plus that of non-Annex I regions. Since climate change is a global problem we will eventually have to be able to maximize the sum of both impacts.

7.2.6 What we can say about the perverse incentive

Stringent environmental policy in principle poses a barrier for CDM projects to pass the additionality test. A number of scientists state that the current project based form of CDM creates a perverse incentive that prevents non-Annex I countries to adapt stringent environmental policy (Lohmann, 2006; Sterk et al., 2006; Halsnæs et al., 2008). The perverse incentive could be considered a serious downside to the CDM; however literature fails to empirically prove that assumption.

Although Winkler (2004) argues that the perverse incentive is countered due to a guidance that was put forward by the CDM executive board at its eleventh meeting, current additionality rules still take current national rules and regulation into account (CDM EB, 2009). The guidance put forward by the executive board appears to reduce the problem but it does not take the sting out of the perverse incentive.

Within this research I do not give a definite answer about whether the perverse incentive occurs but I do present some findings that might help understand this phenomena.

Firstly an actor analysis shows that the interests of the different actors might lead to a number of dilemmas (see Appendix A Actor analysis).

According the actor analysis both Annex I countries and non-Annex I countries have an incentive to keep a steady flow of low cost CERs; either to lower the costs of their Kyoto commit-

ment (Annex I countries) or to attract foreign investment (non-Annex I countries). This however contradicts stringent regulation in non-Annex I countries for that would render CDM projects non additional. Also individual governments do not have an incentive to commit to climate commitments and would prefer to free ride on the activities of other governments (see also Hardin (1968) on the tragedy of the commons and pollution).

Secondly within the wind sector we found that diffusion is taking place and that interestingly the new trend appears to be to use CDM as additional co-finance. According to the data a limited number of wind turbines were installed in 2002-2003 which were largely co-financed by CDM, in 2004-2006 the expansion of wind power increased more rapidly although little to no CDM co-finance was used. However from 2007-2008 expansion of wind power continues with co-finance through CDM reaching up to 100% in 2008 (see Figure 6-4). This raises the question whether co-finance was needed and whether developers have not learned to use CDM co-finance in addition to other resources. Another explanation might be that national support for wind power declined (or did not grow appropriately) as governments learned of the opportunities of international finance through CDM.

Thirdly in the iron and steel sector it was found that many PDDs mentioned the fact that local regulation did not oblige them to use waste energy. This raises the question if CDM prevents developing countries from putting in place more stringent regulation to stimulate the use of waste energy.

Fourthly literature suggest that the with respect to HCFC-22, CDM creates a perverse incentive for developing countries to move ahead with the implementation of the Montreal protocol (Coninck et al., 2007b; Castro et al., 2008).

This research found that many PDDs actually mention that local policy is insufficient to render projects feasible. It also found interesting results in the wind power sector that indicate that current wind power projects are all co-financed through CDM although previous projects were executed without CDM co-finance.

Two reasons why national governments are to create their own environmental policy are that decentralized policy can be more specific and tailor made and that it is important a country goes through its own development cycle based on a intrinsic imperative (Kroesen, 2003).

I also propose a new policy idea that creates a positive incentive for non-Annex I governments to install more stringent environmental policy. I propose to do this by allowing a time lag of five years between the moment new national (non-Annex I) policy is put into place and the moment this policy needs to be considered in the additionality check of CDM projects. This time lag would give non-Annex I companies five years to comply with local regulation by using co-finance from CDM.

This removes the negative incentive that prohibits governments of non-Annex I countries to adopt progressive environmental policy. In return it actually gives governments the means to stimulate and encourage the diffusion of technologies under CDM. It gives them the possibility to govern and stimulate the use of CDM within their country without being negatively rewarded for doing so.

7.2.7 Developing methods for design and monitoring of policies on TC

Neij et al. (2006) propose “a framework for the evaluation of policy instruments designed to effect development and dissemination of new energy technologies”. Their method is basically a statement that it is important to measure outcome indicators, rather than output or input indicators, and do regular monitoring. Possible outcome indicators would be the CO₂ per capita or the production function. This method however makes it impossible to disentangle the contributions of individual policies.

We learn from this article that it is important to start systematic analysis of the effect of policy on technological change. The research performed on the impact of CDM on TC hopes to contribute to the discussion on finding ways to measure and monitor the impact of policy on TC.

7.2.8 Assessment of technology orientated SD benefits under CDM

In a recent article Olsen and Fenhann (2008) work towards a methodology for sustainability assessment based on text analysis of the project design documents. They however do not include technological aspects since: “it has not been possible to come up with good indicators based on the information given in the PDDs” (Olsen et al., 2008). I hope that the indicators for technological development that were developed as part of this research could be included in their analysis as technology benefits. In particular those indicators that relate to learning, R&D and spillover. This research did find that these indicators could be traced in PDDs.

8. Conclusion and recommendations

In the context of international effort to fight climate change there is a need for an improved understanding of the impact of the Clean Development Mechanism (CDM) on technological change (TC) in developing countries. This report aims to contribute to filling in this research gap.

In this research TC is defined as technology diffusion, technology development and change of the national innovation system. Because this research is first of its kind it includes a new method to measure TC. The method includes indicators for technology diffusion, technology development and changes in the national innovation system and uses data from the CDM pipeline, national GHG emission data, PDDs and other freely available sources. The method was applied to three Indian case studies: the electricity sector, the iron and steel sector and HFC producing industries. The method has proven to be useful in studying the effect of CDM on technological change.

The CDM has a considerable impact on technology diffusion in India, but the impact differs greatly between sectors. In 2006 India emitted an estimated 1,975Mt CO₂-eq while technology diffusion by the CDM mitigated 75 Mt CO₂-eq (3.8%) measured in CERs.

An estimated 11M CERs/yr are mitigated from HFC emitting industries which equals about 100% of the sector's 2006 production (mainly due to HFC-23 destruction), the 37M CERs/yr from the electricity sector equal about 7% of the sector's 2006 emissions and the 8M CERs/yr in the iron and steel sector equal about 6% of the sector's 2006 emissions. However in other sectors such as the transport, residential & commercial and manure sectors the CDM has had almost no impact.

It is found that CDM does not only impact technology diffusion but that CDM projects may also benefit technology development. Within this research, technology development is a result of learning, R&D, spillover and economies of scale.

In the iron and steel sector the assessment indicates that CDM projects impact technology development through stimulating a combination of learning, R&D and spillover. In the electricity sector it was found that CDM aided the market expansion of domestic wind turbine manufacturers. In the HFC producing industries it was found that CDM contributed mainly to technology transfer of HFC-23 destruction technology from Europe. In the first two CDM projects using different HFC mitigation technologies CDM contributed to a combination of learning, R&D and spillover.

The method proved to be unsuitable to study the impact of CDM on the national innovation system. Different indicators of changes in the NIS and different data sources to measure these indicators will have to be used in future research.

Although literature suggests that CDM may create a perverse incentive to non-Annex I countries to take on stringent environmental policy there remains no empirical research to confirm this occurrence.

The technology diffusion data from this research does however suggest that India used to develop wind turbines without CDM co-finance from 2004-2007, but that by 2008 India had learnt to use CDM in addition to domestic support in all new wind turbine projects.

