Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Cost Benefit Analysis of Wind and Hydro Power CDM Projects in China

Chunyan Shao

Master's thesis · 30 credits · Advanced level
Environmental Economics and Management
Degree thesis/SLU, Department of Economics,
No 1270 · ISSN 1401-4084
Uppsala 2020

Cost Benefit Analysis of Wind and Hydro Power CDM Projects in China

Chunyan Shao

Supervisor:	Katarina Elofsson, Swedish University of Agricultural Sciences, Department of Economics
Assistant supervisor:	Franklin Amuakwa-Mensah, Swedish University of Agricultural Sciences, Department of Economics
Examiner:	Jens Rommel, Swedish University of Agricultural Sciences, Department of Economics
Credits:	30 credits
Level:	A2E
Course title:	Master thesis in Economics
Course code:	EX0537
Programme/Education:	Environmental Economics and Management, Master's Programme
Responsible dep.:	Department of Economics
Faculty:	Faculty of Natural Resources and Agricultural Sciences
Place of publication:	Uppsala
Year of publication:	2020
Name of Series:	Degree project/SLU, Department of Economics
Part number:	1270
ISSN:	1401-4084
Online publication:	http://stud.epsilon.slu.se
Keywords:	CDM projects, cost-benefit analysis, net social benefit,

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Abstract

Renewable Energy (RE) is a solution to solve the Chinese energy problem of increasing demand for energy with high pollution resulting from fossil-fuel energy. The Clean Development Mechanism (CDM) allows China to implement an emission-reduction project, such as wind and hydro power projects, which account for a large share in all renewable energy projects. The aim of the thesis is to apply a cost-benefit analysis to wind and hydro power CDM projects in China. Private Net Benefits (PNB) and Social Net Benefits (SNB) of wind power to hydropower projects under deterministic and stochastic conditions are compared. Monte Carlo simulation is used to analyse the stochastic condition of uncertainty. The results indicate that hydro projects are better than wind power projects, since hydro projects show a high benefit-cost ratio. In addition, the ancillary benefit of citizen’s life saved from using two renewable energy CDM projects is calculated. When taking ancillary benefits into account, the benefits increase substantially. The average level of stochastic estimation of net benefits is close to the deterministic calculation, but stochastic results shows the net benefit for wind and hydro projects can vary dramatically. Furthermore, sensitivity analysis is applied to investigate how a change in discount rates impacts net benefits and the benefit-cost ratio.

Abbreviations

RE: Renewable Energy

CDM: Clean Development Mechanism

PNB: Private Net Benefit

SNB: Social Net Benefit

CERs: Certified Emission Reductions

VSL: Value of Statistical Life

CAD: Case of Avoided Death

PDDs: Project Design Documents

UNFCCC: United Nations Framework Convention on Climate Change

Contents

List of figures

List of tables

1 Intruduction

1.1 Problem Background

As a newly industrializing country, China faces the combination of high energy consumption with high carbon emissions. The fast-economic growth and industrialization need sufficient energy supply. Coal continues to be primarily used for electricity generation, commercial heat and domestic use. In 2017, the proportion of China's global coal consumption is 50.7 percent, which remained the largest coal consumer in the world with a 0.4 percent increase from 2016 (Word Energy Outlook 2017: China). In addition, large proportions of coal used in China are of low quality, low productivity, and there is a large share of highly polluting brown coal. China's coal usage increased over the recent decades and has had a significant impact on national environment and public health. For example, the air quality of major cities deteriorated. Combustion of coal generates CO_2 and harmful air pollutants, such as sulfur dioxide (SO_2), particulate matter (PM), and nitrogen oxides. These pollutants are the main cause of smog, acid rain and toxic air pollution. Epidemiological studies have illustrated that the number of people suffering from cough, respiratory illness, asthma attacks, lung cancer, and related deaths are increasing with the expansion usage of fossil-fuel energy (Matus *et al.*, 2012).

