THE COST STRUCTURE OF EMISSIONS ABATEMENT THROUGH THE CLEAN DEVELOPMENT MECHANISM

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Abstract

This paper examines the cost structure of emissions abatement through different types of Clean Development Mechanism (CDM) projects. Alternative models for abatement costs are specified and estimated using CDM project-specific data. Empirical results indicate that there exist economies of scale in emission abatement through the CDM projects, and that the marginal cost of abatement significantly varies across different types of projects. The distribution of various CDM project types corresponds to the relative attractiveness of the types, in terms of the structure of the estimated marginal cost function. Thus, empirical results suggest that the CDM market operates efficiently and sends the right signals to the investors, which further explains the shying away from costly carbon sequestration projects funded by many international development agencies, such as the World Bank. Contrary to the hypothesis that that the marginal costs of abatement through CDM decrease over time due to experience or learning by doing, empirical results show non-decreasing marginal cost of abatement over time. This finding suggests that there may be other incentives to invest in certain types of CDM projects in specific locations, thus implying location-specificity of various investment opportunities. While non-decreasing marginal cost of abatement over time implies a tougher prospect for CDM in future commitment periods, the current growth pattern of the CDM suggests that this flexibility provision of the Kyoto Protocol is still highly attractive for the host and investor countries.

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1. Introduction

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) sets binding targets for industrialized countries and the European Community (i.e., countries listed in Annex B of the Kyoto Protocol) for curbing anthropogenic greenhouse gas (GHG) emissions. While Annex B countries are committed to limit GHG emissions to their assigned amount units (AAUs) primarily through national measures, the treaty offers three market-based mechanisms intended to lower the cost of mitigation: (1) Emissions Trading (known as "the carbon market"), (2) Joint Implementation (JI), and (3) the Clean Development Mechanism (CDM).[1] The provision of Emissions Trading (ET) allows Annex B countries to trade assigned amount units (AAUs) among themselves.[2] The JI and CDM are the two project-based mechanisms that allow the Annex B countries to meet their targets by reducing GHGs from the atmosphere in other countries in a cost-effective way. While the JI mechanism enables the Annex B countries to carry out bilateral or multilateral emissions reduction projects among themselves, the CDM encourages investment in sustainable

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[1] Annex B countries have accepted targets for limiting or reducing emissions. These targets are expressed as levels of allowed emissions, or "assigned amounts," over the 2008-2012 commitment period. The allowed emissions are divided into "assigned amount units" (AAUs).

[2] As set out in Article 17 of the Kyoto Protocol, Annex B countries with less emissions than permitted are allowed to sell the excess AAUs to the countries with more emissions than permitted.

development projects that reduce emissions in developing countries.[3] In response to the CDM provision, a large number of emissions reduction projects have been initiated in different developing countries, which widely vary both in the type of abatement technology and size of operation. Emissions reduction costs typically vary across different types of technology and sizes of operations. This paper examines the abatement cost structure of the CDM projects in the pipeline with the objective of assessing the prospect of GHG reductions through CDM and providing policy relevant perspectives for improving the existing incentive structure of the mechanism towards a cleaner environment.

The CDM provides an incentive to the Annex B countries for meeting their targets by reducing emissions or removing GHGs from the atmosphere in developing countries (i.e., non-Annex B countries) at lower costs. For measurable and verifiable emissions reductions that are additional to what would have occurred without the CDM project, an Annex B country earns certified emission reduction (CER) credits, each equivalent to one ton of CO2 (tCO2e hereafter) abatement. The Annex B country is allowed to use the earned CERs to meet a part of its emission reduction targets under the Kyoto Protocol or sell the credits to other parties. Stimulating sustainable development through technology transfer and foreign direct investments, the CDM also provides an incentive to the developing countries to contribute to emissions reduction efforts.

Both industrialized and developing countries have quickly responded to the incentives provided through the CDM. Many CDM projects were submitted to the UNFCCC for validation (as early as 2003) even before the Kyoto Protocol entered into force in 16 February 2005. As of October 2008, there have been 4,151 projects in the pipeline. Given that all of

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[3] The JI and CDM are also intended to attract the private sector to contribute to mitigation efforts. According to the JI and CDM pipeline database, most of the projects are private initiatives (UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008).

these projects are to be validated by the Executive Board (EB) and implemented to their full potentials, there would be a total emissions reduction of 2.84 billion tCO2e (i.e., generating 2.84 billion CERs) during 2008-12, the first commitment period of the Kyoto Protocol (UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008).[4]

While the rapid increase of the CDM projects indicate that this provision somewhat aligns the incentives of the Annex B and non-Annex B parties, the gains from CDM are yet to be assessed. Moreover, how the potential gains from CDM could be maximized with better alignment of the incentives of the Annex B and non Annex B parties are yet to be explored. Potential gains from the CDM crucially depend on the costs of abatement, which significantly vary across different types of abatement technology and sizes of the operations. An examination of the cost structure of the CDM is necessary to understand the prospect of this provision in reducing GHG from the environment.

A wide variety of CDM projects, located in different parts of the world endowed with alternative renewable resources, provides a unique opportunity for such examinations and effective policy design for a cleaner environment. Reviewing relevant theoretical and empirical literature, this paper first specifies alternative forms of emissions abatement cost function for the CDM projects, and then estimates the cost functions using project-level data.

The main hypothesis of this analysis is that there exist economies of scale in emission abatement through the CDM projects, which significantly vary across different types of abatement technologies. An additional hypothesis of this analysis is that the marginal cost (as well as the average cost) of abatement through CDM decreases over time due to experience or

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[4] The extent of JI is much smaller than CDM. As of October 2008, there have been 185 projects in the JI pipeline. Given that all of these projects are to be registered and implemented to their full potentials, there would be a total emissions reduction of 312.27 million tCO2e (i.e., generating 2.84 billion ERUs) during 2008-12 (UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008).

learning by doing. We test these hypotheses using CDM project-level data obtained from the Project Design Documents (PDD) submitted to the CDM Executive Board (EB) during 2003-2008. Based on the empirical results, we also examine how CDM technologies are evolving over time and, depending on the technological prospects, how emissions abatement pattern through CDM and respective costs would evolve in the future.