The main conclusion from this research is that the CDM can have a considerable impact on TC in non-Annex I countries. The impact is primarily the result of technology diffusion; however the CDM also appears to positively influence technology development. The impact on the national innovation system is important but remains little understood.

Recommendations

About the method and its application in future research I recommend a number of improvements. This study is limited in the number of countries that were looked at and in the number of PDDs that were studied. Also the method proved to be unsuitable to study changes in the national innovation system.

Therefore future research could apply technology diffusion analysis to a larger number of countries and increase the effort with respect to looking for explanations in the differences between sectors and countries.

With respect to measuring technology development I recommend refining the indicators and applying them to a larger number of PDDs. Due to the biased nature of PDDs I also recommend field visits to get more balanced data. These measures are needed to increase validity and improve our understanding of the causality between CDM projects and technology development.

With respect to the changes in the national innovation system I recommend using different indicators and data sources, for instance interviews with stakeholders. The current method is ill suited and therefore a creative new approach is needed.

These recommendations aim to move the research field a step ahead. Where this research set a first step in measuring TC, follow up research could increasingly focus on finding explanations for the measured differences, using these explanations to build theory and applying theory to design future policy interventions.

With respect to policy I recommend the members of the UNFCCC to consider the sectors in which CDM has had little or no impact on technology diffusion. Technology diffusion in these sectors may be achieved by either considering different (new) mechanisms apart from CDM or by improving the effectiveness of the CDM.

I also propose the idea that CDM could be used as a mechanism to stimulate the development and demonstration of innovative new technologies. This is in the same line of thought as Ghana's proposal "on options for effective mechanisms and enhanced means for technology development and transfer" which includes the idea to credit "technology development, deployment, diffusion and transfer".

This could be done by awarding additional credits to CDM projects with specific technology development benefits. Awarding credits through a market based instrument could be a politically acceptable tool to secure part of the large amount of finance that is needed for low carbon technology development.

The CDM executive board could manage a list of technologies that are in need of development and demonstration assistance and changes to this list could be proposed by governments, civil society, industry representatives and the scientific community.

I also propose a new policy idea that creates a positive incentive for non-Annex I governments to install more stringent environmental policy. I propose to do this by allowing a time lag of five years between the moment new national (non-Annex I) policies are put in place and the moment this policy needs to be considered in the additionality check of CDM projects. This time lag would give non-Annex I companies five years to comply with local regulation by using co-finance from CDM.

This removes the negative incentive that prohibits governments of non-Annex I countries to adopt progressive environmental policy. In return it actually gives governments the means to stimulate and encourage the diffusion of technologies under CDM. It gives them the possibility to govern and stimulate the use of CDM within their country without being negatively rewarded for doing so.

9. Reflection

In this chapter I reflect upon the strong and weak points of this research. I will ask myself what the relevance of my work has been to society in general and more specifically the scientific community. By answering these questions I will also try to explore what the consequences have been of choices that I have made at the start of this research.

Strong points:

- A strong point of this research is that it contains conclusions based on empirical data that improve our understanding of the impact of CDM on TC. The latter is important because there is a global need for TC especially in the context of fighting climate change. Improving the speed of TC could greatly reduce the costs of mitigating climate change. Studying the impact of CDM on TC is important because the CDM has grown to become a very large global policy. The CDM contains over 45000 projects (UNEP/Risø, 2009) and is expected to generate over \$45 billion in LCT investments (UNFCCC, 2009).
- The results of this study allow policy makers insight into the effect of CDM on TC. With respect to technology diffusion this study showed that some sectors are not influenced by CDM and thus policy makers might consider alternative strategies to effect these sectors. This study has also shown that CDM can contribute to technology development. This insight will be useful for policy makers that have to plan technology development policies.
- This study has been relevant for science because it is first of its kind and includes a new method to measure the impact of CDM on TC. In combination with the preliminary explanations behind the results that were measured in the case studies this research could serve as step to move the research field ahead. The next step would be more detailed research into specific aspects of TC that could increasingly focus on finding explanations for the measured differences, using these explanations to build theory and applying theory to design future policy interventions.

Weak points

- Because this research defined TC very broad (technology diffusion, technology development and change in the NIS) this study has not been able to go into much detail. It was also limited in the number of cases and PDDs studied. If the choice would have been made to study a single element of TC, this might have led to more specific data, improved insight into the causalities, more detailed explanations and more specific policy recommendations about this single aspect of TC.
- The data sources used for this study have been very top down. Because of limited recourses it became all desk studies. This study did not go to the people that are influenced by CDM in developing countries and just ask them how they think CDM influences TC in their country. The latter might have resulted into very interesting and different kind of results.
- Firms are an important storage of knowledge and technological development. A weak point is that this research did not study into detail to what extent CDM led to improved technological capabilities on a firm level.
- This study did not compare the impact of CDM on TC with any alternatives, such as other market based instruments, CO₂ taxes or command and control strategies. Such as comparison might have been done by using theoretical innovation and diffusion models. Therefore the results of this study tell us little that could be used in the discussion of ranking CDM relative to other instruments with respect to their impact on TC.

I conclude my reflection by saying that I believe that this study and its results are relevant for society and science. I however also acknowledge that were limitations to this research, most notably due to choice to take a broad definition of TC. A more specific focus on a single aspect of TC might have made it possible to take more measurements and explain a single specific relation into more detail.

I hope that others will find the conclusions interesting and useful and that this research proves a useful starting point for interesting future research.

"Would you tell me, please, which way I ought to go from here?"
"That depends a good deal on where you want to get to", said the Cat.
"I don't much care where—" said Alice.
"Then it doesn't matter which way you go," said the Cat.
"— so long as I get somewhere," Alice added as an explanation.
"Oh, you're sure to do that," said the Cat, "if only you walk long enough."

Lewis Carroll, Alice's Adventures in Wonderland

Appendix A Actor analysis

In this Appendix I will deal with human side of the relations within CDM mechanism. The actors and their behaviour do in fact prove interesting insight into the functioning of the CDM. I conducted an actor analysis which I will present in this appendix.

From the analysis three dilemmas can be distilled. Between Annex I and non-Annex I governments, between firms that receive and firms that supply technology and between governments and multilateral institutions.

Dilemma 1: Between governments and UNFCCC

Governments have committed under the Kyoto protocol to reduce their emissions. However the goals of the UNFCCC to achieve these targets interfere with the dilemmas each government faces in their own country. There is an incentive for governments to defect from agreements made under the Kyoto protocol and free ride on the efforts of other governments. The goals of the principle (UNFCCC) and its agents (national governments) do not align exactly.

Dilemma 2: Between Annex I and non-Annex I countries

The interests of Annex I countries lie with their inhabitants. These governments will seek ways to (within the limits of the law and taking into account the crime vs. punishment trade off) lower the costs of emission abatement and strengthen their local economy. Governments try to become technological leaders (competitive regions), create new jobs and use non-Annex I countries as markets to diffuse their low carbon technologies.

