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Renewable Energy Investment in Emerging Markets: Evaluating Improvements to the Clean Development Mechanism

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ABSTRACT

In the past, industrialized countries have invested in or financed numerous renewable energy projects in developing countries, primarily through the Clean Development Mechanism (CDM) of the Kyoto Protocol. However, critics have pointed to its bureaucratic structure, problems with additionality and distorted credit prices as ill-equipped to streamline renewable energy investment. In this paper, we simulate the impact of policy on investment decisions on whether or not to invest in wind energy infrastructure in India, Brazil and China. Data from 2,578 past projects as well as literature on investor behaviour is used to inform the model structure and parameters. Our results show that the CDM acts differently in each country and reveal that while streamlining the approval process and reconsidering additionality can lead to non-trivial increase in total investment, stabilizing policy and decreasing investment risk will do the most to spur investment.

KEYWORDS

Agent-based modelling, Clean Development Mechanism, Energy finance, Renewable energy, Simulation, Wind power

INTRODUCTION

Over the next two decades, developing countries will account for 80% of increased electricity demand worldwide. Renewable energy is expected to play a large role in meeting this demand. However, development of renewable energy infrastructure has been hindered by lack of financing and difficulty attracting capital [1, 2]. The high risk perception leads to a higher cost of capital [3], and in developing countries, other social priorities act as competition for scarce funds [1]. Many countries also experience a "carbon lock-in" of incumbent energy sources, with existing infrastructure unable to adapt beyond fossil-fuel based resources [4].

In the past, industrialized countries have provided much of the investment and financing to develop renewable energy in emerging markets. This was due in part to the Clean Development Mechanism (CDM), a flexibility mechanism defined in the Kyoto Protocol aimed to reduce overall global greenhouse gas emissions by providing financial incentives for using zero or low-emitting technologies. Although many projects have been realized through the CDM, academics and industry professionals alike have deemed it inefficient and bureaucratic. Since the renewable energy industry is highly influenced

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by regulatory drivers as compared to other industries [1, 4], it is especially important that policies encouraging renewable energy development are well-designed and effective. Given that future financing for renewable energy in developing countries will likely come from developed countries [3], the research community needs to evaluate the CDM as a tool to encourage such investment.

In this paper, we evaluate the impact of potential improvements to the CDM on investment using agent-based simulation techniques. We focus our analysis on the level of wind energy investment in India, Brazil and China under three different policy improvements. The next section provides details of the CDM including its most common criticisms and suggested improvements, as well as policy backgrounds for the three countries studied. This is followed by an introduction to agent-based simulation and details of our model. We then share our results and analysis before concluding with policy recommendations and a discussion of opportunities for future research.

KYOTO PROTOCOL AND THE CLEAN DEVELOPMENT MECHANISM

Program Description

The Kyoto Protocol is a binding pledge adopted by several industrialized ("Annex I") countries to reduce greenhouse gas emissions, in part by using zero- or low-emitting technologies for electricity production. Emission reduction is awarded with certificates that can be traded between countries, a system intended to reduce emissions in the most cost effective manner. The CDM is a flexibility mechanism defined in the Kyoto Protocol that allows projects in developing countries with no binding commitments to qualify for emission avoidance certificates, also known as Certified Emission Reduction (CER) certificates. The certificates are issued based on a baseline emission scenario and the avoided emission attributed to development of renewable energy projects. Projects must meet the additionality criteria, which requires evidence that the project would otherwise not be built without the added benefit of receiving credits. CERs can be used by Annex I countries to meet part of their binding commitments.

In theory, the CDM should encourage bi-lateral development of renewable energy projects in developing countries, in which an industrialized country's investment in a project is repaid in part by CERs. Recently, unilateral projects developed solely by the non-Annex I host country have also emerged, with the CERs sold via various exchanges to a country looking to meet its own binding target. As of 1 April 2013, 6,660 projects have been registered worldwide with 2,337 projects under review. The CDM is one of the primary ways in which developed countries subsidize renewable energy infrastructure in developing countries [3, 5, 6].

Key criticisms of the Clean Development Mechanism

Despite its apparent success and the potential impact on air pollutants [7], the CDM has been widely criticized, leading some researchers to suggest that it be abandoned in favour of fiscal regulation specific to individual countries alongside binding emission reduction goals [6, 8]. Other academics believe correcting some key flaws will greatly enhance the CDM's effectiveness. Three main issues examined here are its bureaucratic process, the effectiveness of "additionality," and distorted credit prices due to uncertainty around credit supply.

<u>Bureaucratic process</u>. Each renewable energy project must apply for CDM status in order to receive CER credits through a lengthy, "unwieldy and opaque bureaucratic structure" [5 pg. 91]. The Samana wind farm in Gujarat, India, for example, was

commissioned in 2009 and did not receive CDM status until February 2013. Project developers rank the risk of non-approval as a primary concern when developing renewable energy in emerging markets [5]. The high transaction costs of participating in the program, therefore, reduce its benefits. Lewis [6] and Dechezlepretre et al. [9] suggest that streamlining the approval process as well as approving a program with multiple projects would greatly strengthen the design of the CDM.

Additionality. For a project to receive CDM approval, it must meet the additionality criteria, which requires developers to show that the project could not have been built without the additional revenue stream from sale of CER credits. However, these calculations of financial feasibility are based on self-reported rates of return of developers [3, 4] and there is no standard or uniform way through which this is done. Evidence from China [6], Brazil and India [5] imply some projects receiving CDM approval were not "additional."

Distorted credit prices. Lastly, critics have cited distorted CER credit prices as a major drawback of the CDM. Aside from the market reactions to the recent global recession and European debt crisis, the particularities of the CDM have led to irrational market fluctuation of credit prices. Because of the lengthy and oftentimes opaque approval process, there is uncertainty around the number of credits that will be available on the market in the future, clouding price-change signals [8]. Additionally, because the number of credits issued for a project is relative to a theoretical business-as-usual baseline, credits earned for identical projects in different locations will vary [5], adding to the uncertainty around credit supply. The future of the CDM is also undetermined, since countries have yet to renew their reduction commitments. This increases risks for developers, raising the required rate of return to participate in renewable energy projects for some investors and possibly deterring others. Stabilization of policy with greater certainty in future credit supply could increase investor confidence and lead to additional investments.

Need for quantitative analyses of Clean Development Mechanism improvements. In short, the CDM in its current state is ill-equipped to streamline renewable energy investment in emerging markets [8]. Although suggestions have been made to improve the CDM, no research has quantitatively evaluated the effect of these changes on total investment in renewable energy infrastructure. Informing policy makers of which changes can bring about the greatest increase in investment is valuable in designing future policy and continuing to encourage renewable energy investment in emerging markets. As a step in this direction, we use agent-based simulation to measure the total investment in wind energy infrastructure in India, Brazil and China under improvements to the CDM.

Key participants of the Clean Development Mechanism

India, Brazil and China are among the top countries in terms of CDM participation. According to the UNEP Risø Centre, China and India are the most active countries in Asia making up 55.0% and 29.7%, respectively, of all Asian CDM projects. Brazil leads with 35% of all Latin American CDM projects. Specifically for wind power, China, India and Brazil have the most installed capacity of wind energy infrastructure out of all countries eligible to participate in the CDM as of 2012 [10]. Additionally, all three countries are in the top ten countries with the most installed capacity during 2012 [10]. Developers in India were early to take advantage of the CDM program for wind energy, with almost 40 projects submitting for approval in Q4 of 2005. Between Q2 2007 and Q2 2010, approximately 30 projects per quarter applied for CDM status. Starting at the end of 2010, between 40 and 60 projects were proposed until the end of 2012. Chinese developers started regularly submitting wind power projects in Q1 of 2008 at a steady pace of approximately 40 per quarter. Since then, there has been a significant increase per quarter leading to a peak of 185 projects being considered in Q2 of 2012. Brazil dabbled with participation in the CDM for their wind projects starting in early 2006, although they had previously developed biomass/biogas projects under the program. Wind power developers did not start consistently applying for CDM status until the end of 2010, reaching a peak of 23 projects in Q4 of 2011. Although progress has been made, each country's potential wind resource is still much greater than the existing infrastructure, as shown in Table 1, and will continue to increase as turbine technology advances.