The empirical literature (surveyed in the next section) provides useful analyses of abatement cost estimations for various pollutants. A majority of those studies use secondary data, or use approximated coefficients in the abatement function they apply. Data on CO2 abatement at the plant level, the focus of our study, have not been collected and analyzed before. This paper takes advantage of the available CDM data to answer several questions that are important for the future CDM policy design, which have not been addressed earlier. We use plant-level data on different types of existing (prospective) CDM projects that are (to be) located in different parts of the world during 2003-2008. Thus, our dataset allows distinction of the projects across types (technologies), location, and time. These features of our dataset are crucial for the policy design of CDM beyond the first commitment period of the Kyoto Protocol.

The next section summarizes a large body of literature on estimating costs of pollution abatement and discusses their relevance to the CDM. Section three specifies alternative forms of cost function for emissions abatement through CDM. Section four describes the data used to estimate the cost function and provides primary analyses. Section five delineates the estimation procedures and results, and discusses their implication. Finally, the last section concludes and gives direction to future research.

2. Estimating Emissions Abatement Cost

One of the early studies on pollution abatement cost was undertaken by Rossi, Young, and Epp (1979). They specify a production function associated with water pollution abatement activity in which the volume and quality of effluent stream is a function of the volume and quality of the influent stream and other factors of production such as land, labor, capital, and materials. With this production function, they derive a cost function in which abatement cost is a function of the volume and quality of both effluent and influent streams and factor prices (i.e., prices of land, labor, capital, and materials). Several subsequent studies on abatement cost are based on the framework proposed by Rossi, Young, and Epp (e.g., Fraas and Munley, 1984).

Golder, Misra, and Mukherji (2001) identify problems associated with the cost function proposed by Rossi, Young, and Epp, and argue that output of abatement activity should be defined as the reduction in the pollution load. They define output of water pollution abatement as a function of the volume of waste water treated, the difference in the pollution levels of influent and effluent water, and inputs used to purify the water. Golder, Misra, and Mukherji specify a water pollution abatement cost function in which the cost of abatement is an explicit function of the quantum of abatement (i.e., the difference between water quality before and after the treatment) and factor prices. There are some similar studies that do not include factor prices in the abatement cost function (e.g., Mehta, Mundle, and Sankar, 1993)

Some studies consider pollution abatement as an inseparable multi-output process, and suggest that the cost of abatement may not be separable from the cost of production (see Pizer and Kopp, 2003; Maradan and Vassiliev, 2005; Boyd, Molburg, and Prince, 1996). Gollup and Roberts (1985) use observed data on utility pollution abatement and production costs to estimate a cost function that includes emission control rates as a predictor of production costs. Nordhaus (1994) compared a number of published models in terms of percentage difference of carbon emissions from a baseline path and propose an aggregate formula relating cost to output and reduction of greenhouse gases. In a similar manner, Newell and Stavins (2003) explore the pollution abatement cost heterogeneity (i.e., the relative cost of uniform performance measured in terms of emissions per unit of product output) by using a second-order approximation of the costs around the baseline emissions. This approach is based on variation in baseline emission rates, thus estimation of the cost function requires data on baseline and project emissions. In contrast, Newell, Pizer, and Shih (2003) develop a quadratic abatement cost function in which the cost of pollution abatement per unit of output depends on abatement rather than emissions. Using plant-level Census data on compliance costs and emissions abatement in four industries, they estimate the parameters of the cost function and compute gains from emission trading.

Several studies estimate the abatement cost function by separating cost of abatement from the cost of production. Using data from the U.S. Census Bureau, Hartman, Wheeler, and Singh (1994) estimate air pollution abatement costs by industry sectors. Assuming that the abatement cost function is separable from the firm’s production cost function, they estimate abatement costs as a quadratic function of emissions abatement. One problem with this specification is that it does not allow for economies of scale. Hamaide and Boland (2000) define abatement costs as a second-order polynomial function of abatement alone (which is forced to pass through the origin, i.e., without an intercept).

While estimating the cost of abating agricultural nitrogen pollution in wetlands, Bystrom (1998) tests linear, quadratic, and log-log specifications of the cost function. We adopt a similar approach to specify the emissions abatement cost function and estimate the model using CDM project-level data.

3. The Empirical Emissions Abatement Cost Function

Emission reduction by a CDM project is typically calculated by subtracting the net emissions of the project from the baseline emissions (i.e., emissions in the absence of the project).[5] In a similar fashion, the cost of emissions abatement through CDM can be defined as the difference between the total costs of the project with and without abatement. For projects that generate no output other than CERs, the total cost of the project can be regarded as the cost of emissions abatement. However, for the projects generating tradable outputs other than CERs, the costs of abatement can be calculated by the difference between the total costs of the project and the costs of producing the tradable output using a conventional (baseline or business-as-usual) technology. See Annex I for an engineering method of calculating emissions abatement costs of an electricity generating CDM project.

We start with three alternative specifications of the emissions abatement cost function: linear, quadratic, and log-log. Assuming fixed input prices, the basic expressions for the alternative functional forms of the abatement cost for project *i* can be given by

$$C_i = \alpha^L + \beta^L A_i + \theta^L q_i \tag{1}$$

$$C_i = \alpha^Q + \beta^Q A_i + \gamma^Q A_i^2 + \theta^Q q_i \tag{2}$$

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[5] The CDM Executive Board has defined the general methodologies for calculating baseline emissions for each type of projects (http://cdm.unfccc.int/methodologies/index.html, November 2008). Specific methodology for a certain type of projects may vary depending on the emission intensity of the host country and its conventional (business-as-usual) technology. Based on the tradable outputs generated from the projects, the CDM projects can be categorized into two major types: first, projects that generate CERs only (e.g., forestation); second, projects that generate other outputs than CERs (e.g., hydro electric). For an electricity generating CDM project (e.g., hydro electric), emissions reduction in a year is calculated by subtracting the emissions from the project in that year from the emissions from a conventional (i.e., baseline or business-as-usual) electricity generating project (e.g., coal based) with the same capacity of electricity generation.

$$\ln(C_i) = \alpha^{LL} + \beta^{LL}\ln(A_i) + \theta^{LL} q_i \qquad (3)$$

where C is the total abatement costs, A is total emissions abatement, and q is a vector of control variables (e.g., project and technology types).[6] In contrast to Newell, Pizer, and Shih (2003), we do not scale costs and abatement by output in order to take account of the CDM projects that generate CERs only.