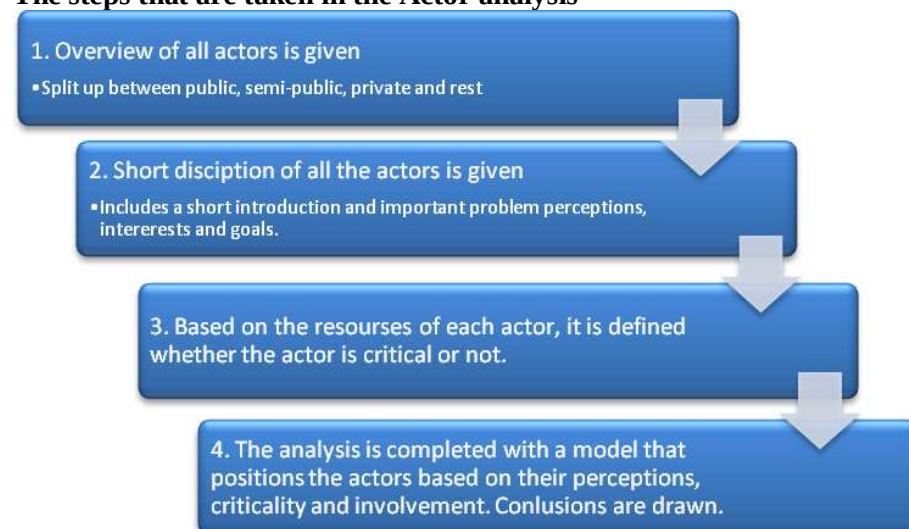
The interest of non-Annex I countries lie with their inhabitants. Economic progress and a lift out of poverty are the main goals. Instead of being a market for the diffusion of technology from Annex I countries, non-Annex I want to develop their own industries and find markets for their own products and capabilities.

Both Annex I countries and non-Annex I countries have an incentive to increase the flow of cheap emission credits, either to keep the price of their Kyoto commitments low (Annex I) or to draw foreign investments (non-Annex I).

Dilemma 3: Between technology supplying firms and technology receiving firms

The major dilemma that becomes clear is that there is the opposing view between firms. Firms that have acquired technology (both tangible and tacit) do not have any incentive to transfer advanced capabilities to competitors. They are interested in acquiring new markets to export their technology and skills, but there is no incentive to strengthen the capabilities of their competitors.

The steps that are taken in the Actor analysis



List of actors

Actors			
Public	Semi-public	Private	Unorganized
• UNFCCC • EB • Annex I Govern-ment • Non Annex I Gov-ernment • DNA • DOE	• IPCC • Environmental pressure groups	• Technology suppli-ers • Technology receiv-ers • Project Developer	• Local stakeholders

Description of each actor

Actor	
Annex I government	<i>Description:</i> Annex I Governments are governments that signed the Kyoto protocol and committed to GHG reduction by means of a cap. These include all OECD countries minus the USA. <i>Problem perception:</i> Reducing CO2 emissions is costly. Reducing GHG's by applying technologies in developing countries is cheaper than in in-house reduction. <i>Interests:</i> Increase the wellbeing of inhabitants. <i>Goal:</i> Achieve GHG emissions reduction targets for lowest possible price.
DNA	<i>Description:</i> Designated National Authority. Non-Annex I DNA's are responsible for determining whether a project meets all sustainability criteria. <i>Problem perception:</i> attract more CDM projects <i>Interests:</i> National interests <i>Goals:</i> Development of CDM projects
DOE	<i>Description:</i> Accredited company responsible for the Validation, Verification and Certification of projects. <i>Problem perception:</i> Since the DOE is hired by the project developer, objecting to projects might lower the chances of a DOE to receive future projects. <i>Interests:</i> Continuity and profit <i>Goals:</i> Getting more projects
EB	<i>Description:</i> The EB oversees the execution of the CDM mechanism <i>Problem perception:</i> The pressure to supply cheap credits puts pressure on the integrity of the CDM. <i>Interests:</i> Maintain the integrity of the CDM. <i>Goals:</i> Making the CDM a success
Environmental Pressure groups	<i>Description:</i> Environmental pressure groups <i>Problem perception:</i> The current form of CDM undoes the responsibility of Annex I countries to achieve GHG reduction and does not lead to a reduction of GHG. <i>Interests:</i> Maintain local support of their donors <i>Goals:</i> Achieving a clean environment
IPCC	<i>Description:</i> International Panel created by the World Meteorological Organization and the UN. <i>Problem perception:</i> Needs to maintain objective with respect to policy making. <i>Interests:</i> Maintain scientific credibility <i>Goals:</i> Give an objective overview of the most recent scientific status of research related to climate change.
Local Stakeholders	<i>Description:</i> Inhabitants of non-Annex I countries <i>Problem perception:</i> Lack of good jobs <i>Interests:</i> Prosperity <i>Goals:</i> Increase income

Non Annex I government	<i>Description:</i> Non-Annex I governments are governments that signed the Kyoto protocol but did not committed to GHG reduction by means of a cap. Most of these countries are considered developing countries. However there is a large difference between non-Annex I countries such as Bangladesh and non-Annex I countries such as Singapore or Malaysia. <i>Problem perception:</i> (sustainable) Economic development is needed to lift country out of poverty (increase prosperity). Current climate problem should not dampen their economic development. <i>Interests:</i> Increase the wellbeing of inhabitants. <i>Goals:</i> Attract foreign investment.
Project Developer	<i>Description:</i> Project developers that actively seek projects to develop and finally sell the CER's to Annex I parties. <i>Problem perception:</i> High transaction costs due to complicated CDM procedures slow down project development activities. <i>Interests:</i> Continuity and profit <i>Goals:</i> Successful project certification and issuance of CER's
Technology receiving firms	<i>Description:</i> Non-Annex I companies <i>Problem perception:</i> Current CDM practice transfers insufficient technology and tacit knowledge <i>Interests:</i> Profitability and continuity of their firm <i>Goals:</i> Increase their technological capabilities. Become more technological advanced.
Technology supplying firms	<i>Description:</i> Both Annex I and Non-Annex I companies that have access to technology that is allegeable to CDM project finance. <i>Problem perception:</i> Transferring their knowledge harms their competitive position <i>Interests:</i> Profitability and continuity of their firm <i>Goals:</i> Use CDM to find new export markets
UNFCCC	<i>Description:</i> The UNFCCC is part of the UN and aims to stabilize GHG emissions to prevent dangerous anthropogenic interference with the climate system" (article 2 of UNFCCC). <i>Problem perception:</i> Insufficient GHG reduction <i>Interests:</i> A solution to solve global climate change that suites the global community taking into account the "common but differentiated responsibilities". <i>Goals:</i> Reduce Greenhouse Gas emissions

Criticality

Actor	Means	Substitutability	Dependability	Critical
Annex I government	Political, financial	Medium	High	Yes
DNA	Authorization	Medium	High	No
DOE	Authorization	High	High	No
EB	Authorization	Low	High	No
Environmental Pressure groups	Political, public perception	Medium	Low	No
IPCC	Knowledge	Low	Low	No
Local Stakeholders	Political	Medium	Low	No
Non Annex I government	Political	High	High	Yes
Project Developer	Financial	Medium	Low	No
Technology receiving firms	Organizational	High	Low	Yes
Technology supplying firms	Knowledge	Low	High	Yes
UNFCCC	Political, Authorization	Low	High	No
Means :	Which production resources or other means of influence does this actor have?			
Substitutability :	Could this actor be replaced by another actor?			
Dependability :	Does the project depend on this actor?			
Critical :	Is this actor critical to the success of the project?			
Authorization :	The authorization power to either allow or disallow the project.			
Financial :	Those financial resources that directly influence the likelihood of creating a profitable and competitive business case.			
Knowledge:	These parties are able to supply knowledge about low carbon technologies			
Organizational :	Parties that are advocate of the project and can assist during the development.			
Perception :	Parties whom are capable of changing public perception about the project, either in favor or opposing the project.			
Political:	These parties can give or withhold political support to the CDM.			