The renewable energy (RE) obtain from, such as sunlight, wind, water, tides wave, and geothermal heat is a worldwide agreeable green substitute to high-polluting fossil-fuel energy. In China, implementation RE projects can bring public health benefits by improving air quality and, at the same time, satisfy its national energy demand. According to Figure 1, the increasing usage of RE in China can fulfill the growing energy demand nationally when the coal usage falls down.The share of coal in China's energy proportion shrinks from 58 percent in 2016 to less than 40 percent in 2040 as expected. Meanwhile, the RE led by hydropower, wind, and solar PV grows increasingly and consists of 60 percent of total generation capacity by 2040 (Word Energy Outlook 2017: China).

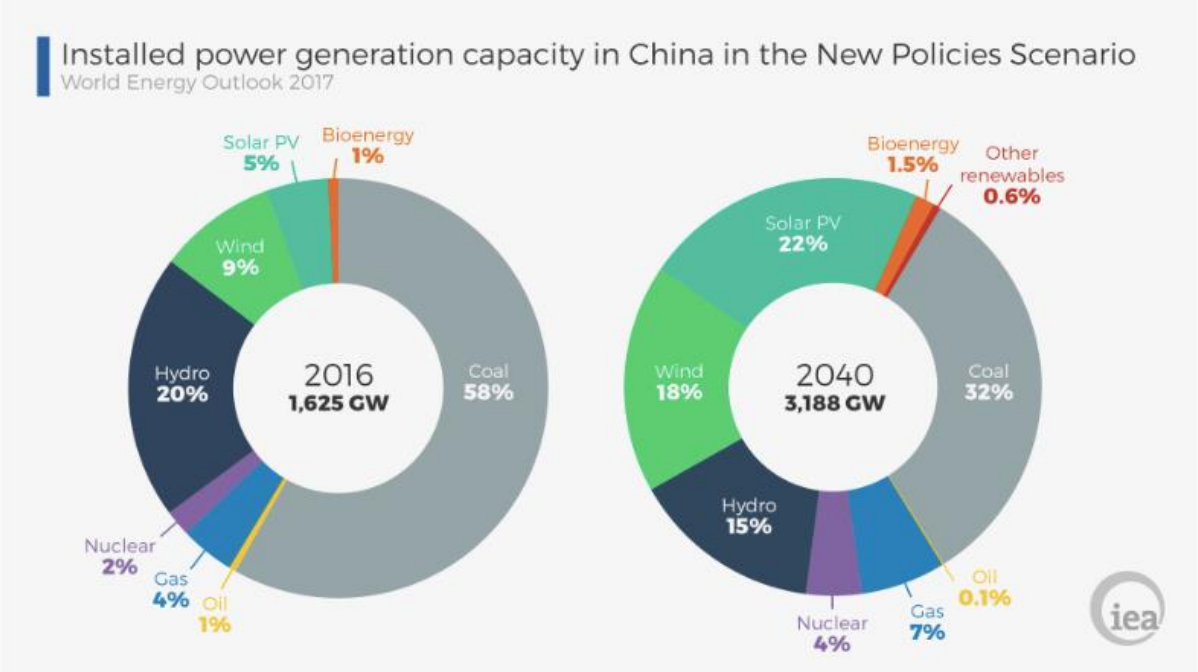


Figure 1 The proportion of power generation capacity of China in 2016 and 2040

Source: Word Energy Outlook 2017: China

The Clean Development Mechanism (CDM) aims to meet the Kyoto target of reducing greenhouse gas emissions by allowing industrialized countries with emission reduction commitment under the Kyoto Protocol to implement the emission reduction project in developing counties. Since the marginal abatement costs in developing countries are relatively lower than those in the industrialized regions, these projects can earn economic income from certified emission reductions (CERs) credits, which equates to one tone of CO_2. And most of the CDM projects are renewable energy projects. China, as the biggest Non-Annex I country, ratifies its position since 2002. The CDM project, as the additional investment opportunity for renewable energy, provides good platform for China to implement more renewable energy in the local area. Since each CDM project in China will obtain financial assistance and technology transfer from developed (annex I) countries to undertake emission reduction project. Implement the renewable energy CDM projects can help China to reach its national sustainable development goal due to its positive externality to the environment, nature, and society.