Given the parameter estimates, the marginal (as well as the average) cost of abatement can be computed for different types of CDM projects. Assuming an interior solution, the marginal cost of abatement corresponding to equations (1), (2), and (3) are given by

$$MC_i^L = \frac{\partial C_i}{\partial A_i} = \beta^L, \qquad (4)$$

$$MC_i^Q = \frac{\partial C_i}{\partial A_i} = \beta^Q + 2\gamma A_i, \qquad (5)$$

$$MC_i^{LL} = \frac{\partial \ln(C_i)}{\partial \ln(A_i)} \frac{\hat{C}_i}{A_i} = \beta^{LL} \frac{\hat{C}_i}{A_i}. \qquad (6)$$

Given that the CERs generated from the CDM projects are tradable, the equilibrium level of emissions abatement by each project would be determined by equating the marginal cost of abatement to the competitive price of CER.[7] The next section describes the data used to estimate the abatement cost function.

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[6] In the current setting, we suppress the time subscript assuming that the equilibrium level of abatement would be the same in each year. This restriction is consistent with the CDM pipeline dataset in which expected emissions abatement and investments are annualized based on the PDDs. We expect to relax this assumption in future when data on actual abatement and investments are available.

[7] Given the size of the market for CERs (which in turn depend on the equilibrium quantity of ERUs given the Kyoto restriction), the market price of CER is likely to be jointly determined along with the quantity demanded and supplied. In this version of the paper we assume that the price of CER is exogenous. We intend to estimate a system of equations in the future.

4. Description of CDM Project Data

The CDM/JI Pipeline Analysis and Database of the United Nations Environment Programme (UNEP) Risoe Center constructs and maintains an up-to-date dataset consisting of all CDM projects that have been sent to the UNFCCC for validation. The dataset includes information about each individual CDM project such as project name, type, and registration/validation status, baseline and monitoring methodologies, involved host countries and credit buyers, expected CERs to be generated in each year during the life of the project, potential power generation capacity, etc. Available information about all CDM projects that have been sent to UNFCCC for validation up until October 2008 are obtained from that dataset.

Scrutiny of the dataset shows that, the CDM portfolio has been growing very rapidly since its inception in 2003. As of October 2008, 4,257 CDM projects have been sent to UNFCCC for validation. 1,190 of these projects have been registered, 277 are in the process of registration, 2,684 are in the process of validation, 22 projects are withdrawn, and 84 projects were rejected by the CDM Executive Board (UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008). The 4,151 CDM projects (excluding the rejected and withdrawn projects) in the pipeline are expected to reduce approximately 572.2 Million tCO2e in each year and 2.84 billion tCO2e during the first commitment period of the Kyoto Protocol.

Based on the Project Design Documents (PDD), the CDM projects in the pipeline can be categorized into eight major types: (1) renewable resource based, (2) methane reduction, coal bed/mine and cement, (3) supply-side energy efficiency, (4) demand-side energy efficiency, (5) hydrofluorocarbon (HFC), perfluorocarbon (PFC), and nitrous oxide (N2O) reduction, (6) fossil fuel switch, (7) forestation, and (8) transport. Except for fossil fuel switch and transport projects, each major category can be divided into several specific types. Table 1 reports the number and percentage of the CDM projects in the pipeline by both major and specific types. Annual and total CERs to be generated during the first commitment period from each major and specific type of CDM projects are also reported in Table 1.

As can be seen from Table 1, about 62.7 percent of the projects in the CDM pipeline are renewable resource based power generating projects accounting for 37.5 percent and 34.2 percent of the annual and total abatement during the first commitment period, respectively. Hydro, biomass, and wind energy projects account for about than 55.4 percent of total number of projects generating 34.7 percent of the annual and 31.4 percent of the total abatement. Methane gas reduction, coal bed/mine and cement is the second largest category in terms of number (15.8 percent), which accounts for 17.7 percent of the annual and 19.2 percent of the total abatement. However, a small number (2.3 percent) of HFC, PFC, and N2O reduction projects account for about 23.2 percent and 26.7 percent of the annual and total abatement during the first commitment period, respectively. Thus, in terms of CO2e (CO2 equivalent) abatement, HFC, PFC, and N2O reduction is the second largest category. Supply- and demand-side energy efficiency projects (14.9 percent) account for 13.5 percent of the annual and 12.2 percent of the total abatement. Only 3.3 percent of the CDM projects are fossil fuel switch projects accounting for about 7.7 percent of the annual and 7.2 percent of the total abatement. Forestation and transport projects together account for only 1.0 percent of the CDM projects in the pipeline and 0.5 percent of the total CO2e abatement during the first commitment period.

In terms of both annual and total CO2 abatement, the size of individual CDM projects varies widely. The smallest project in the CDM pipeline is expected to reduce only 524 tCO2e per year, while the largest project is expected to abate more than 10.4 million tCO2e per year. Figure 1 shows the number of CDM projects within different size intervals (uneven) specified in terms of ktCO2e (kiloton CO2e) abatement per year. About 19 percent of the projects have the capacity of reducing 10-25 ktCO2e every year, while 23 percent are with the capacity of reducing 25-60 ktCO2e, 20 percent with the capacity of reducing 60-100 ktCO2e, and 25 percent with the capacity of reducing 100-500 ktCO2e every year. Only 1.6 percent of the projects have the capacity of reducing more than 1,000 ktCO2e, while 10.5 percent of the projects are with the capacity of reducing less than 10 ktCO2e. Figure 2 shows the frequency distribution of the CDM projects with less than 1,000 ktCO2e abatement capacity.

The average size of the CDM projects also widely varies across types. Table 2 shows the ranges of annual GHG abatement and electricity generation by the CDM projects in the pipeline. As can be seen from Table 2, in terms of average annual GHG abatement, HFC, PFC and N2O reduction projects are the largest and forestation projects are the smallest among the major categories, respectively. Some N2O and HFC reduction projects have the capacity of reducing more than 10,000 ktCO2e per year. Emissions reduction is the sole purpose of the HFC, PFC and N2O reduction, forestation, and transport projects. Electricity generation is a joint purpose of the projects in other categories. In terms of average electricity generation (megawatt hour) per year, supply-side energy efficiency and fossil fuel switch projects are the largest and second largest categories, respectively. Geothermal and hydro electricity projects are the largest and second largest among the renewable resource based electricity generation projects. Electricity generation projects that have the capacity of reducing more than 1,000 ktCO2e per year are in hydro, biogas, landfill gas, coal bed/mine methane capture, cement, fugitive, and energy efficiency supply-side and own generation sub-categories. However, it is evident from the range of emissions reduction capacity shown in Table 2 that the scales of all types of projects widely vary both in terms of abatement and electricity generation capacity.