Overview

	Involved		Not Involved	
	Critical actor	Non critical actor	Critical actor	Non critical actor
Matching perceptions, interests and goals.	• Non Annex I government • Technology receiving firms	• DNA • DOE • EB • Environmental Pressure groups • IPCC • Local Stakeholders • Project Developer • UNFCCC		
Contradicting perceptions, interests and goals.	• Annex I government • Technology supplying firms			

Appendix B Multi Level perspective on transitions

Increasing structuration
of activities in local practices

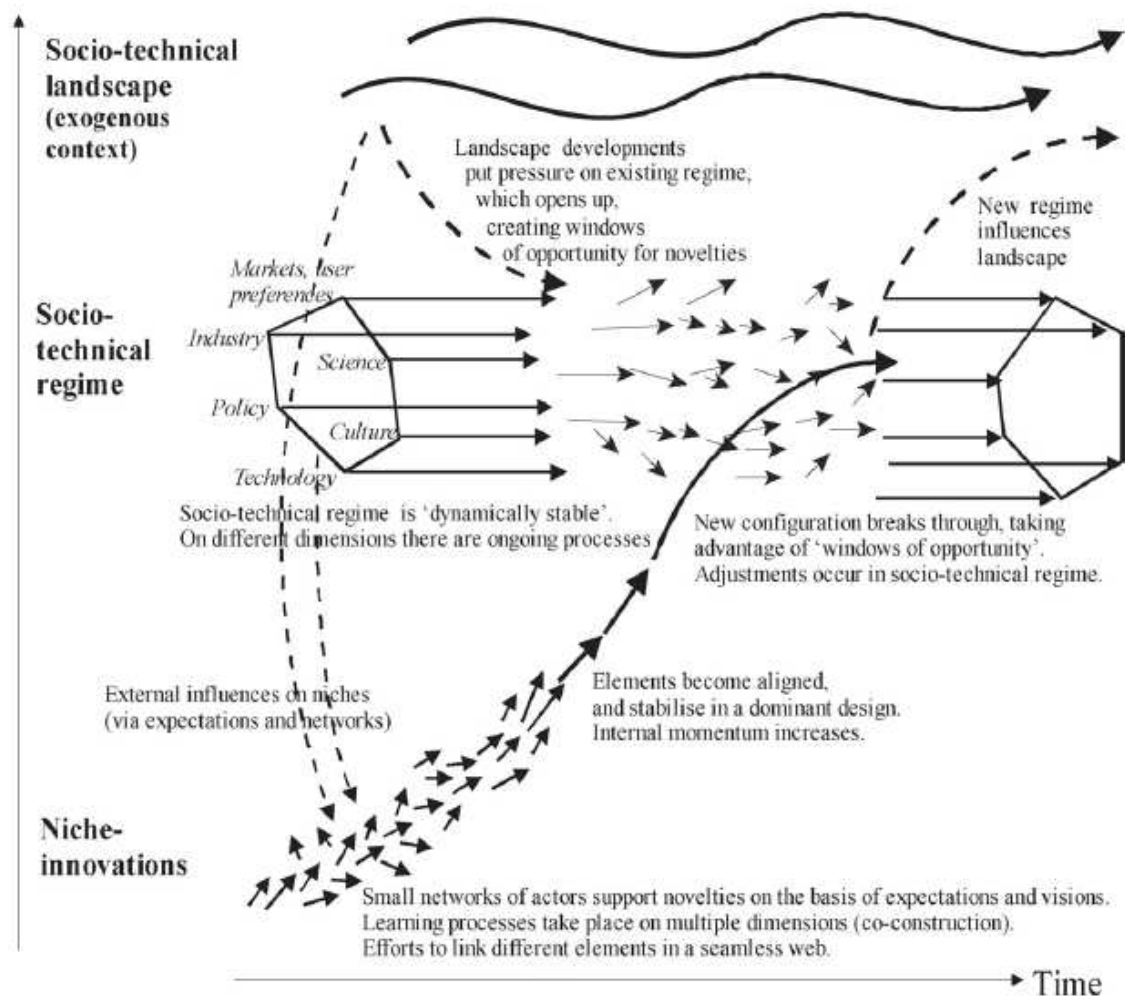
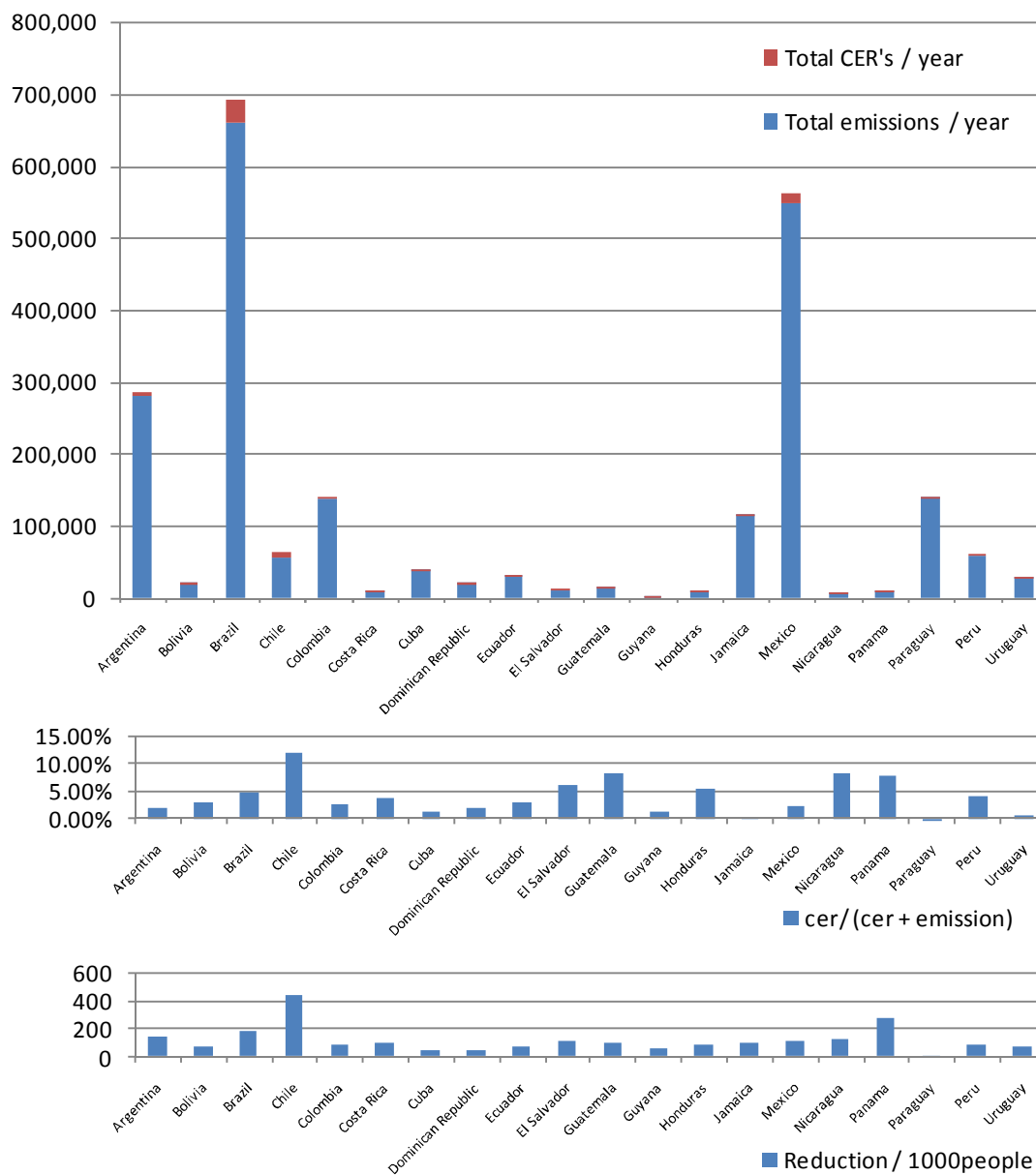