Data on wind power potential and installed capacity in Table 1 show that India, Brazil and China are important players in the CDM program with a rich dataset of projects to study, and continue to be leaders in the growing global wind industry. Below are brief descriptions of the wind development and regulatory landscape in each country.

Table 1. Wind power potential and installed capacity in India, Brazil and China

Country	Potential	Installed Capacity in 2012 [10] (% of potential)
India	102 GW [10]	18.4 GW (18%)
Brazil	350 GW [10]	2.5 GW (0.71%)
China	2380 GW [11, 12]	75.3 GW (3.16%)

India. In 1983, the Wind Energy Program was started by the Ministry of Non-conventional Energy Sources (MNES) (currently the Ministry of New and Renewable Energy (MNRE)) and had broad goals of assessing wind resources, building demonstration projects and creating industry-utility partnerships [13, 14]. Although an initial leader in the wind energy industry compared to other developing countries, India's lack of an integrated energy framework and a national mission dedicated to wind has stunted its growth and allowed countries such as China to soar past its progress [10]. Despite this, several incentives have helped wind energy grow considerably over the past two decades, and India currently ranks fifth in installed capacity worldwide. At the national level, a bundle of tax incentives, including accelerated depreciation, low tariffs on imported wind energy technology and reduced or exempt tax for income from power sales helped developers largely using balance sheet financing (as opposed to project financing). Additionally, the Indian Renewable Energy Development Agency (IREDA) was established in 1987 to provide financing to developers. It instilled confidence in the economic viability of wind power and paved the way for private banks to lend to developers. Several state governments have enacted preferential feed-in tariffs, which encourage wind power development by providing a higher rate to electricity produced from wind. Recently, some states have also implemented Renewable Purchase Obligations (RPO) which require a certain amount of power produced to come from renewable sources, although lack of enforcement have negated much of its intended effect. Looking forward, some challenges facing the wind industry in India include implementing an integrated framework and a national feed-in tariff program, as well as continued development of transmission and other support infrastructure.

Brazil. Brazil has long been a leader in renewable energy due to its numerous hydroelectric power plants. In an effort to diversify its energy portfolio and to hedge against low power production during the dry season and droughts, Brazil has aggressively promoted wind as part of its primary energy mix. Although a recent entrant into the wind power industry, the country is characterized by strong winds that allow turbines to operate for a longer period of time than in many other countries, giving the technology operational and financial advantages [15]. In 2002, the government created the Program for Incentive of Alternative Electric Energy Sources (Proinfa), which consolidated several previous actions promoting alternative energy development and provides subsidies and financial incentives funded through an electricity surcharge on power consumers [16]. The National Development Bank also provides financing for machinery and equipment through its subsidiary Finame. It has created a strong domestic industry and eleven international equipment manufacturers have opened production facilities in the country [10]. Starting in 2009, the government has held several wind-only energy auctions, essentially guaranteeing that wind energy operators received over half of the contracts to sell power in 2011 and 2012 [17]. However, the prices at which developers have agreed to sell electricity are extremely low and have caused concerns over the sustainability of future wind power growth [17]. In order to continue growth of its wind industry in the upcoming years, Brazil must ensure sufficient transmission infrastructure to keep up with the increase in electricity production and reduce financial risks through improved government regulations [10, 18].

China. Over the past decade, China has experienced rapid growth and currently has the highest installed capacity of wind energy infrastructure globally. In 2005, the government created the Renewable Energy Law of the People’s Republic of China. After its adoption, a series of policies have been enacted to promote renewable energy development, including a dedicated renewable energy development fund supported by an electricity surcharge on consumers [12]. Additionally, feed-in tariffs have been used to give wind power a financial advantage. The manufacturing industry has also flourished due to policy incentives, creating a full supply chain with 88% of the domestic market occupied by Chinese manufacturers [12]. Since most developers are stated-owned enterprises supported by government-backed commercial banks eager to invest in infrastructure, the wind industry in China experiences lower financial risks and was largely unaffected by the 2009 crisis that upset the US and European industries [10]. Several obstacles still remain, however, most notably the inadequate transmission system and lack of regulations for wind power integration into the grid [10, 12].

Opportunities created by India, Brazil and China analyses. By analysing these three countries, not only can we gain insight into which improvements to the CDM are the best at encouraging development, but under what circumstances. By doing so quantitatively, we aim to measure the effect of improvements to the CDM policy will have on investment decisions. Our results will better inform policy makers as to where they should concentrate their efforts to create the greatest increase in total renewable energy investment in emerging markets.

AGENT-BASED SIMULATION

In order to determine the impact of changes to the CDM, we built an agent-based model to simulate the total investment in renewable energy given certain policy environments. Agent-based simulation was selected because of its extensive use in past studies to model and evaluate investment decisions under various policy scenarios. Mueller and de Haan [19] and Eppstein et al. [20] used agent-based simulation to determine how much incentives affect car purchase decisions and market penetration of plug-in hybrid electric vehicles. Jackson [21] analysed energy efficiency of a smart grid program and Veit et al. [22] determined the implications of transmission constraints on the German electricity market, both using agent based simulation.

Our agent-based model simulated investment decisions of an individual or firm seeking to develop a wind energy project. The decision is based on several factors that influence a project's potential revenue and profitability, including project properties, local conditions, and an investor's own characteristics. The model aggregated all investment decisions of investors over time to determine the total investment. Simulations were performed for investors in India, Brazil and China, allowing us to quantify the incremental investment on wind energy infrastructure under the presence of the CDM in each country. Sensitivity analysis was done to measure the impact of three improvements to the CDM program: streamlining the approval process, reconsidering the requirement of additionality, and reducing investor risk by stabilizing policy. The results allowed us to compare the effectiveness of the CDM and various program changes within and across countries.

Model structure

The agent-based model was designed and coded in AnyLogic, a powerful and robust simulation environment. The simulation environment is populated with agents representing individuals or firms, which we call "investors". An investor decides whether or not to build a wind energy project by evaluating its profitability. The decision process is represented in Figure 1.