The CDM dataset also includes information on electricity generation capacity to be installed by the projects and corresponding (expected) full time hours of electricity generation. While annual electricity generation can be calculated from these data, the UNEP Risoe Center reports that information about full time hours of electricity generation are incomplete.[8] Excluding the observations with missing data there remains 1,820 observations in the dataset to be used for our estimation purposes.

The UNEP Risoe Center does not report capital investments in the projects. Estimated capital investments data for 1,200 CDM projects and annual operation and maintenance cost data for 122 projects are obtained from the PDDs with the help of Climate Solutions (2007). See Annex II for details on how capital costs are calculated. Capital investments in each project are annualized by dividing total investments by total ktCO2e abatement over the life of the project and then multiplying the per unit investment by annual ktCO2e abatement. Using the available operation and maintenance costs data, project-level per unit operation and maintenance costs of CO_2 abatement are calculated by dividing the annual operation and maintenance cost by annual expected ktCO2e abatement. Average per unit operation and maintenance cost of abatement across the CDM projects categorized by project types are calculated and then used as proxies for average carbon abatement costs of the projects for which such data were not available.

Out of the 1,200 observations with cost information, only 840 observations have data on annual electricity generation as well. For those observations, annual total costs of abatement are calculated by subtracting estimated electricity generation costs for the baseline

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[8] See http://www.cdmpipeline.org/publications/GuidanceCDMpipeline.pdf

technologies from the annual fixed and variable (operation and maintenance) costs of the project as described in Annex I (Timilsina and Lefevre, 1999). Estimates of electricity generation costs for different types of projects are obtained from International Energy Agency (2005). Conventional technologies of generating electricity from coal and gas are assumed to be the baseline scenario. Based on the 840 observations, a summary statistics of the dependent variable and major explanatory variables included in the model are presented in Table 3.

5. Model Specification and Estimation Results

We begin with the specification of the functional form of the abatement cost function. First we estimate the simplest versions of equations (1), (2), and (3) using ordinary least squares estimation technique, and then check how the models fit the data. The OLS estimates of the linear, quadratic, and log-log abatement cost functions are displayed in Table 4. The coefficient estimates are highly significant in each specification. While the *F*-test statistics indicate that all of the model specifications fit the data well, the adjusted *R*-squared value for the linear model is very low. The quadratic and log-log models have similar levels of goodness of fit, but the Breusch-Pagan Chi-squared test statistic for heteroscedasticity is very high and significant in the cases of linear and quadratic models. This suggests that a linear and quadratic specification of the abatement cost function is incorrect. On the other hand, a low and insignificant Breusch-Pagan Chi-squared test statistic for the log-log model suggests that the null hypothesis of homoscedasticity cannot be rejected. A log-log model also appears to explain the variation in total abatement costs better than linear and quadratic models. Therefore, the remainder of this paper employs the log-log model to estimate the abatement cost function using alternative sets of dependent variables.

We estimate the log-log abatement cost function with four alternative specifications. First, the logarithm of abatement cost is regressed on the logarithm of emissions abatement and dummy variables for major project types. Second, a separate set of dummy variables are used for different types of renewable resource based projects, such as biogas, biomass, hydro, wind, and geothermal. Third, the logarithm of project submission years is used as an additional continuous dependent variable along with abatement and major project type dummies. Finally, a full model is estimated with both of the continuous variables and project type and sub-type dummies. The estimation results are presented in Table 5.

As can be seen from table 5, the coefficient estimate of abatement is positive and highly significant in each of the four specifications of the log-log model, suggesting that the cost of abatement increases with the volume. Also, the intercept term is positive with the coefficient estimates of dummy variables for HFC, PFC, and N2O reduction, methane gas reduction, and fossil fuel switch projects are negative and significant in all four specifications. The dummy variables for renewable and supply-side energy efficiency projects do not appear to be significant in the first and third specification. When dummy variables for different types of renewable projects are used (columns II and IV in Table 5), the coefficients for biogas, hydro, and supply-side energy efficiency projects become significant. Corresponding adjusted R-squared values indicate that the model also better fits the data with the inclusion of dummy variables for the sub-types of renewable projects. All of the coefficient estimates of project-type dummies being negative indicate that the intercepts of the cost functions for all other types of CDM projects is smaller than the one for forestation projects, which were used as benchmark in the analysis.

The last two columns of Table 5 exhibit coefficient estimates of the models with project submission year as an additional continuous variable. The coefficient estimate of year is positive and significant only when dummy variables for different renewable resource based projects are included in the model. Comparing the results reported in columns II and IV of Table 5, we see that inclusion of year in the model affects the magnitude of other coefficient estimates, but does not alter their signs. In particular, inclusion of year in the model significantly reduces the intercept of the cost function. However, the corresponding F and adjusted R-squared statistics indicate a similar fit of the models (with and without the year variable).

The marginal cost of abatement for different types of CDM projects can be calculated using the coefficient estimates reported in Table 5. We calculate the marginal costs at different levels of abatement for different types of projects. Figure 3 depicts the marginal cost curves for hydro and fossil fuel switch projects. As can be seen from the figure, marginal cost decreases with the volume of abatement, indicating economies of scale in abatement. However, the intercept of the curve varies by the type of project. The marginal cost curves for other types of projects can also be depicted in a similar way, but could not be placed in the same figure as the intercepts vary widely across types.

6. Conclusions and Policy Implications

This paper examines the cost structure of emissions abatement through alternative types of CDM projects. We begin with the hypothesis that there exist economies of scale in emission abatement through the CDM projects. We also hypothesize that the marginal cost of abatement significantly varies across different types of projects. Using alternative functional forms (namely, linear, quadratic, and log-log) and several empirical specifications, we estimate the cost function of CO2 abatement, using CDM project specific data. Based on the log-log model, estimated marginal cost curves appear to be convex with different intercepts depending on project types. In particular, nitrogen and methane gas reduction projects are characterized by much lower marginal costs relative to wind or biomass projects. Indeed, forestation projects are the least efficient in terms of marginal cost of abatement, which may explain the shying away from carbon sequestration projects funded by many international development agencies, such as the World Bank.