Figure 9-1, multi level perspective on transitions (Geels et al., 2007c)

Appendix C Impact assessment on Latin America

Note: The data of each country are based on their National Communications towards the UNFCCC plus the CDM pipeline database. National Communications are often based on the emission levels of 1994. In some cases countries emissions have risen by at least 50% since.

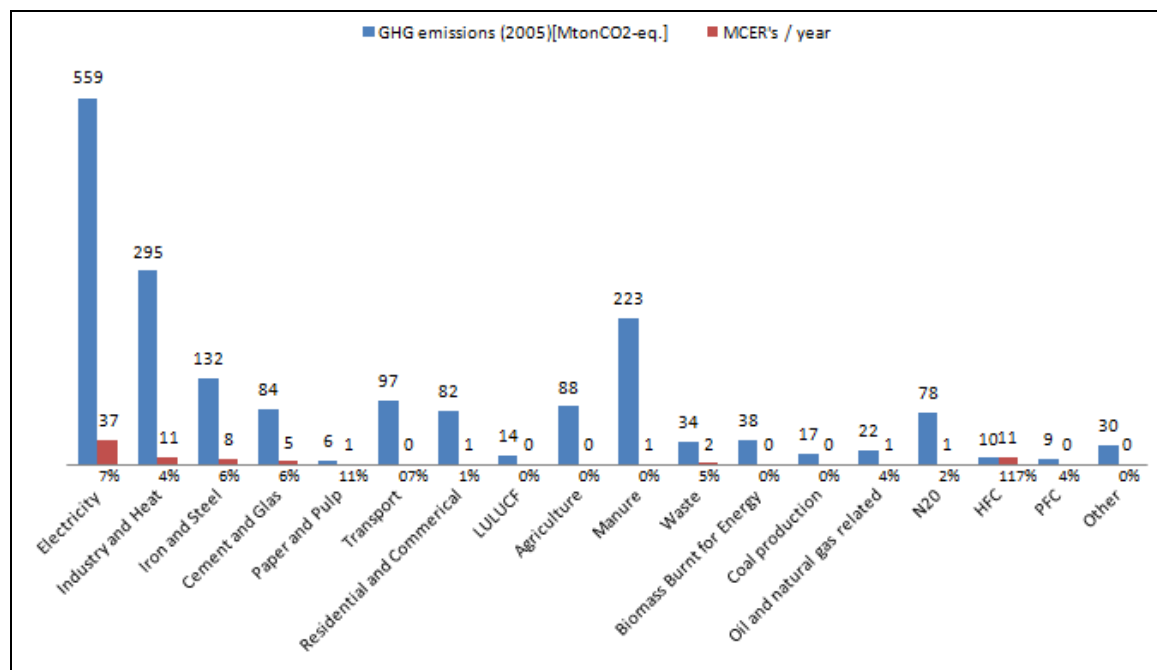


Appendix D Literature on technology transfer under CDM

Article	Conclusions
(Hansen, 2008)	-Transferor companies have limited incentive to transfer more than the basic needed operation and maintenance capabilities concerning valuable technology knowhow. -Transfer of technological capabilities appears to increase with a more strengthened bind between the transferring and the receiving company.
(Dechezleprêtre et al., 2008)	-Project often transfers both equipment and knowledge and operation skills. -Much TT: End-of-pipe destruction projects (HFC, CH₄ and N₂O) within the chemical, agricultural and waste management sector and within the wind power sector. -Mainly local T: biomass, energy efficiency. -Mexican and Chinese projects are more frequent to attract TT -Europe is the main TT provider -More TT when project developer is subsidiary of a company from an annex I country. -More TT with large projects -Capacity building is advised for the energy and chemical sector
(Seres, 2007)	-TT more common for large projects -TT more common if foreign participants are included -India has lower TT than other countries -Countries can influence TT through tariff structures and SD criteria used by DNA
(Youngman et al., 2007)	-In case of TT most technology (80%) comes from Europe -The investment value of these projects is €390 million (83%) of a total of €470 million (projects as of November 2007). -This mainly consists of high capital project in the wind and hydro sectors. -CDM does not change project economics; it does improve the IRR, which makes it easier to attract financiers.
(Coninck et al., 2007a)	-TT in almost 50% of the cases -More TT within non-CO₂ reducing projects and wind than with other renewable projects -Notifies a trend in the development of high-tech industries in emerging economies. -Confirms the need for capacity building -Foreign technology: non-CO₂ GHG reduction, wind and some hydropower. -Local technology: bio-energy, thermal efficiency, some hydropower and landfill gas projects. -Europe benefits mostly from the technology investments
(Haïtes, Duan & Seres, 2006)	-1/3 of projects claim TT -High share of TT: agriculture, landfill gas, solar and wind -High share of local T: Fossil fuel switch, hydro projects -TT more common when foreign partners are involved. -Equipment transfer is more common in large projects -Host countries can influence TT through tariffs and their project approval criteria. -GDP does not seem to influence TT