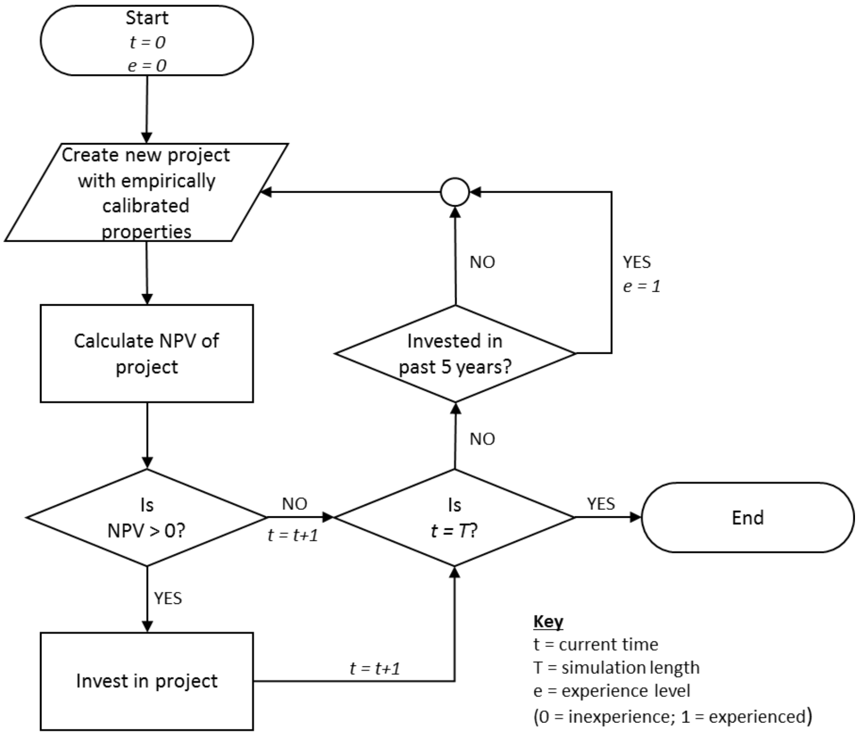

Figure 1. Decision process of an investor

By default, the simulation initially treats all investors as "inexperienced." Each year, an investor decides makes his or her decision by calculating the project's net present value (*NPV*) using its required rate of return. The cost and revenue streams for a project are based on four components: a) initial cost, b) yearly revenue from electricity sales, c) yearly operations and maintenance cost, and d) yearly revenue from Certified Emission Reduction (CER) credit sales. The *NPV* for each project is calculated as follows:

$$NPV = -\text{initial cost} + PV(\text{electricity revenue}) - PV(\text{O \& M}) + PV(\text{CER revenue})$$

where *PV* represents the present value of all future revenue or cost streams discounted to present day. The parameters used to calculate each of the four components and the discount rate used vary by country and are detailed in the next section. If the NPV is positive, then the project is built and the investor becomes “experienced”. If an experienced investor does not build any projects for five years, then it reverts back to inexperienced. We ran the simulation for a period of *T* years and aggregated the costs of built projects to determine the total investment.

Baseline calibration

While the structure of the model remained the same for all three countries analysed, model parameters necessary to calculate costs and revenue were derived for each country using a database of all projects that have applied for CDM registration as of 1 April 2013, publicly available from the UNEP Risø Centre. After streamlining the data to focus on wind energy and removing duplicate projects that were listed more than once because of resubmissions, 83 projects were used to calibrate parameters for Brazil’s model, 1544 for China’s, and 931 for India’s. For each country, a project’s properties and situational characteristics are presented in Table 2. The rates of return used for experienced and inexperienced investors are based on a study done by Donovan and Nunez [3] on the cost of capital for renewable energy projects in emerging markets, and are also listed in Table 2.

Table 2. Parameters used in baseline agent-based simulation

	Parameter	**India**	**Brazil**	**China**
Environment	Number of investors	50	50	50
	Delay in receiving credits*	3 years	2 years	2 years
	Probability of getting CDM approval*	80.57%	77.5%	97.91%
Investor	Experienced investor discount rate**	19.06%	13.68%	11.08%
	Inexperienced investor discount rate**	14.80%	12.09%	8.32%
	Time of inactivity to revert back to inexperienced	5 years	5 years	5 years
Project	Years credits are received*	10 years	7 years	7 years
	Years electricity is produced	20 years	20 years	20 years
	Project size*	Exponential distribution with mean = 17.02 MW	Exponential distribution with mean = 75.13 MW	Either 50 MW or 200 MW
	Capacity factor*	23.3%	42.7%	24.5%
	Average CER credit received per MW capacity*	N (1891, 298)	N (1259, 409)	N (2032, 304)
	Average project cost per MW capacity*	N (122901, 237711) USD	N (1971742, 682573) USD	N (1289005, 160466) USD
	Yearly O&M cost per MWh electricity produced***	10 USD	10 USD	10 USD

* Empirical values derived from CDM project database
** Empirical values from [3]
*** Empirical values from International Renewable Energy Agency [23]

The initial cost of a project was calculated by multiplying the project size in megawatts [MW] of installed capacity by the average cost per MW. For each country, project size was randomly simulated based on an empirically-determined distribution of past projects. In the models for both India and Brazil, an exponential distribution with positive skewness (long right tail) was observed for project size with a mean of 17.02 MW and 75.13 MW, respectively. In China, the majority of CDM wind energy projects were between 40 and 50 MW, with an astonishing 999 (64.7%) projects with the exact size of 49.5 MW. This is because projects larger than 50 MW require approval from the National Development and Reform Commission (NDRC) while smaller projects are approved by local provincial governments and recorded with central government authorities [12], suggesting that developers prefer working with local authorities. Therefore in China's model, a project's size was simulated as either 50 MW with a probability of 0.9 or 200 MW with probability 0.1 in order to include the larger scale projects. The average unit cost per MW was also determined from information in the database. Project cost in all three countries followed a normal distribution, with no significant correlation found between project size and unit cost.

Yearly revenue from electricity sales was forecasted by multiplying the yearly electricity production by the expected price of electricity. It was received for the lifecycle of the project, which is 20 years. Yearly electricity production was calculated using capacity factors derived from the CDM project database for each country. The expected price of electricity was determined using feed-in tariff data for wind power in India [24] and China [12]. To maintain flexibility in the model, the feed-in tariffs for each Indian state were averaged and applied uniformly to all projects in India. Similarly for China, feed-in tariffs for individual zones were also averaged. A breakdown of the feed-in tariffs for each state and the average tariff utilized in our model is provided in Table 3 and Table 4. Brazil does not currently utilize feed-in tariffs for wind energy. Instead, the average price of the 2011 wind power auction of 99.58 BRL per MWh as reported by Bloomberg News and Merco Press was used to inform the model.

Table 3. Feed-in tariffs for electricity produced from wind power in India

State	Feed-in tariff per kWh [INR]
Andhra Pradesh	4.70
Gujarat	4.23
Haryana	Wind Zone 1 - 6.14 Wind Zone 2 - 4.91 Wind Zone 3 - 4.09 Wind Zone 4 - 3.84
Karnataka	3.70
Kerala	3.64
Madhya Pradesh	4.35
Maharashtra	Wind Zone 1 - 5.67 Wind Zone 2 - 4.93 Wind Zone 3 - 4.20 Wind Zone 4 - 3.78
Orissa	5.31
Average	4.448*

Source: [24]

*Converted to USD using ave. monthly exchange rate for 2011 of 1 USD = 44.899 INR

Table 4. Feed-in tariffs for electricity produced from wind power in China

Resource Zone	Feed-in tariff per kWh [CNY]
Category 1	0.51
Category 2	0.54
Category 3	0.58
Category 4	0.61
Average	0.56*

Source: [12]

*Converted to USD using ave. monthly exchange rate for 2011 of 1 USD = 6.464 CNY

While data for yearly operations and maintenance costs is not widely available, a survey of over 60 projects built in the 2000s revealed an average operations and maintenance cost of 10 USD per MWh of electricity produced (International Renewable Energy Agency [23]), making the total annual operations and maintenance dependent on project size. The unit cost was used for the models of all three countries and incurred for the lifecycle of the project.