According to Figure 2, there are 6013 Chinese CDM projects registered or registering under UNFCCC by the end of May 2019. The first CDM project registered in the year 2004, since then, the number of projects undergone increasingly rise before the year 2012. However, the number of CDM projects experienced a deep drop in 2014 after its peak situation in 2013.

Among all types of renewable energy projects, the wind hydro CDM projects dominant the large share. By 31st May 2019, the wind and hydro CDM projects are 1510 and 2127, respectively, whose proportion to total CDM projects is 19 percent and 27 percent, respectively.

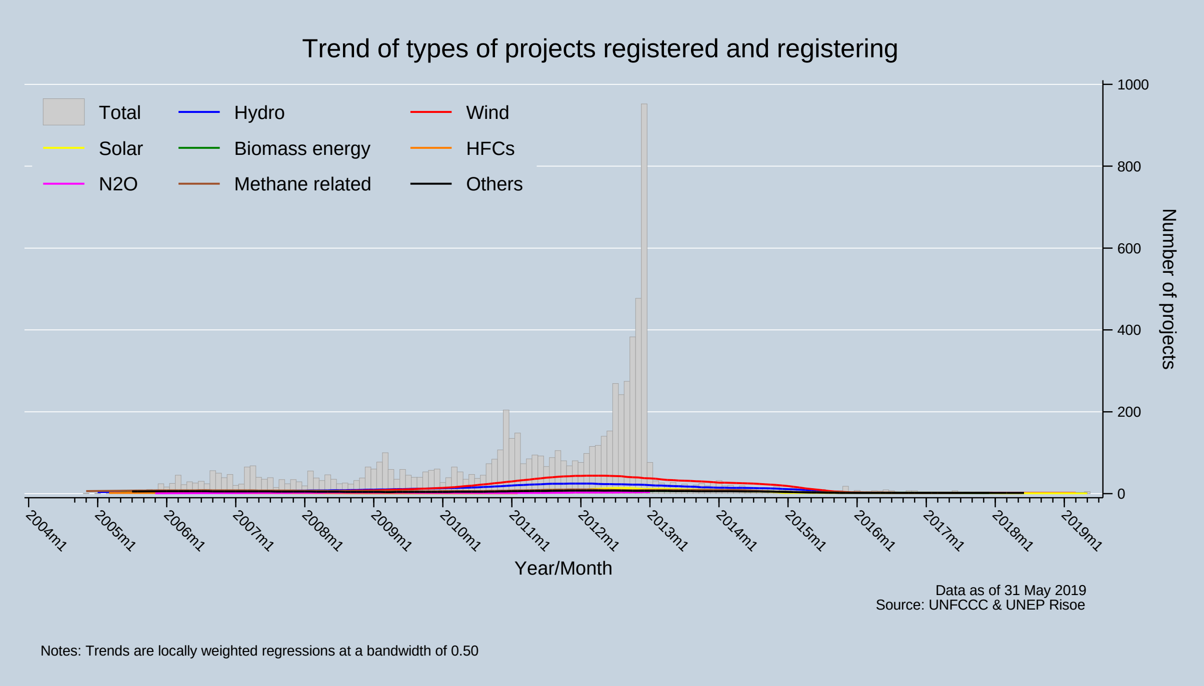


Figure 2 Trend of registered and registering CDM projects in China 31st May 2019

Source: UNFCCC

1.2 Aim and outline

The purpose of the thesis is to compare the benefits of wind power to hydropower CDM projects in China to see which renewable energy technology performs better under deterministic and stochastic conditions. The Cost-Benefit analysis is used to examine each and overall wind and hydro CDM projects in China. The impact of the ancillary benefit of two renewable energy projects is evaluated by comparing the private and social benefits of these two types of energy projects. Besides, Monte Carlo simulation is applied to evaluate the impact on net benefit resulting from relative uncertainty factors changes in stochastic conditions. Then, by examining the probability of negative total net benefit in two types of CDM projects, it shown the risk of promoting the CDM projects in China by private incentive. Furthermore, the thesis also evaluates the benefit-cost ratio to determine which renewable projects are more efficient and valuable.