There are several policy implications that can be drawn from the analysis so far. First, the results suggest that the CDM market operates efficiently and sends the right signals to the investors. The distribution of project types that are funded by the CDM mechanism corresponds to the attractiveness of the various project types, in terms of the structure of the estimated marginal cost function. CDM projects with higher intercepts are likely to be less attractive than those with lower intercepts, and not surprisingly, in the pipeline there are more projects (with higher emissions reduction) of the type with a lower intercept of the marginal cost curve. While this result is important from a policy perspective, it needs to be viewed with caution because not only the marginal cost pattern but also other factors such as the availability of renewable energy sources in a given location may be crucial in the decision to invest in a particular CDM project type. We intend to include such factors in the model in our future work.

We further hypothesize that the marginal costs of abatement through CDM decrease over time due to experience or learning by doing. Contrary to this hypothesis, our empirical results suggest that the marginal cost of abatement for the CDM projects which are submitted to the UNFCCC for validation in recent years is higher than those submitted earlier. This finding suggests that there may be other incentives to invest in certain types of CDM projects in specific locations, thus implying location-specificity of various investment opportunities. Moreover, while non-decreasing marginal cost of abatement over time implies a tougher prospect for the CDM in future commitment periods, we are still observing an exponential growth in the number of projects and the volume of investment in CDM projects suggesting the contrary—that this provision of the Kyoto Protocol is still highly attractive for the host and investor countries. However, it is important to note that our dataset consists of nominal abatement costs. While the time horizon for our estimates is short and thus discounting may not be that significant, we intend to estimate the model with real abatement costs in future.

This study contributes to identify the scope of further advancement of CDM and design effective policies to better align the incentives of the Annex B and non-Annex B countries for a cleaner environment. However, our ultimate goal is to examine how CDM technologies are evolving over time in specific locations with alternative renewable resources and technological prospects, how emissions abatement through CDM would evolve in the future, and how the potential gains from CDM could be maximized. While this paper is a step towards that goal, we recognize that further refinement of the model and appropriate estimation techniques with additional data are necessary.

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Table 1: CDM projects in the pipeline - types, number, and annual and total abatement during 2008-201

Project Type	Number of Projects		Annual Abatement		2008-2012 Abatement	
	Number	% Total	ktCO2e/yr	% Total	ktCO2e	% Total
Renewable Resource Based	**2,603**	**62.71**	**214,806**	**37.54**	**971,646**	**34.24**
Hydro	1,098	26.45	114,278	19.97	471,825	16.62
Biomass	632	15.23	38,325	6.70	200,089	7.05
Wind	568	13.68	46,006	8.04	220,299	7.76
Biogas	267	6.43	12,740	2.23	61,578	2.17
Solar	24	0.58	685	0.12	2,990	0.11
Geothermal	13	0.31	2,457	0.43	13,761	0.48
Tidal	1	0.02	315	0.06	1,104	0.04
CH4, Coal Bed/Mine & Cement	**657**	**15.83**	**101,288**	**17.70**	**544,238**	**19.18**
Landfill gas	302	7.28	47,458	8.29	256,959	9.05
Agriculture	226	5.44	8,485	1.48	51,531	1.82
Coal bed/mine methane	61	1.47	27,843	4.87	130,644	4.60
Cement	38	0.92	6,806	1.19	41,342	1.46
Fugitive	29	0.70	10,690	1.87	63,733	2.25
CO2 capture	1	0.02	7	0.00	29	0.00
Supply-Side Energy Efficiency	**425**	**10.24**	**69,505**	**12.15**	**308,500**	**10.87**
EE own generation	375	9.03	58,105	10.15	272,523	9.60
EE supply side	46	1.11	11,269	1.97	34,933	1.23
Energy distribution	4	0.10	130	0.02	1,045	0.04
Demand-Side Energy Efficiency	**194**	**4.67**	**7,569**	**1.32**	**37,327**	**1.32**
EE industry	172	4.14	6,523	1.14	32,916	1.16
EE households	12	0.29	895	0.16	3,739	0.13
EE service	10	0.24	151	0.03	672	0.02
Fossil Fuel Switch	**135**	**3.25**	**43,951**	**7.68**	**204,275**	**7.20**
HFC, PFC & N2O Reduction	**95**	**2.29**	**132,625**	**23.18**	**757,133**	**26.68**
N2O	65	1.57	48,456	8.47	258,450	9.11
HFCs	22	0.53	83,048	14.51	493,898	17.40
PFCs	8	0.19	1,121	0.20	4,785	0.17
Forestation	**34**	**0.82**	**1,740**	**0.30**	**10,987**	**0.39**
Afforestation	5	0.12	344	0.06	1,864	0.07
Reforestation	29	0.70	1,396	0.24	9,122	0.32
Transport	**8**	**0.19**	**728**	**0.13**	**4,002**	**0.14**
Total	**4,151**	**100.00**	**572,211**	**100.00**	**2,838,107**	**100.00**

Source: UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008.

Table 2: Ranges of annual abatement and electricity generation by different types of CDM projects in the pipeline.