Similar to revenue received from electricity sales, the revenue received from sale of CER credits was forecasted by multiplying the total number of credits by its expected price each year for which credits are received. Since the number of credits is calculated based on comparison with a theoretical business-as-usual baseline and may differ for projects of the same size, it was randomly generated in our models based on an empirically-determined distribution of values from the CDM project database for each country. The expected CER credit prices were simulated in MATLAB using techniques from [25]. We assume that daily returns follow Geometric Brownian motion, with the parameters calibrated from historical price data from 1 September 2009 to 31 August 2010. The starting CER price used for this simulation was the price on 1 September 2010: 13.44 EUR or 10.60 USD using the exchange rate of 1 EUR = 1.27 USD at that time. Expected future prices can move in either direction depending on a variety of factors. For example, using the techniques from [25] and running 10,000 simulations, the range of prices after 1 year (approximately 250 trading days) was between 3.93 EUR (31.58 USD) to 40.23 EUR (3.10 USD). The CDM allows a single 10-year crediting period or 7-year crediting period which can be renewed. For model simplicity and due to uncertainty surrounding credit renewal, a single value is used for each country's model. In India, the large majority of past projects applied for a 10-year crediting period while projects in both Brazil and China opted for a 7-year crediting period.

Two additional factors were taken into account: 1) probability of project acceptance and 2) delay in receiving credits. The database indicated that, on average, 80.47%, 77.5% and 97.91% of wind energy projects in India, Brazil and China, respectively, were accepted while the others did not receive CDM status. In our simulation, only projects that are approved were built. The database also indicated that there was an average delay of three years until credits are received in India and an average delay of two years in Brazil and China. In the models, this translated into a delay in receiving credit sale revenue which decreases the present value of credit sale revenue. Each investor evaluated each project independently. The initial costs of all built projects were aggregated to produce the total investment in wind energy infrastructure over the simulation time period.

Policy improvements and sensitivity analysis

The first improvement tested is streamlining the approval process for CDM registration and subsequent distribution of CER credits. To capture its effects, the value for delay in receiving CER credits was manipulated. A more efficient process equates to less waiting time to receive credits. Values of zero to five years were used to simulate total investment, holding all other parameters constant.

The second improvement tested is relaxing or eliminating the condition of additionality. In the models, this was equivalent to changing the probability that a project is accepted, with a probability of 1 meaning that "additionality" is excluded from the CDM. Values ranging from 0.6 to 1 in increments of 0.05 were tested holding all other parameters constant. Analysis was not performed for China since 97.91% of projects were already approved.

The last improvement tested is to reduce the magnitude of credit price distortion by stabilizing policy and providing greater clarity on future credit supply. Policy risk is captured in the discount rate of the investors; the more stable the policy, the lower the discount rate. Since there are different discount rates for experienced and inexperienced investors, this is done in terms of change to the discount rate. For example, "+2.5%" indicates an increase of 2.5% to both discount rates. Values of -5.0% to +5.0% in increments of 0.5% were tested holding all other parameters constant.

RESULTS

Baseline simulations were performed for T equal to 10 years, 15 years, and 20 years for each country. Thirty simulations were executed for each time period and the results for each simulation were averaged to obtain an average total investment for each value of T. Since the three countries differ greatly in population and electricity demand, the raw values of total investment are not appropriate for comparisons across countries. Instead, we simulated one more scenario in which we measure total investment in the absence of the CDM by removing the revenue stream from CER credit sales when calculating a project's *NPV*. Table 5 shows the results for India, Brazil and China and allows us to compare the impact of the CDM in each country. Sensitivity analyses were performed with T equal to 10 years. The results are detailed for each country in the following subsections. Again, 30 simulations were executed for each change of the appropriate parameter and then averaged.

Table 5. Total investment (average of 30 simulations) of the "No CDM" and "CDM baseline" scenarios for each country and each value of T

	Total investment with no CDM [billions USD]			Total investment with baseline CDM (as % of no CDM)		
T	10	15	20	10	15	20
India	1.78	2.89	4.18	2.38 (133%)	3.98 (138%)	5.69 (136%)
Brazil	6.63	9.80	12.8	6.01 (91%)	9.25 (94%)	12.4 (90%)
China	40.0	60.1	79.8	43.3 (108%)	63.8 (105%)	84.0 (105%)

India

The results from Table 5 show total investment of wind energy projects in India increased under the presence of the CDM, indicating that previously unprofitable projects became profitable with additional revenue from CER credit sales and were developed. Figure 2 further demonstrates this point by providing histograms of the *NPV*s of all wind energy projects considered over 10 years in two sample simulations, one including the CDM and one excluding it. More projects had positive *NPV*s during the simulation with CDM. However, the majority of projects still had *NPV*s of less than zero, which indicates that they were rejected by the investor and not built, even with the extra revenue stream.

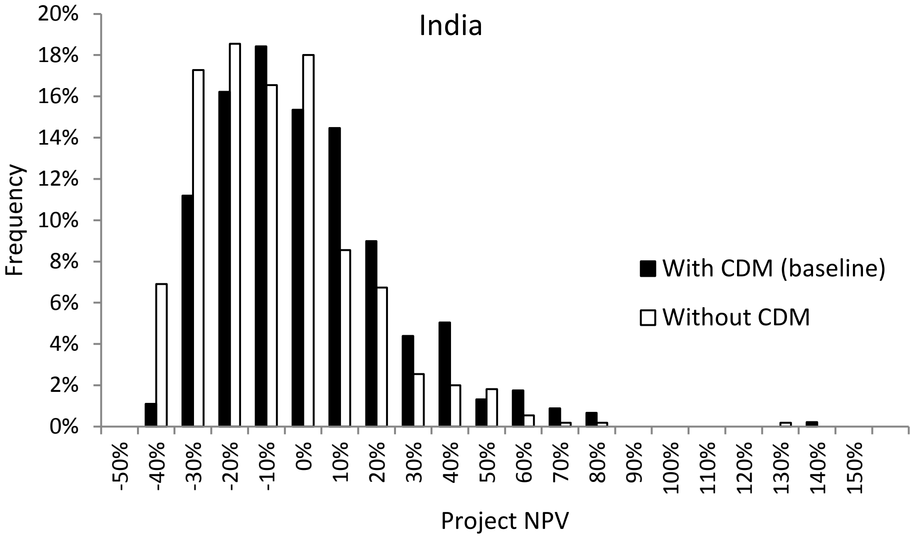

Figure 2. Histogram of *NPV* of all Indian projects considered in a sample simulations of $T = 10$ years

Figure 3 shows the impact on total investment when the delay in receiving CER credits was changed as compared to the baseline CDM scenario. The solid black square indicates total investment under the baseline scenario with a wait time of three years. As expected, total investment increased when the delay is shortened, with a linear trend. Under the best case scenario with no delay, total investment grew by over 30%.