Cost-Benefit analysis is applied to calculate the net benefit under deterministic cases, while Monte Carlo simulation is used in stochastic cases to evaluate the uncertainty variable. This thesis is organized as follows: literature review on cost and benefits of CDM projects in China and its ancillary benefits on human health are in section 2; the methodologies are in section 3; description of data and probability distribution for the uncertain parameter is in section 4; results of cost-benefit analysis of wind and hydropower projects and Monte Carlo simulation analysis on the uncertain ancillary benefit and sensitivity analysis of discount rate are in section 5; conclusion and some discussions are in section 6.

2 Literature review

Studies analyzing the costs and benefits of Chinese wind or hydro CDM projects are discussed first, followed by papers that focus on the ancillary benefits of CDM projects.

Cost-Benefit Analysis of Chinese CDM projects

Aunan *et al*. (2004) investigate the socio-economic costs and benefits of six CO2 abatement plans in Shanxi province, China. First, reduced population-weighted exposure for particles and SO2 are estimated resulting from implementing these CO2 mitigation plans. Second, exposure–response functions from Chinese and international epidemiological studies are applied to assess human health benefits and value it. Then, by subtracting the monetary term of health benefits per ton CO_2 reduction from the abatement costs, it obtains net costs of CO_2 reductions. The result shows that all six abatement plans bring negative costs when using central estimates of health benefits. Besides, the rankings of abatement measures according to cost-effectiveness are changed when considering the co-benefits, since the different plans have different impacts on local pollution and human health. The author's assessment of the CO_2 reduction plan in Shanxi indicates that these measures produce considerable ancillary benefits and profitable in monetary term. So, the abatement plans discussed in this paper are eligible under CDM to assist the host country to achieve human health improvement besides emissions reduction.

Partridge and Gamkhar (2010) investigate 460 registered CDM projects before a cut- off date of 1 April 2009 in China, which are all grid-connected generation projects based on wind, natural gas, or small hydro power. The paper first defines the baseline generation power project and uses its generation cost as the basis for calculation marginal abatement cost in the same region. It is then quantifying the value of external damage avoided per kilowatt hour of electricity generated by a specific project, since the three types of projects could bring quantifiable benefits to human health due to using zero or lower-emission technology compared to a coal-fired plant. The value of CERs revenue per ton of CO_2 and benefit to public health consists of marginal abatement benefit. The overall cost-benefit analysis is applied by comparing each technology's marginal abatement cost to marginal abatement benefit. The result of net gain or cost indicates whether these projects provide overall profit to China. Wind power projects generate negative net benefit (-9.4\$/tCO_2) and natural gas plants are close to zero gain (1.8$/t$CO_2$).In the contrast, the small hydro projects are so profitable (41$/t$CO_2$) that authors doubt it can be established without the CDM financial support.

Yang *et al.* (2010) analyze the wind power investment risks under uncertain CDM benefits in China. The model is taking account stochastic carbon price to evaluate the impact of uncertain CDM benefits on the net present value of Chinese wind power projects. Incorporated with the Monte Carlo simulation and the method of real options analysis, paper performs calculation with 10,000 times to illustrate the net present value distribution under stochastically changed CERs price from 2008 to 2022 for three different scenarios. Comparing the expected net present value under three scenarios to under constant CERs price, respectively, it quantifies the risk premium due to the uncertain carbon price and how much the government carbon price cap and floor policy could reduce the risk premium. The first scenario set the initial CERs price at USD 13.5/unit and assumes the price change stochastically, which produces $41/kW risk premium. The second scenario starts at the same initial CERs price and assumes a price shock happens in 2012, which produces $77/kW risk premium. The third scenario is the most complicated one, considering an uncertain CERs price with shock at 2012 and price cap and floor during 2008 and 2020, which produce a $52/kW risk premium. The key finding of the paper is that uncertain CDM benefits will significantly affect the net present value of wind power projects-The more uncertain the CERs price, the higher risk premiums. The price cap and floor policy will hedge the risk to some degree.