Appendix E Country Impact assessment: India

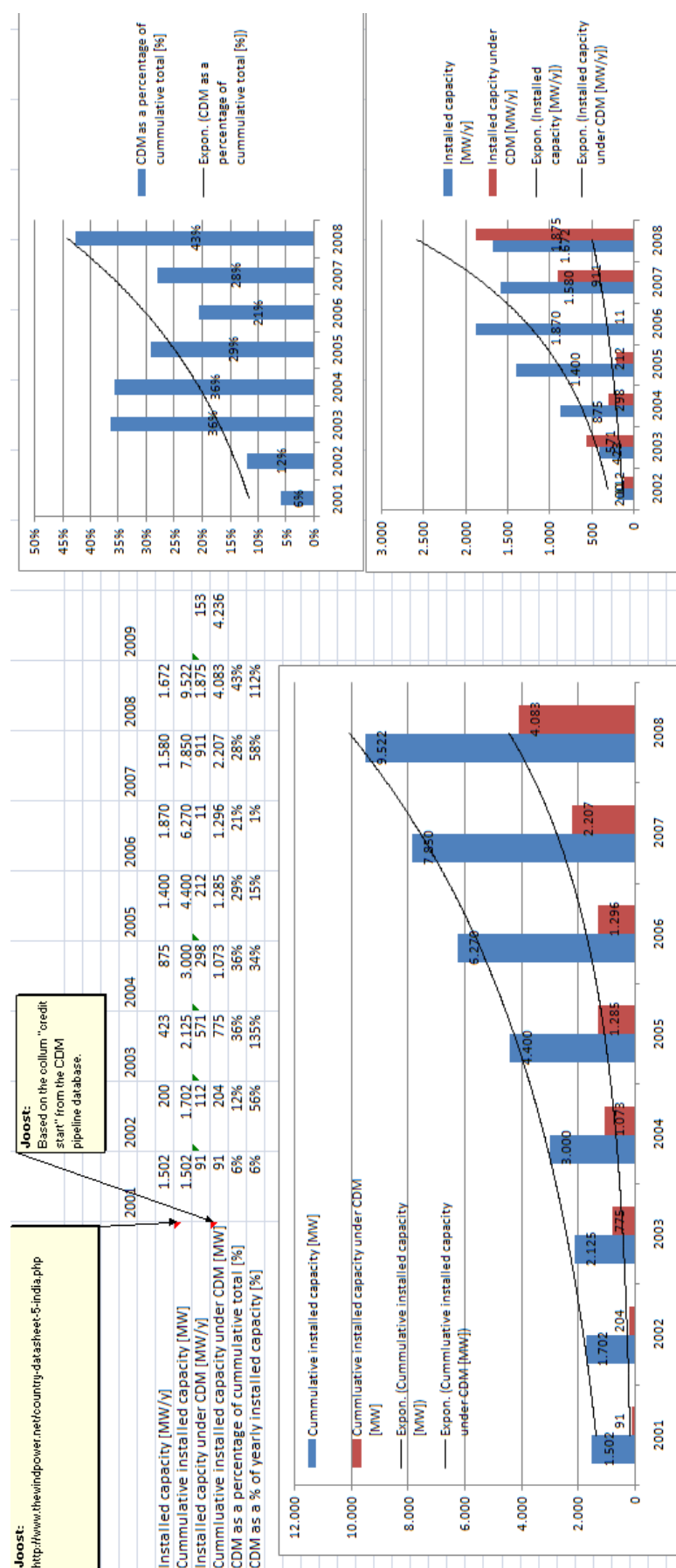
This appendix includes additional data related to Figure 6-2.



Overview		Joost: Most recent data found is from INC.	CO2 from fuel combustion [MtonCO2]	CO2 from process industry	CO2 from LULUCF	CH4	N2O	HFC	PFC	Total	CER's / yeCER's / year		percentage
E	Electricity		559							559	37	36526	7%
I	Industry and Heat		256	38						295	11	10809	4%
I&S	Iron and Steel		74	58						132	8	8118	6%
C&G	Cement and Glas		43	41						84	5	4669	6%
P&P	Paper and Pulp		6							6	1	632	11%
T	Transport		97							97	0	58	0%
R&C	Residential and Commerical		82							82	1	516	1%
LULUCF	LULUCF		x		14					14	0	10	0%
Agr	Agriculture		x			88				88	0	19	0%
Man	Manure		x			223				223	1	649	0%
Was	Waste		x			34				34	2	1745	5%
Bio	Biomass Burnt for Energy					38				38	0	0	0%
Coal	Coal production					17				17	0	0	0%
O&G	Oil and natural gas related					22				22	1	890	4%
N2O	N2O		x				78			78	1	1318	2%
HFC	HFC		x					10		10	16	15731	166%
PFC	PFC		x						9	9	0	323	4%
Other	Other		30							30	0	0	0%
			1147	137	14	422	78	10	9	1817	82	82013	5%

Category	Description
Electricity	- CO2 emissions from fuel combustion (IEA, 2008). - Using an average CO2 emission rating of 0.8 (CEA, 2007) the heat produced is calculated, subtracted and added to the Industry and Heat sector.
Industry & Heat	- CO2 emissions from fuel combustion (IEA (2008)). - Using an average CO2 emission rating of 0.8 (CEA, 2007) the heat produced is calculated, subtracted from the electricity category and added to the Industry and Heat sector. - CO2 emissions from industrial processes are added (based on an extrapolation of the GoI (2004) data).
Iron & Steel	- CO2 emissions from fuel combustion (IEA (2008)) - CO2 emissions from industrial processes are added (based on an extrapolation of the GoI (2004) data).
Cement & Glass	- CO2 emissions from fuel combustion (IEA (2008)) - CO2 emissions from industrial processes are added (based on an extrapolation of the GoI (2004) data).
Paper & Pulp	CO2 emissions from fuel combustion (IEA (2008))
Transport	CO2 emissions from fuel combustion (IEA (2008))
Residential & Commercial	CO2 emissions from fuel combustion (IEA (2008))
LULUCF	CO2 emissions from industrial processes (GoI ,2004)
Agriculture	CH4 emissions in CO2-eq. (table 4, data 2005, Paddy cultivation + Agriculture crop residue burning (Garg, 2006))
Manure	CH4 emissions in CO2-eq. (table 4, data 2005, Manure management + Enteric fermentation (Garg, 2006))
Waste	CH4 emissions in CO2-eq. (table 4, data 2005, Waste water disposal + MSW disposal (Garg, 2006))
Biomass Burnt for Energy	CH4 emissions in CO2-eq. (table 4, data 2005, Biomass burnt for energy (Garg, 2006))
Coal production	CH4 emissions in CO2-eq. (table 4, data 2005, Coal production (Garg, 2006))
Oil and natural gas related	CH4 emissions in CO2-eq. (table 4, data 2005, Oil and Natural Gas Related (Garg, 2006))
N2O	N2O emissions in CO2-eq. (table 5, data 2005, total (Garg, 2006))
HFC	HFC emissions in CO2-eq. (table 7, data 2005, HFC-23 (Garg, 2006))
PFC	PFC emissions in CO2-eq. (table6, data 2005, total (Garg, 2006))
Other	CO2 emissions from fuel combustion (IEA (2008))