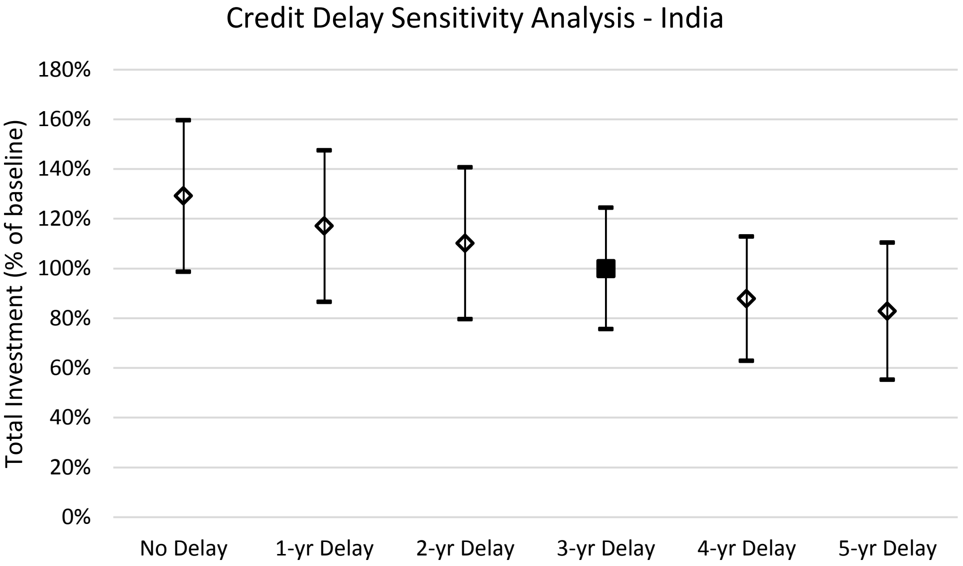

Figure 3. Sensitivity analysis for the delay of issuance of CER credits in India

To test the effect of relaxing or removing the requirement of additionality, we changed the probability of projects being approved and receiving CER credits. If the condition of additionality is completely removed, this is equivalent to the probability equalling 1. Figure 4 shows total investment compared to the baseline scenario. The solid black square represents total investment under the baseline simulation with a probability of 80.57%. As expected, total investment increased when the chances of receiving CER credits were increased. Under the best case scenario with guaranteed credits, total investment grew by approximately 35%.

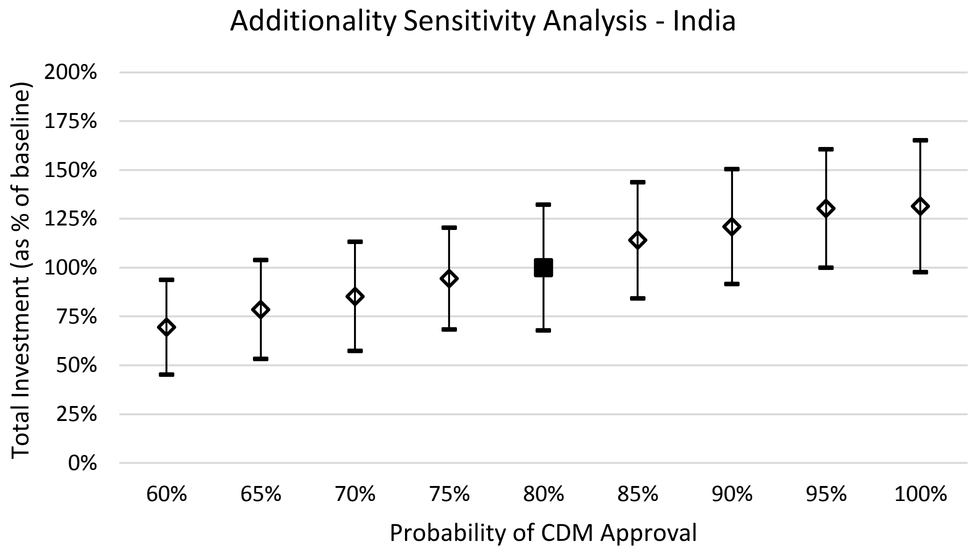

Figure 4. Sensitivity analysis for the probability of CDM program approval in India

Lastly, we used investor discount rate as a proxy for the policy stability, with a decrease in the discount rate representing an increase in stability. Figure 5 shows the total investment compared to the baseline when changing discount rate for both experienced and inexperienced investors. The solid black square represents total investment under the baseline scenario with no changes to either discount rate. Unlike the previous two policy improvements, there appears to be a nearly quadratic relationship between total investment and changes to the discount rate. Additionally, the impact on total investment was greater, reaching 343% of baseline total investment if the discount rate decreased by 5%.

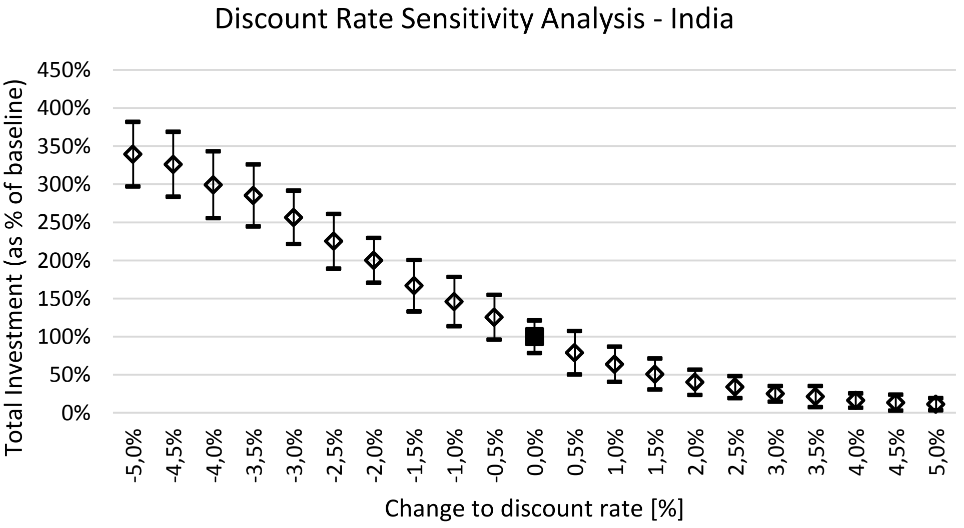

Figure 5. Sensitivity analysis of policy stability (using discount rate as a proxy) in India

Brazil

For wind energy projects in Brazil, Table 5 shows less investment when the CDM existed as compared to investment without the program. Although counterintuitive, this can happen when profitable projects that are built under the no CDM scenario are not built under the CDM scenario because they did not receive CDM approval. Discussion of this phenomenon can be found in the following section. Figure 6 displays histograms of the *NPV*s of all wind energy projects considered over 10 years in two sample simulations, one which included the CDM and one which excluded it. Unlike the histogram of project *NPV*s in India, the aggregate of projects with negative *NPV*s was approximately the same under both scenarios. In both cases, the majority of projects still had *NPV*s of less than zero and were not built.

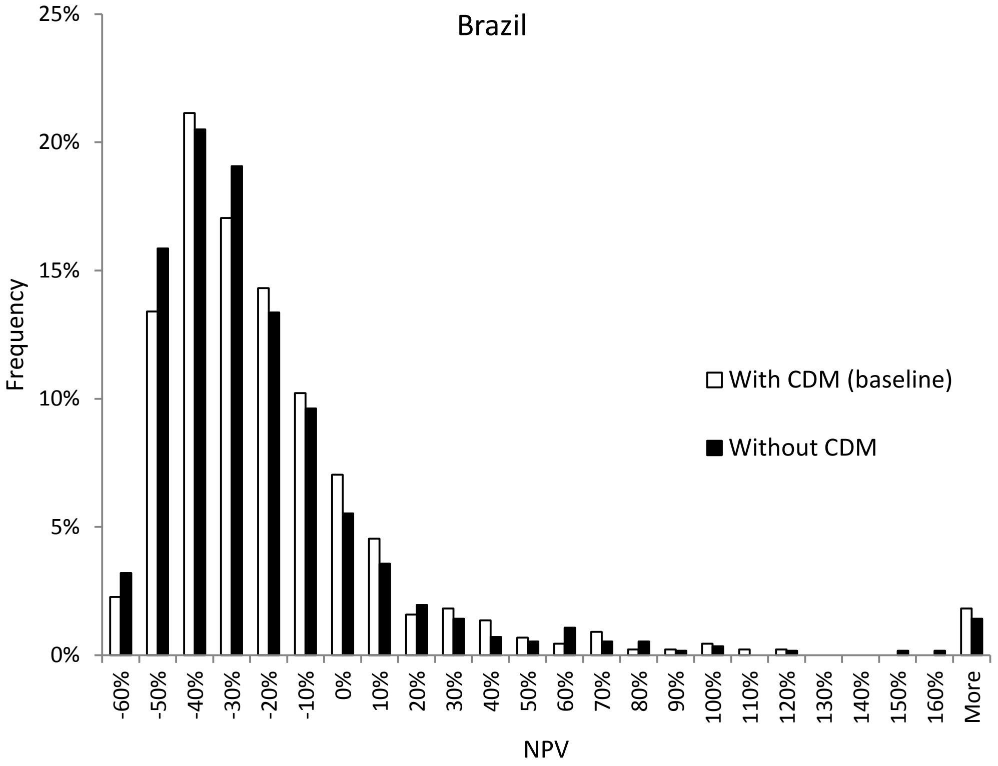

Figure 6. Histogram of *NPV* of all Brazilian projects considered in a sample simulations of $T = 10$ years