Project Type	Annual Abatement (ktCO2e)				Annual Electricity Generation (MWh)			
	Obs.	Mean	Min	Max	Obs.	Mean	Min	Max
Renewable Resource Based		117.9				92,581.8		
Hydro	1,098	103.9	0.00	4,334.0	896	148,487.5	2,189.0	5,183,040
Biomass	632	60.7	1.10	572.0	338	69,492.1	0.0	582,832
Wind	568	80.4	0.00	803.0	462	98,398.1	1,100.0	983,550
Biogas	267	47.7	1.50	1,458.0	156	5,059.9	0.0	58,035
Solar	24	28.5	0.60	168.0	12	25,709.5	0.0	231,000
Geothermal	13	189.0	3.00	652.0	7	208,343.6	18,158.8	472,998
Tidal	1	315.0	315.00	315.0	.	.	.	.
CH4, Coal Bed/Mine & Cement		200.5				22,041.0		
Landfill gas	302	154.2	0.00	1,210.0	134	17,125.8	0.0	267,000
Agriculture	226	37.5	1.30	828.0	135	0	0	0
Coal bed/mine CH4	61	456.4	41.00	3,017.0	38	93,079.4	0.0	823,200
Cement	38	179.2	11.00	1,324.0	17	0	0	0
Fugitive	29	368.6	8.80	2,532.0	11	0	0	0
CO2 capture	1	7.0	7.00	7.0	.	.	.	.
Supply-Side Energy Efficiency		144.3				840,507.2		
EE own generation	375	155.0	1.00	2,257.0	284	165,225.5	0.0	2,295,027
EE supply side	46	245.0	2.20	2,831.0	28	2,356,296.0	0.0	29,800,000
Energy distribution	4	32.8	13.00	55.0	2	0	0	0
Demand-Side Energy Efficiency		112.7				308,567.9		
EE industry	172	37.9	0.70	852.0	75	6,550.7	0.0	134,811
EE households	12	74.7	3.50	439.0	2	0	0	0
EE service	10	15.1	2.00	54.0	2	0	0	0
Fossil Fuel Switch	135	322.9	0.00	3,190.0	78	1,227,721.0	0.0	6,064,032
HFC, PFC & N2O Reduction		1,553.5				0.0		
N2O	65	745.5	29.00	10,017.0	25	0	0	0
HFCs	22	3,774.9	21.00	10,437.0	3	0	0	0
PFCs	8	140.1	11.00	380.0	2	0	0	0
Forestation		54.0				0.0		
Afforestation	5	68.8	1.00	318.0	.	.	.	.
Reforestation	29	39.1	0.00	221.0	7	0	0	0
Transport	8	91.1	6.50	256.0	1	0	0	0
Total	4,151	137.4	0.00	10,437.0	2,715	154,524.9	0	29,800,000

Source: UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008.

Table 3: Summary statistics of annual abatement and abatement costs by different types of CDM projects.

Project Type	Obs.	Abatement (ktCO2e)			Abatement Cost (1000 US$)		
		Mean	Min	Max	Mean	Min	Max
Renewable Resource Based							
Hydro	248	95.1	2.5	570	4,650.2	69.9	42,178.8
Biomass	84	80.2	3.2	454	29,028.8	61.4	162,345.3
Wind	165	92.1	2.9	600	28,955.7	1,480.0	190,309.2
Biogas	18	63.7	19	311	7,732.3	339.2	34,368.2
Solar	.	.	.	.	.	.	.
Geothermal	2	173.0	171	175	35,731.1	31,001.3	40,460.9
Tidal							
CH4, Coal Bed/Mine & Cement							
Landfill gas	52	221.4	7.7	751	12,059.2	278.6	47,363.7
Agriculture	49	76.5	5.1	247	2,141.6	17.4	10,736.9
Coal bed/mine CH4	18	549.8	57	2978	32,728.4	3,381.1	174,234.9
Cement	2	115.0	77	153	7,653.8	4,990.1	10,317.6
Fugitive	2	232.0	137	327	16,057.2	10,781.6	21,332.7
CO2 capture	.	.	.	.	.	.	.
Supply-Side Energy Efficiency							
EE own generation	126	195.7	7.9	2090	18,630.6	889.4	212,591.1
EE supply side	6	341.9	4	899	29,048.7	744.5	86,208.3
Energy distribution	.	.	.	.	.	.	.
Demand-Side Energy Efficiency							
EE industry	17	34.0	2.7	194	3,992.7	345.0	19,701.2
EE households	2	25.3	1.5	49	3,397.7	1,394.6	5,400.8
EE service							
Fossil Fuel Switch	23	553.9	2	1511	19,616.0	173.3	56,265.4
HFC, PFC & N2O Reduction							
N2O	4	3,602.8	83	10017	7,363.4	238.6	19,631.6
HFCs	.	.	.	.	.	.	.
PFCs	1	86.0	86	86	237.4	237.4	237.4
Forestation							
Afforestation	.	.	.	.	.	.	.
Reforestation	2	179.0	11	347	63,413.5	3,977.2	122,849.9
Transport	.	.	.	.	.	.	.
Total	821	155.7	1.5	10017	16,020.3	17.4085	212,591.1

Source: UNEP Risoe CDM/JI Pipeline Analysis and Database, 01 November 2008.

Table 4: Regression results for linear, quadratic, and log-log specification of the annual total abatement costs.

Variables	Linear	Quadratic	Log-Log
Abatement (ktCO2e)	19.99^{***}	71.65^{***}	
	(1.88)	(3.32)	
Abatement squared (MtCO2e)		-0.007^{***}	
		(0.0004)	
Log of Abatement			0.82^{***}
			(0.04)
Constant	12908.55^{***}	6422.49^{***}	5.22^{***}
	(870.81)	(825.28)	(0.18)
No. of Observations	821	821	821
F-value	113.52	236.41	417.49
Adjusted R-squared	0.12	0.36	0.34
Breusch-Pagan Chi-Sq. Score	3727.65	1724.97	0.10

Note: The dependent variable in each of the log-log specification is the log of total abatement costs.Standard errors of the coefficients are given in the parentheses.

Table 5: Abatement cost estimation results with alternative log-log specifications.

Log-Linear Specifications	I	II	III	IV
Continuous Variables				
Log of Abatement (ktCO2e)	0.97^{***}	0.99^{***}	0.97^{***}	0.96^{***}
	(0.038)	(0.028)	(0.038)	(0.028)
Log of Year			0.26	1.08^{***}
			(0.231)	(0.173)
Project Type Dummies				
Renewables	-1.09		-1.09	
	(0.830)		(0.830)	
Biogas		-1.18^{*}		-1.21^{*}
		(0.660)		(0.645)
Biomass		-0.05		-0.002
		(0.634)		(0.62)
Hydro		-2.07^{***}		-2.12^{***}
		(0.629)		(0.615)
Wind		-0.13		-0.09
		(0.630)		(0.616)
Geothermal		-0.55		-0.52
		(0.886)		(0.866)
HFC, PFC & N2O Reduction	-4.88^{***}	-4.92^{***}	-4.86^{***}	-4.84^{***}
	(0.984)	(0.744)	(0.984)	(0.727)
CH4, Coal Bed/Mine & Cement	-2.85^{***}	-2.86^{***}	-2.80^{***}	-2.67^{***}
	(0.836)	(0.632)	(0.837)	(0.619)
Supply-Side Energy Efficiency	-1.30	-1.31^{**}	-1.31	-1.37^{**}
	(0.835)	(0.631)	(0.835)	(0.617)
Demand-Side Energy Efficiency	-1.00	-0.98	-0.99	-0.96
	(0.872)	(0.659)	(0.872)	(0.644)
Fossil Fuel Switch	-2.17^{**}	-2.19^{***}	-2.15^{***}	-2.11^{***}
	(0.865)	(0.654)	(0.865)	(0.639)
Constant	5.99^{***}	5.93^{***}	5.63^{***}	4.42^{***}
	(0.843)	(0.637)	(0.902)	(0.668)
No. of Observations	821	821	821	821
F-value	116.07	185.30	101.75	181.02
Adjusted R-squared	0.50	0.71	0.50	0.73