The paper Morimoto and Hope (2012) focus on the Chinese Three Gorges project- the national largest hydro project nowadays. This paper applies the comprehensive probabilistic Cost-Benefit Analysis to investigate whether the project is worth of carrying out and contribute to regional sustainable development. In order to examine the profitability of the project, first set up the present value model and assume all the parameters in the model follow either triangular or Beta distribution, with assigned a minimum, most likely, and maximum value. Then 10,000 Monte Carlo simulations are run to obtain the probability distribution of the net present value of the Three Gorges project. The value of the mean cumulative net present value with a 5% discount rate is the US $ 51 billion. Finally, two among six parameters are found to have a significant impact on the cumulative NPV when making sensitivity analysis. Besides, the discount rate has a strong effect on the value of the outcome. The mean net present value becomes negative if the time preference is approximately more massive than 5%. Thus, this analysis indicates that the net present value is sensitivity to the choice of discount rates.

Wang *et al.* (2016) propose that waste to energy is a form of energy recovery, which is regarded as effective waste management. Taking account of its impact on global warming, this study applies cost-benefit analysis of greenhouse gas emission for two energy recovery technologies: incineration with combined power and heat and landfill disposal with gas utilization. The paper estimated costs and benefits per ton of CERs for 10 waste to energy CDM projects in North and 10 in South cities in China. For the CDM projects, the CERs revenue is an important benefit when the price of CERs is about \$10/t CO_2 before 2011. However, CERs price decreased rapidly. By 2013, CERs price had dropped to below \$1/t CO_2. The CERs revenue benefit is lowest in 2015 and has little impact on benefit. Therefore, this study set two scenarios without the CERs revenue: benefit from recovery energy revenues and benefit from these revenues plus gate fee revenues. The result indicate that incineration with combined power and heat is more beneficial from the point of greenhouse emission reduction and the ratio of CERs revenue to benefit is significant before the year 2011. However, the gate fee revenue from the government becomes more important for both waste to energy CDM projects when CERs price decrease. This study suggests there exists a considerable emission reduction potential in China by waste management, and the geographical region has an impact on the selection of waste recovery methods.

Ancillary benefits of Chinese CDM projects

Bell *et al*. (2008) summarize several studies about the ancillary benefit of greenhouse gas policies for a variety of places, pollutants, and policies. These studies are based on the notion that greenhouse gas mitigation policies can provide co-benefits in terms of short-term improvements in air quality and associated health benefits. The paper first evaluates the reductions in local air pollutants resulting from government policies. Then it estimates the impacts on human health from changes in air pollutant concentrations and economic valuation of avoided health consequences. Among all health outcomes, the avoided premature mortality associated with environmental policies is usually the most substantial category benefit. The merits and demerits of different methods used in various policies and regions are examined. In the end, strong evidence from multiple pieces of researches shows that public and economic benefits of ancillary benefits associated with greenhouse gas mitigation strategies are massive. Further, the authors also point out it is possibility to underestimates the ancillary benefits since there are several important health and economic endpoints cannot be quantified in monetary term.

Vennemo *et al.* (2006) synthesize a large number of researches on China's energy-related CDM potential, estimation of local air pollution reductions and ancillary benefits in monetary term resulting from CO_2 abatement. Since the measures to reduce CO_2 emissions can also reduce the emission of total suspended particles and SO_2, it estimates that realizing the Chinese energy-related CDM potential will abate SO_2 emission from 0.5 to almost 3 million tons and reduce particular from 0.2 to 1.6 million tons. Then paper summarizes that approximately between 34 and 161 lives will be saved from per million tons of CO_2 mitigation. According to the estimated total million ton of CO_2 reduction annually, the range of premature lives saved is between 2,700 to 3,800 every year. This result indicates the significant ancillary benefit of the CO_2 abatement project. Therefore, the authors suggest that the government can consider these co-benefits when making policies.