Figures 7, 8 and 9 show the results of scenario analysis for Brazil of streamlining the approval process, reconsidering additionality, and changes to the discount rate as a result of policy stability, respectively. The solid black squares in each figure represent total investment under the baseline CDM scenario and the top and bottom bars indicate two standard deviations of investment over 30 simulations. Streamlining the approval process and allowing investors to receive CER credits earlier had an almost negligible effect on total investment. Increasing the number of projects receiving CDM status does lead to additional investment, with an increase of 35% of all projects are approved. Similar to the results of the India analysis, stabilizing policy and decreasing investor discount rates drastically increased total investment.

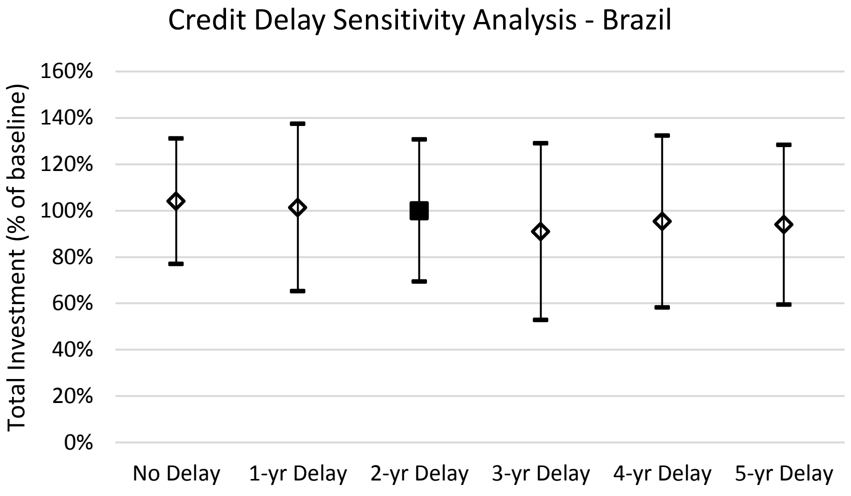

Figure 7. Sensitivity analysis for the delay of issuance of CER credits in Brazil

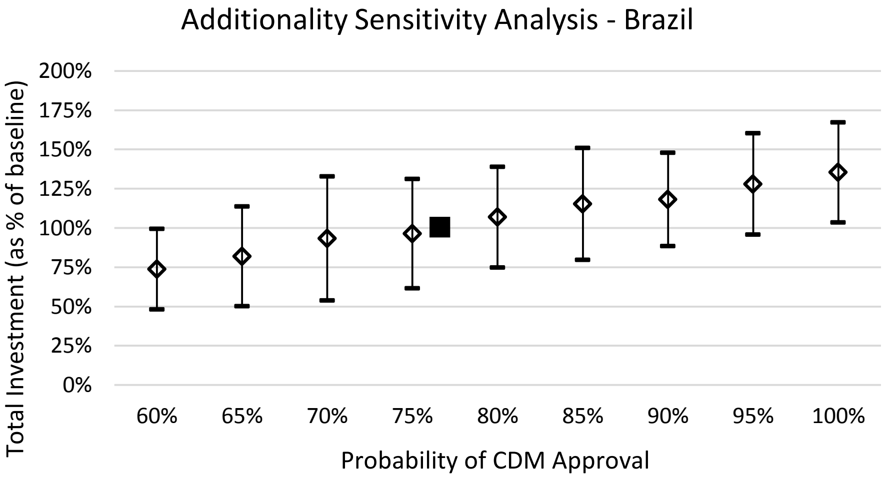

Figure 8. Sensitivity analysis for the probability of CDM program approval in Brazil

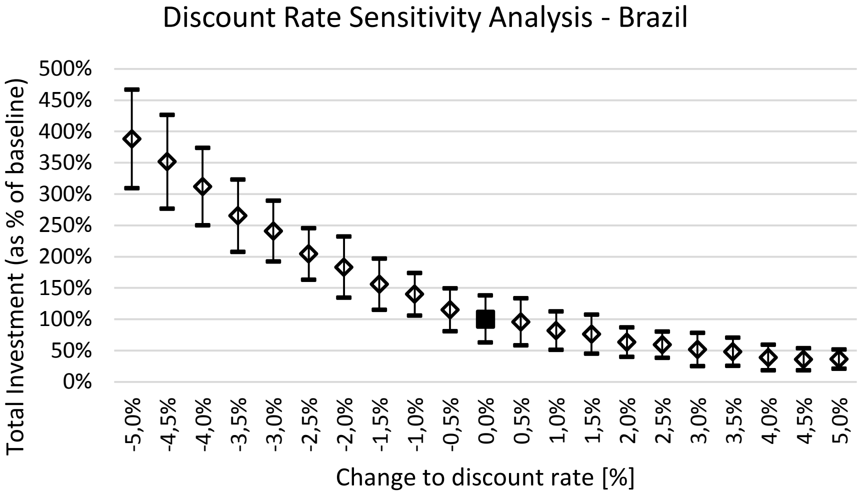

Figure 9. Sensitivity analysis of policy stability (using discount rate as a proxy) in Brazil

China

The presence of the CDM in China increased total investment in wind energy infrastructure according to the results of Table 5. However, most projects are profitable even without the extra revenue of CER credit sales, as shown in Figure 10. Therefore we can expect that any improvements to the CDM will not drastically increase investment, reflected in Figures 11 and 12. Because over 97% of projects are already receiving CDM project approval, sensitivity analysis was not performed on this parameter. Same as with the results of the previous two countries, the solid black squares represent baseline CDM investment with the top and bottom bars indicating two standard deviations of investment over 30 simulations.