Note: The dependent variable in each of the log-log specification is the log of total abatement

Figure 1: Number of CDM projects within different size intervals.

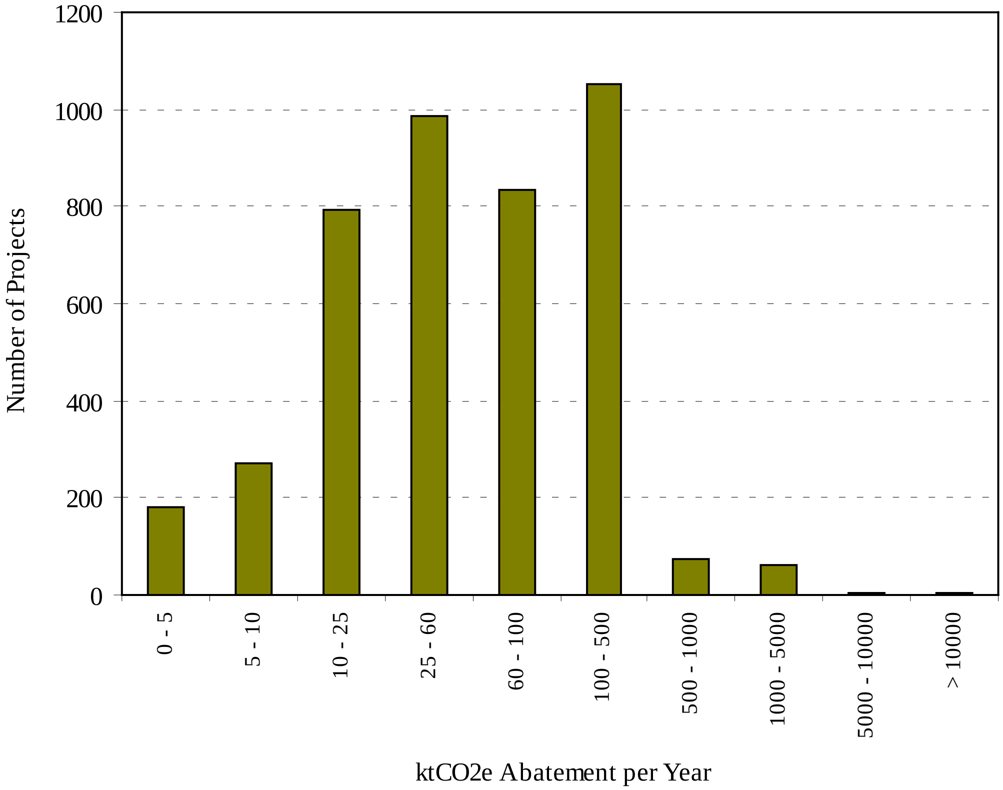


Figure 2: Frequency Distribution of the CDM Projects.

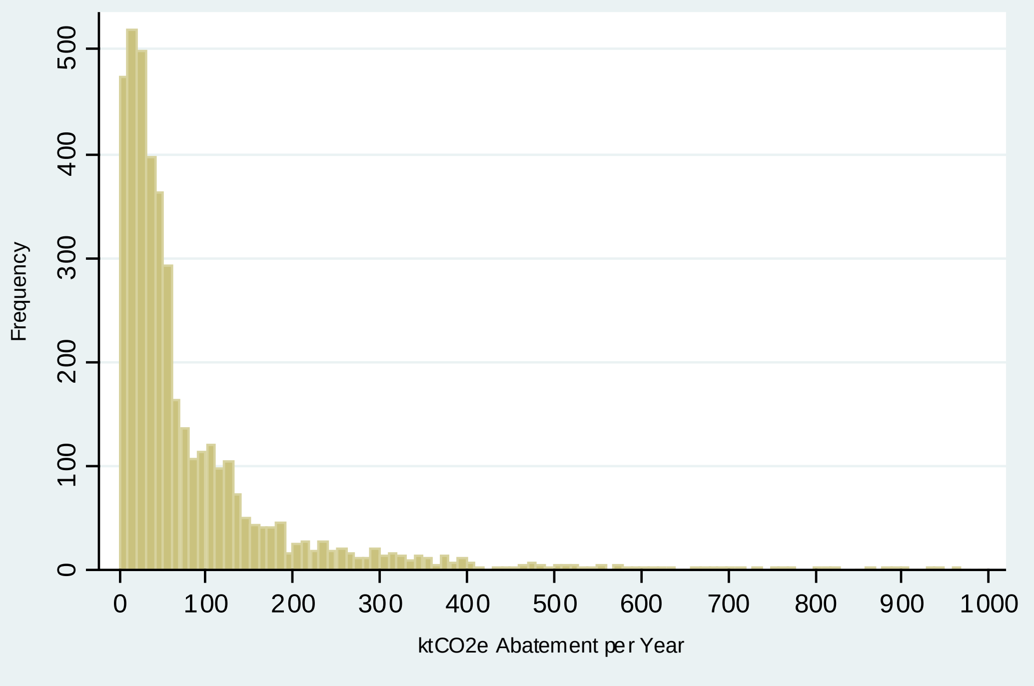
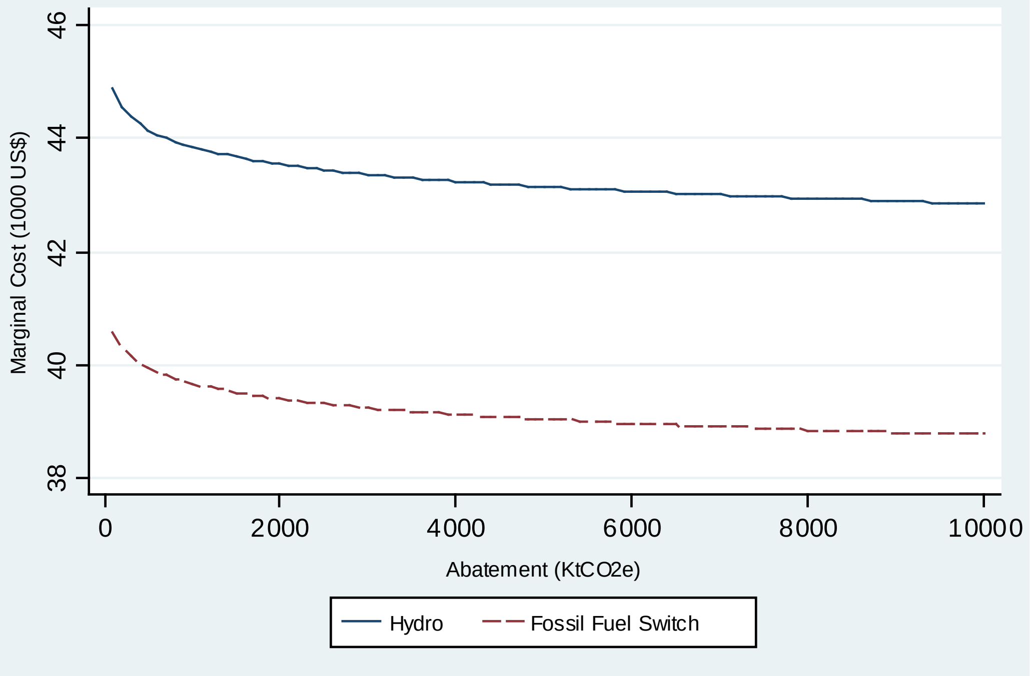