Zhang and Wang (2011) propose a semi-parametric partially linear model to assess the ancillary benefit of CDM projects by using the relationship that CO_2 and SO_2 are co-pollutants of fossil-fuel combustion. However, in contrast to the model prediction, empirical results show CDM projects do not have statistically a significant impact on reducing the sulfur dioxide emissions at the Chinese prefecture-level. Therefore, findings cast doubt on additionality for Chinese CDM projects; that is, projects may occur even without the compensation of carbon credits. Also, paper performs robustness check separately to four CDM project categories: hydropower, wind energy, energy efficiency, and other activities. For power plants, empirical results do not support the notion that these projects could lower the industrial SO_2 emission. Finally, the authors present that the result is limited by the available data, only the CDM projects registered before 2008 are included, whose number is relatively small. However, the micro-econometric approach applied in that paper is worth further tests the ancillary benefit effect when the number of registered CDM increases.

Zhao and Guo (2015) imply a hybrid method of multi-criteria decision making was applied to estimate the external benefit of wind, solar photovoltaic and biomass power in China. The purpose of evaluating the external benefits of renewable energy power in China is to help the Chinese government to set energy policies more effectively and efficiently. In this paper, the external benefit evaluation index system takes account of the economic, social, and environmental benefit criteria. Each criterion includes several indexes for comprehensive calculation. Then, the hybrid multi-criteria decision-making method employed in this paper for three renewable energy power in China. The results indicate that solar photovoltaic power ranks the highest external benefit, followed by wind and biomass power. According to the results, it courage more national and regional support policies to promote solar photovoltaic power to reach more sustainable development.

Murata *et al.* (2015) evaluate the effectiveness of the co-benefits of reducing air pollutant emission for renewable energy CDM projects in China and India. In this paper, the ancillary benefits of CDM projects are attributed to air pollutant mitigation resulting from the clean electricity supply from renewable energy power plants. Therefore, the monetary value of co-benefit is measured as the marginal damage cost of air pollutants reduction. This study evaluates the marginal damage cost of pollutants by quantified it as damage factors to human health and social estates. By modifying the corresponding values obtained under Japanese conditions based on life-cycle assessment, it uses a formula to estimate the damage factors of air pollutants in other Asian countries from damager factors in Japan. Population density and gross domestic product are normalized to that of Japan in the base year as the adjustment factor for the impact on human health and social estates, respectively. According to the formula 2 in that paper, the future damage cost is equal to the willingness to pay for a reduction in the damage multiply by damager factor and ratio of gross domestic product per person. The estimation for China is based on average multiplying willingness to pay value obtained in Beijing, Shanghai, and Taiyuan city. Then the marginal damage costs associated with per ton of reduced SOx, NOx, and PM emissions in China are shown in Table 1, which is 1.0, 0.88, and 0.03 $/kg in the year 2016, respectively. The results show the co-benefits of reducing air pollutant per carbon dioxide mitigation is much lower than the figure investigated in previous studies. Because the amount of air pollutant emission is predicted to decrease in China in the future, the co-benefits of renewable energy CDM projects will not be significant as previous studies.

Cost Benefit Analysis of renewable energy resource worldwide in recent years

Zhao *et al.* (2014) comprehensively analyzed the costs and benefits of renewable energy power subsidy supported by the Chinese government from 2006 to April 2011. Renewable energy electricity power has developed rapidly since the Renewable Energy Act is implemented in China. The analysis results indicate that the cost of renewable energy power technologies subsidy (including wind power, biomass power, and solar PV power generation) was 0.248 RMB/kWh between 2006 and April 2011.The benefits of China's renewable energy power subsidy, including environmental benefit, energy security, technological innovation, economic development. Specifically, the environmental benefit amounted to 17.88 billion RMB, and other benefits were also significant. However, the authors also found that due to the inconsistent between electricity generation and power grid consumers, abundant power generation obtained the subsidy cannot be used by target consumers and results in being abandoned. The Chinese government is needed to pay attention to solve the problem of inconsistent to avoided the national capital resources waste.