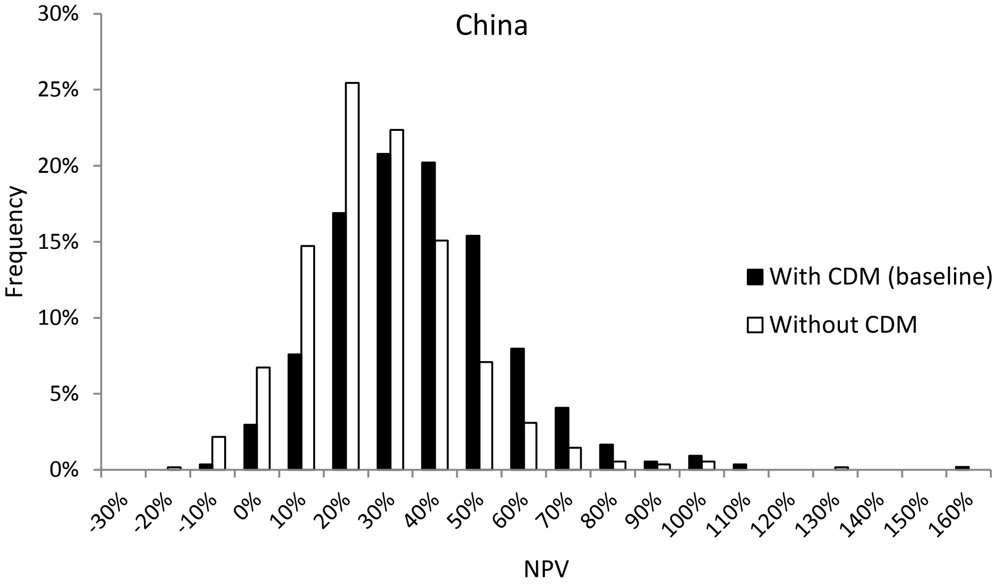

Figure 10. Histogram of *NPV* of all Chinese projects considered in a sample simulations of *T* = 10 years

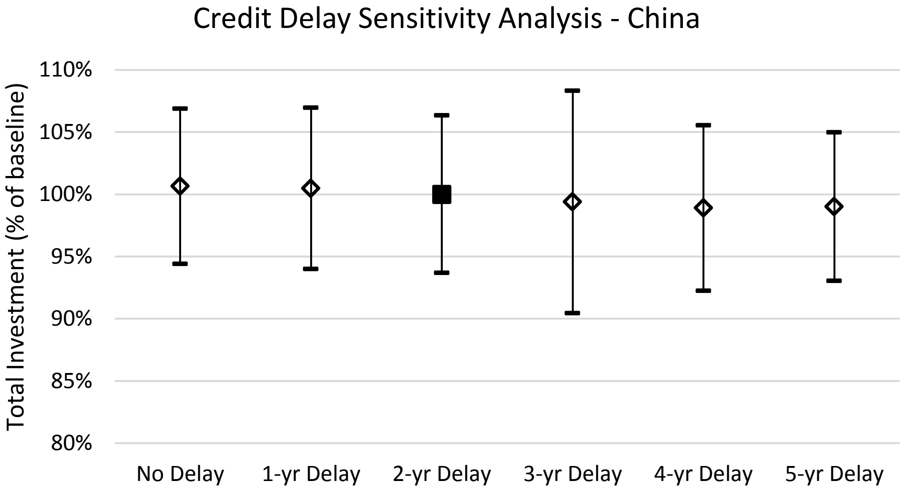

Figure 11. Sensitivity analysis for the delay of issuance of CER credits in China

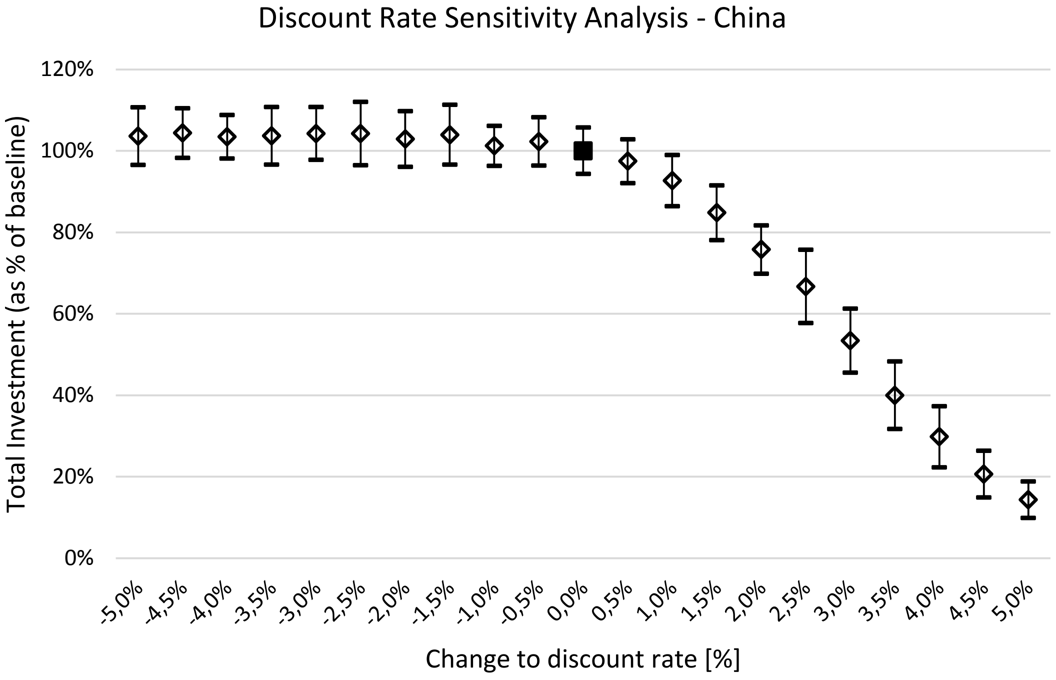

Figure 12. Sensitivity analysis of policy stability (using discount rate as a proxy) in China

DISCUSSION

Although originally intended as a reference point for scenario analysis of the three policy improvements, the CDM baseline results provide some interesting insights for individual countries and comparison across them. We discuss below two key findings: 1) why most projects considered in China have positive *NPV*s while the reverse is true for India and Brazil; and 2) why Brazil's level of investment actually decreases under the presence of the CDM. We then discuss the results of the policy improvements to the CDM and its implications for the future of the program as well as other energy policy measures.

Baseline comparisons between countries

In the sample simulations of all wind energy projects considered, Figures 2, 6 and 10 show that the *NPV*s of most projects in India and Brazil are negative and rejected, while most projects in China are profitable and built. Since this is the case for the scenario when the CDM does not exist, we can attribute China's superior performance to the landscape in which projects are developed. A study done by [26] showed the importance of a comprehensive strategic approach to initiatives used to promote diffusion of renewable energy technologies. We use this strategic structure matrix as a framework to analyse each country's existing policies.

The matrix breaks down each policy into five different categories in terms of which area it targets. Table 6 summarizes the five categories, and details on development and usage of the matrix can be found in [26]. Table 7 classifies the policies and incentives of each country as discussed in the "Key participants of the Clean Development Mechanism" section of this paper.

Table 6. Strategic Structure Matrix [26]

Lowering a Diffusion Barrier	Empowering Actors	Creating an Enabling Environment	Direct or Indirect Influence	Supply or Demand
Technical: decreases uncertainty with technical capabilities *- or -* Financial: decreases cost or increases future value *- or -* Regulatory: decreases regulatory hurdles to diffusion	R&D: increases support of research laboratories and organizations developing new technologies *- or -* Systems and Infrastructure: provides support for surrounding infrastructure (physical, market, etc.) *- or -* Knowledge and learning: strengthens ties between facilitating organizations	Institutional Change: improves institutional landscape for easier diffusion of the technology *- or -* New/Expanded Market: creates a new market or expands existing market *- or -* Advocacy coalition: creates or promotes pro-diffusion organizations	Direct: targeted primary at technology being diffused *- or -* Indirect: targeted primary at infrastructure surrounding the technology	Supply: ultimately decreases costs or lowers barriers associated with adoption of the technology *- or -* Demand: ultimately raises the payoff after adoption of the technology