Figure 3: Marginal Cost of Abatement through Hydro and Fossil Fuel Switch Projec



Annex I: The methodology for calculating (separating) the cost of emissions abatement for the CDM projects that produce tradable outputs.

Following Timilsina and Lefevre (1999), the average cost of emissions abatement for the CDM projects that produce tradable output can be calculated according to the equations given below:

$$AC = \frac{C_a - C_b}{E_b - E_a}$$

$$C_i = FC_i + \sum_y \frac{VC_{iy} - R_y}{(1+r)^y}; \qquad \text{for } i = a, b$$

where, AC = Average cost of emissions abatement

C_a = Net present value of the project costs with the abatement technology

C_b = Net present value of the project costs with the baseline technology

E_a = Emissions (CO2e) with the abatement technology

E_b = Emissions (CO2e) with the baseline technology

FC_a = Fixed cost (capital cost or investments) of the project with the abatement technology

FC_b = Fixed cost (capital cost or investments) of the project with the baseline technology

VC_{ay} = Variable cost (operating cost) of the project with the abatement technology in year y

VC_{by} = Variable cost (operating cost) of the project with the baseline Technology in year y

R_y = revenue generated by the project (i.e., revenue from selling the tradable output) in year y

r = Risk-free interest rate

Annual and total (life-time) costs of abatement for a CDM project can be calculated by multiplying AC by the annual and total emissions reduction amounts, respectively.

Annex II: The methodology for the data collection on the capital cost data from Clean Development Mechanism Project activity[9]

CDM project capital cost data is not a reporting criterion, but is sometimes used in the demonstration of additionality for the project. As such, the way in which this information is presented is not normalized and some interpretation is required.

Of those PDDs that contain capital cost information, it is often reported as "Capital costs" or "fixed costs" for the project, and as a single number either in host country currency units or USD. From what is reported, capital cost in the CDM PDDs generally includes:

- procurement of any plant and/or machinery dedicated to the realization of the CDM project
- construction and civil works
- engineering consultation (non-ongoing)

In some cases, the following were included in the capital costs:

- Costs incurred for the validation, registration, and verification of the project as a CDM project
- Contingency and margin money for working capital
- interest during construction
- licenses

Unfortunately, it was not possible to disaggregate the costs as only one (all inclusive) number was reported. In some cases, project participants reported all costs, including

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[9] We thank Stephen Seres of Climate Solutions for helping with this Annex.

variable costs in a table. For these cases, capital cost had to be reconstituted into a single number in order to record it into the dataset.[10].

Methods in obtaining capital cost data

As stated above, information on project costs is sometimes used in the demonstration of "additionality" of the CDM project. The section of the PDD where participants prove the additionality of the project is section B.5.

In each of the PDDs, this section was thoroughly reviewed to determine if capital cost data was included. In addition, the entire PDD was searched using key words such as USD, $, investment, cost, capital, and currency acronym for the host country (ex: for projects in china, key words included, CNY, RMB, yuan).

All cost data were recorded in the spreadsheet in the currency units used in the PDD. All cost data were converted into USD using the spot exchange rate on the 20th of November 2007. The exchange rates used were included in the dataset.

Perspective in capital cost data

It may be important to note two facts with regard to the capital cost data from CDM project activity.

First, it should not be assumed that the CDM projects have been implemented yet and so capital cost outlays may not have occurred. The CDM project data represents all projects that have been put forth for validation and registration. This may, and often does, occur prior to commitments on capital purchases have been made. However, it is largely expected that these projects will be implemented.

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[10] Most PDDs provided one single capital cost value which generally included construction, equipment, and engineering costs. Where detailed tables were included, only the values for construction, equipment, and engineering costs were summed to produce a single value for the dataset with hopes at maintaining comparability.

Second, it should not be assumed that the reported capital expenditures on CDM projects are solely attributable to the CDM. In many cases, capital expenditures would have taken place in its absence. For instance, wind farm and hydro projects are implemented to increase the host country's power generation capacity. In the absence of the CDM, it is likely that capital expenditures would have taken place regardless, in order to increase the host country's power generation capacity, albeit with a different technology and less of a capital outlay. However, for certain project types, where there is no revenue stream other than CDM credits, i.e. Landfill gas and animal waste flaring projects, it would be fair to assume that the capital cost expenditures are solely attributable to the CDM.