Appendix F Diffusion analysis: case electricity sector, wind graphs



Appendix G Diffusion analysis: case electricity sector, wind data

State	Gross Potential [MW] (*1)	Technical Potential [MW] (*1)	Installed capacity (March 2008) [MW] (*5)	Projects prior to 31-12-2004 without CDM (*4)	CDM projects with starting date before 31-12-2004 (*2)	Installed Capacity on 31-12-2004 [MW] (*1)	CDM projects with starting date after 01-01-2005 (*2)	Total in CDM Pipeline [MW] (*2)	CDM projects a percentage of the technical potential	CDM projects a percentage of installed capacity in march 2008	Grid Penetration of wind on 31-01-2003[%] (*3)
Andhra Pradesh	8.275	1.750	123	88	14	101	4,5	18	1%	15%	1,0%
Gujarat	9.675	1.780	1.253	198	22	220	511,3	534	30%	43%	1,9%
Karnataka	6.620	1.120	1.011	102	174	276	561,1	735	66%	73%	1,2%
Kerala	875	605	11	2	0	2	0	0	0%	0%	0,0%
Madhya Pradesh	5.500	825	189	21	6	28	18,15	24	3%	13%	0,0%
Maharashtra	3.650	3.020	1.756	333	79	411	934,3	1.013	34%	58%	2,6%
Orissa	1.700	680	0	0	0	0	0	0	0%	0%	0,0%
Rajasthan	5.400	895	539	142	122	263	380,89	502	56%	93%	0,4%
Tamil Nadu	3.050	1.750	3.873	1.021	657	1.677	752,64	1.410	81%	36%	9,2%
West Bengal	450	450	1	1	0	1	0	0	0%	0%	0,0%
Total	45.195	12.875	8.756	1.906	1.073	2.979	3.163	4.236	33%	48%	
*1	Source: mnre.gov.in/annualreport/2004_2005_English/ch6_pg1.htm Technical potential is limited to 20% grid penetration and thus can be expected to grow										
*2	Source: CDM pipeline of september 2008										
*3	Source: Ministry of Power Annual Report 2002-2003. Data as on 31/01/2003. PDD: Jaisalmer Wind Power Project										
*4	Equals (Installed capacity on 31-12-2004) - (CDM project with starting date before 31-12-2004)										
*5	http://www.inwea.org/installedcapacity.htm										

Appendix H Diffusion analysis: General findings electricity sector

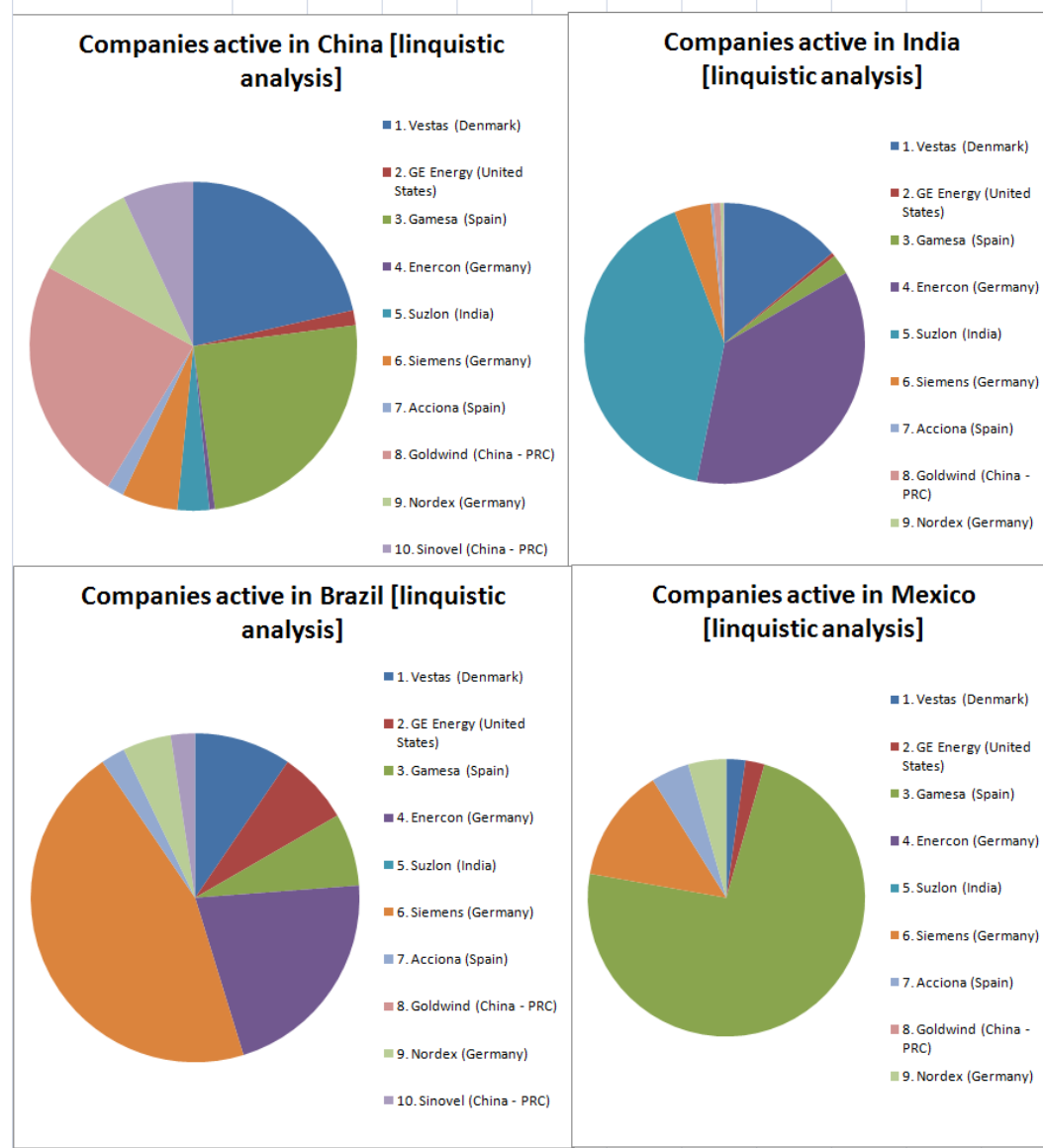
	Region	Potential [MW] or otherwise specified	Source [potential]	Yet realised [installed MW] or otherwise specified	% yet realised	Source [yet realised]	Untapped potential [MW] or otherwise specified	Source	MW's that will be realised by CDM, based on data from this pipeline	% realised including the CDM projects	% of CDM on total potential	% of CDM on total untapped potential
Energy	India	208,000	Extra amount that needs to be added in coming years	108,315	52%	pdd 0471p25 refers to cea.nic.in over 2002-2003	99,685		20,547	62%	10%	21%
Wind	India	45194	PDD 0471p25 refers to mnes.nic (http://www.mnre.gov.in/annualreport/2004_2005_English/ch6_pg1.htm)	1870	4%	(****) in 2002-2003	43,324		4,295	14%		10%
Wind	Tamil nadu	3050	PDD 0111: 18MW biomass plant in Tamilnadu (10/2005)	833	27%	(****) as of december 2001 see also PDD 0991p22 for after 2001	2217	(****)	1444	75%	47%	65%
Wind	Andhra Pradesh		PDD 0399p9 (poultry)	2		(****) in 2004-2005			18			
Small-Scale	Tamil nadu	339	PDD 0111: 18MW biomass plant in Tamilnadu (10/2005)	85	25%	(****)	254	(****) 100 is expected to be possible by 2012	33	35%	10%	13%
Hydro	India	150,000	PDD 0111p14	25500	17%	(****)	124500		2051	18%	1%	2%
Biomass	India	16000	PDD0111: 18MW biomass plant in Tamilnadu (10/2005)	480	3%	(****)	15520		3057	22%	19%	20%
Biomass	Tamil nadu	500	PDD 0111: 18MW biomass plant in Tamilnadu (10/2005)	98	20%	(****) 44 MW under installation	402	(****) 300 may be possible by 2012	187	57%	37%	47%
Biomass	Punjab											
Poultry waste	Andhra Pradesh	54,2	PDD 0399p5	0	0%	(****)	54,2		3	6%	6%	6%
Carbon Black plants	India	10	PDD 1905p25 [number of plants]	6	60%	3 of these plants use CDM finance	4			60%		
(Energy India:) This data includes the projects that were rejected and this data is based on PDD's, not on validation reports												
Wind India:			mnre.gov.in/annualreport/2004_2005_English/ch6_pg1.htm states that this is the gross potential									
Wind tamil nadu: PDD 0991p25 calculates that 97% of all the wind projects in Tamil Nadu between 2002-2005 are co-financed by CDM			mnre.gov.in/annualreport/2004_2005_English/ch6_pg1.htm states that this is the gross potential									