Table 7. Classification of country specific policies and incentives

	Initiative	Barrier	Actor	Environment	Direct/ Indirect	Supply/ Demand
India	Bundle of Tax incentives	Financial	Systems and infrastructure	Market	Direct	Demand
	Loans from IREDA	Financial	Systems and infrastructure	Market	Indirect	Supply
	Feed-in tariffs	Financial	Systems and infrastructure	Market	Direct	Demand
China	Renewable Energy Law	Regulatory	Knowledge and learning	Institutional change	Direct	Supply
	Government-backed banks	Regulatory	Knowledge and learning	Advocacy coalition	Indirect	Supply
	Renewable Energy Development Fund	Financial	Systems and infrastructure	Market	Direct	Supply
	Feed-in tariffs	Financial	Systems and infrastructure	Market	Direct	Demand
Brazil	Proinfa	Financial	Systems and infrastructure	Market	Direct	Supply
	Financing from Finame	Financial	Systems and infrastructure	Market	Indirect	Supply
	Wind Auctions	Financial	Systems and infrastructure	Market	Direct	Demand

China's policies toward wind power development are more comprehensive in terms of the number of strategies covered. Most notably, its renewable energy law and government involvement in the commercial banking sector is able to overcome regulatory hurdles to diffusion, strengthen ties between facilitating organizations, improve the institutional landscape for wind power deployment, and advance organizations interested in developing more renewable energy infrastructure. These strategic areas are missing from the bundle of policies and incentives offered by India and Brazil, and support previous findings that a comprehensive approach to increasing diffusion is most effective [26]. By doing so, China offered investors stability and reduced risk. It was thought of as a "safe haven" for wind power investment when the effects of the global financial crisis reached the wind industry in other parts of the world [10], explaining the low required rates of return found by Donovan and Nunez [3] and used as the discount rates in our simulation. The importance of the discount rate to total investment is clear when looking at Figures 5, 9 and 12, which will be discussed in more detail in the following subsection.

Brazil and India's focus on market-forming financial incentives are usually found in the early phases of technology diffusion. While this is understandable for Brazil since it recently entered the market, India has been a part of the wind power industry for over 20 years. India's lack of a comprehensive national policy for wind power combined with the segmented nature of the energy sector emphasizing states is hurting its growth. Researchers agree that a unified vision with national goals is essential for India's continued growth [10]. As part of a study done by Martins and Pereira [18], questionnaires were sent to companies, academic and research institutions, and national organizations and associations asking them to rank initiatives to expand renewable energy deployment in Brazil. Two of the highest ranked issues were a) improve government regulations and b) reduce financial risks. For both countries, the sustained regulatory uncertainty means investors will continue to require higher rates of return.

Table 5 shows that total investment in wind energy infrastructure in Brazil actually decreased under the presence of the CDM. This seemingly counterintuitive finding is due to the country's ratio of revenue from electricity sales to CER credit sales. Brazil's wind resources allow increased power production, leading to an average capacity factor of 42.7% compared to 23.3% for India and 24.5% for China (see Table 2). This may be a contributing factor to the low bid prices from investors in recent auctions. However, average capital cost is much higher, leading to the highest frequency of non-profitable projects in our simulation. Unfortunately for Brazil, since CER credits issued through the CDM are based on comparison against a baseline scenario, Brazil's success with hydropower actually hurts its wind industry with respect to participation in the program. The average number of credits it receives for the same size of a wind farm is much less than that received by India or China since Brazil's energy mix is already heavily reliant on emission-free sources. Combined with the higher volume of electricity produced, it means that revenue received from electricity sales matters more than revenue from CER credit sales when calculating NPV. This explains the decrease in investment under the presence of the CDM. The extra credit revenue does little to push unprofitable projects into profitability, while rejection of approximately 33% of projects from the CDM means that they will not be built, even if they are profitable.

China's tight regulatory control over the wind power industry is rare and should not be considered normal for renewable energy development in emerging markets. While the feed-in tariff and CER credit sales generate extra revenue for the investors, some projects are still unprofitable, as presented in our simulation results from India and Brazil. This highlights the need for continued financial support of wind energy infrastructure in emerging economies. Although some projects may be financially feasible without additional government support, to achieve the level of investment necessary to meet future demand, incentives must continue to exist. The different reactions to the CDM from the three countries in our analysis, however, support the view that CDM should play a secondary role and developing countries should adopt their own commitments to reduce emissions [6, 8].

Policy Improvements

Several improvements to the CDM may encourage greater investment in renewable energy infrastructure in emerging markets. Since most of China's wind power projects were already being developed under the CDM baseline simulation, improvements to the program cannot meaningfully increase investment. It should be noted that these improvements may increase the profit margin for individual projects and investors in China. However, the only way to increase total investment is to increase revenue for a proposed project with negative *NPV* so that it is profitable and subsequently built. Therefore we focus our analysis here on Brazil and India.

Our simulation results shows that streamlining the approval process and shortening the length of time it takes to receive CER credits raises the total level of investment in wind power in India. As a regulatory improvement that strengthens ties between organizations promoting diffusion of wind power, it is unsurprising for India to have such a positive reaction. However, it had a negligible effect on total investment for Brazilian projects. This is likely due to the fact that the revenue from credit sales is less of a factor in calculating *NPV* as discussed previously. Few unprofitable projects that are already receiving credits will become profitable when changing the present value of credit revenue. Allowing more projects to receive credits, however, does lead to higher investment.

Investments in both India and Brazil increased when the goals of additionality were reconsidered, with total investment rising by 31% and 35%, respectively. By allowing all renewable energy projects to receive credits regardless of their financial viability in its absence, previously unprofitable projects became profitable, were developed, and increased total investment. This is encouraging to researchers who believe the CDM would be greatly improved without the additionality criteria [3-5].

Most striking, however, is the effect of stabilizing policy and lowering investment risk for developers. A 1% decrease in discount rates leads to, on average, 50% more simulated projects becoming profitable in India and 56% more projects in Brazil, with a doubling of investment realized at a 2% decrease in India and a 2.5% decrease in Brazil. This has clear implications for policy makers. No matter how attractive they make the financial incentives, having them be stable (for example, longer periods until renewal) will do much more to increase investment. The baseline comparisons between the three countries also echo this fact, as the simulation results for China, the country with the lowest discount rates, show many more projects being realized and higher levels of investment. Additionally, the sensitivity analysis on the Chinese discount rates show investment cut in half when the discount rates increase by 3%, which is still lower than the discount rates used for the Brazil simulation. The importance of policy stability and lower risk has been observed historically as well as by many researchers. For example, the appearance and disappearance of tax credits in the US led to a bust-boom development cycle for wind power in the 1990s [27].

CONCLUSION

In an attempt to encourage renewable energy investment, the CDM has provided an incentive for parties from industrialized countries to develop renewable infrastructure in emerging markets. As the future of the CDM is currently being debated, there have been many suggestions to improve the program and address some of its shortcomings, including streamlining its bureaucratic process, relaxing or removing the requirement of additionality, and lowering investor risk by stabilizing policy. We utilized agent-based simulation to quantify total investment in three countries: India, Brazil and China, which are key participants in both the CDM and the global wind power industry. While we intended primarily to evaluate the effects of various regulatory improvements to the CDM, country comparisons of the baseline scenario provided valuable insights. The success of China's wind power development can be attributed in part to a comprehensive approach to renewable energy policy and initiatives, especially the high level of regulatory oversight. However, this should not be considered widespread and the results from India and Brazil reveal the need for continued financial incentives for emerging markets. Our results from the sensitivity analysis of policy improvements show that, compared with the baseline, streamlining the approval process and increasing the odds of project approval has the potential to add significant investment to the wind power sector. However, stabilizing policy is even more effective in increasing the level of investment. This provides key insights to policymakers when designing future policy to encourage renewable development in developing countries. Future research can expand this analysis to other countries that also participate in the CDM and incorporate simulation of investment decisions into larger models of policy evaluation.

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