Appendix I National presence of selected companies

The following data is a result of a semantic search using google.

Search query that was used: site:cdm.unfccc.int/UserManagement/FileStorage +china +vestas										
	China	India	Brazil	Mexico	Total		China	India	Brazil	Mexico
Number of wind projects	235	216	7	11		1. Vestas (Denmark)	117	120	4	1
1. Vestas (Denmark)	117	120	4	1	242	2. GE Energy (United States)	8	4	3	1
2. GE Energy (United States)	3	0	0	0	3	3. Gamesa (Spain)	136	20	3	33
3. Gamesa (Spain)	27	29	6	3	65	4. Enercon (Germany)	3	316	9	0
4. Enercon (Germany)	8	4	3	1	16	5. Suzlon (India)	17	355	0	0
5. Suzlon (India)	136	20	3	33	192	6. Siemens (Germany)	30	36	19	6
6. Siemens (Germany)	3	316	9	0	328	7. Acciona (Spain)	9	3	1	2
7. Acciona (Spain)	17	355	0	0	372	8. Goldwind (China - PRC)	132	7	0	0
8. Goldwind (China - PRC)	38	124	67	10	239	9. Nordex (Germany)	55	3	2	2
9. Nordex (Germany)	30	36	19	6	91	10. Sinovel (China - PRC)	38	1	1	0
10. Sinovel (China - PRC)	9	3	1	2	15					
7. Acciona (Spain)	132	7	0	0	139	Top 3	India	China		
8. Goldwind (China - PRC)	55	3	2	2	62		Suzlon	Gamesa		
9. Nordex (Germany)	38	1	1	0	40		Enercon	Goldwind		
10. Sinovel (China - PRC)	545	865	42	45			Vestas	Vestas		
total										

Top 10 wind turbine manufacturers (Source: BTM Consult ApS - March 2008) (source:http://en.wikipedia.org/wiki/List_of_wind_turbine_manufacturers)



Appendix J List of PDDs studied and their references

Type	CDM.ID. (UNEP/Risø, 2008)	Title
Wind 1	CDM.ID.1700	6.75 MW Small Scale Grid Connected “Wind Electricity Generation Project” by Tamil Nadu Newsprint and Papers Limited.
Wind2	CDM.ID.0120	Bundled Wind power project in Jaisalmer (Rajasthan in India) managed by Enercon (India) Ltd.
Wind3	CDM.ID.0658	5 MW Wind Power Project of Alembic Ltd., at Vadodara
Wind4	CDM.ID.1333	75 MW wind power project in Maharashtra by Essel Mining industries Limited
Wind5	CDM.ID.0451	Project 0471: 56.25 MW bundled wind energy project in Tirunelveli and Coimbatore districts in Tamilnadu, India.
Wind 6	CDM.ID.1362	Project 0991: Bundled Wind power project in Tamilnadu, India co-ordinated by the TamilNadu Spinning Mills Association (TASMA)
Hydro1	CDM.ID.0594	24 MW Chayadevi Mini Hydro Power Project in Karnataka, India
Hydro2	CDM.ID.3206	“100 MW Malana – II, Hydro – Electric Power Project (Malana – II HEP)” at Kullu district of Himachal Pradesh State, India, by M/s Everest Power Private Limited
EE1	CDM.ID.2035	Energy efficiency and fuel switch project at Welspun India Limited
EE2	CDM.ID.2592	Project 1905: Generation of power from process waste heat at Hi-Tech Carbon, Tamil Nadu
EE3	CDM.ID.0400	Project 0340: Reduction in steam consumption in stripper reboilers through process modifications
Biomass 1	CDM.ID.0117	Project 0109: 24 MW Biomass Based Renewable Electricity Generation & Consumption in Ropar, Punjab, India
Biomass 2	CDM.ID.0010	Project 0111: 18 MW Biomass Power Project in Tamilnadu, India
Biomass 3	CDM.ID.0668	Project 0399: 3 MW Poultry Litter Based Power Generation Project, Hyderabad
I&S	CDM.ID.0222	Electricity generation at 8 MW captive power plant using enthalpy of flue gases from blast furnace operations of Kalyani Steels Limited, in Karnataka state of India.
I&S	CDM.ID.0269	Use of waste gas use for electricity generation at JSW Energy Limited
I&S	CDM.ID.0387	Generation of Electricity through combustion of waste gases from Blast furnace and Corex units at JSW Steel Limited (in JPL unit 1), at Torangallu in Karnataka, India
I&S	CDM.ID.3755	Electricity generation from BF gas at Hiriya, Karnataka
I&S	CDM.ID.3917	Waste heat utilization for charge pre-heating in a sponge iron manufacturing facility of HKMPL, India
I&S	CDM.ID.3914	Power generation by utilizing Blast Furnace Gas at Mukand Limited, Ginigera, Karnataka
I&S	CDM.ID.3260	Waste heat recovery based power plant
HFC	CDM.ID.0001	GHG emission reduction by thermal oxidation of HFC 23 in Gujarat
HFC	CDM.ID.0134	GHG emission reduction by thermal oxidation of HFC 23 at refrigerant (HCFC-22) manufacturing facility of SRF Ltd
HFC	CDM.ID.0484	Destruction of HFC-23 at refrigerant (HCFC-22) manufacturing facility of Chemplast Sanmar Ltd
HFC	CDM.ID.0897	GHG emission reduction by thermal oxidation of HFC 23 at Navin Fluorine International Limited (NFIL), Surat, Gujarat, India.
HFC	CDM.ID.2705	GHG emission reduction by thermal oxidation of HFC 23 at refrigerant (HCFC-22) manufacturing facility of HFL Ltd.
HFC	CDM.ID.3884	Avoidance of HFC-134a emissions in rigid Poly Urethane Foam (PUF) manufacturing by Acme Tele Power Limited (ATPL)
HFC	CDM.ID.4079	Avoidance of GHG emissions in rigid Poly Urethane Foam (PUF) manufacturing by LIL

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