Margarita and Pablo (2016) state that the deployment of electricity from renewable energy sources brings two main benefits in the European Union, which are CO2 emissions mitigation and fossil-fuel savings. These benefits are quantified in monetary terms in this paper. Regarding the cost perspective, only policy support cost has been considered and not system generation costs, which would be needed for a cost-benefit analysis. Therefore, a cost-benefit analysis is not carried out in this paper. Support costs have been defined as and obtained from the annual cost of incentives paid to renewable energy sources electricity generation as the result of national support schemes. A methodology proposed by the United Nations Framework Convention on Climate Change has been used to evaluate the CO_2 emission reduction and fossil-fuel savings. And this methodology is commonly used to calculate the baseline in clean development mechanism projects. The results of this paper show that two main benefits (CO_2 emission reduction and fossil-fuel savings) are slightly lower than those policy support costs. Besides, fossil fuel savings are higher than the savings associated with CO2 emissions reductions. However, a country-based analysis shows that the benefits outweigh the policy costs in a majority of European Union countries, e.g., all except Belgium, the Czech Republic, Germany, Spain, Italy, Poland, and the United Kingdom. Furthermore, different renewable energy technology shows the different cost-benefit result: the benefits are above policy support cost for hydro and wind, but below those costs for bioenergy, solar photovoltaics and other renewable energy resources in Europe.

Atanasoae *et al.* (2019) present that the electricity generation from renewable sources, which is over 1 MW capacity, is supported by the mechanism of mandatory quotas combined with the certificate’s transaction in Romania. However, this is no support for electricity generation from small scale renewable energy sources recently. This paper analyzes the economic viability of electricity generation from small scale renewable energy source by using a cost-benefit analysis approach when Romania promote a feed-in tariff support scheme. The financial analysis indications were used for economic evaluation: the cash flow, the payback period, the net present value, and the internal rate of return. The results show that a lower payback period and a higher internal rate of return are obtained if the self- consumption has a more significant share of the total amount of renewable energy produced. This finding suggests that the sizing of the renewable energy source should be based on the consumer's electricity demand. The specific investment costs of renewable energy sources are currently declining. Under these conditions, consumers can save money by generating electricity from renewable sources rather than purchasing it from the public network.

Liang *et al.* (2019) use a Long-range Energy Alternative Planning system model to simulate the expected development path of China's power sector range from 2015 to 2050. Three scenarios, including a base scenario, a renewable energy policy scenario, and a technological progress scenario, are used to evaluate the costs and benefits of renewable energy and technologies. The simulation results indicate that the cost of power generation would increase at least 2.31 trillion RMB and CO_2 emissions would decrease 35.8 billion tones by the end of 2050. Moreover, when capacity factors of renewable energy electricity grow 1 percent, the cumulative CO_2 abatement decrease 979 million tones and the average CO_2 emission decrease by 5.56 RMB/tCO_2 during the target research period. The authors propose several policy suggestions for China government, such as implement the gas-fired power and nuclear power to reach a low-carbon electricity target.

The literature review shows that the economic method of Cost-Benefit Analysis is widely used in the appraisal of CDM project or greenhouse gas mitigation policy in China. (Aunan *et al.*, 2004; Partridge and Gamkhar, 2010; Morimoto and Hope, 2012; Wang *et al.*, 2016) Traditional Cost-Benefit Analysis is applied to evaluate different projects or measures by calculating the net benefits or net cost, respectively (Aunan *et al.,*2004; Partridge and Gamkhar, 2010). While the method of comprehensive probabilistic CBA is adopted by Morimoto and Hope (2012) to investigate whether the Chinese largest hydro project is worth of implementation from the aspect of regional sustainable development. For risk and uncertainty, both Yang *et al.* (2010) and Morimoto and Hope (2012) use Monte Carlo simulation to assess the economic impact on the net present value resulting from stochastic factors. Mainly, Yang *et al.* (2010) incorporated the Monte Carlo simulation with the method of real options analysis to study the investment risks under uncertain CDM benefits resulting from stochastic CERs price in China. Besides, Morimoto and Hope (2012) also make the sensitivity analysis of net present value responding to the discount rate changes.

The ancillary benefit of human health impact is an important issue when quantifying the social benefits. Zhang and Wang (2011) propose the econometric method of a semi-parametric partially linear model to assess the ancillary benefit of CDM projects in China. Based on a large number of research and studies, Bell et al. (2008) and Vennemo *et al.* (2006) synthesize ancillary benefits of improved air quality resulting from pollutant mitigation projects or policies. A hybrid method of multi-criteria decision making was applied to estimate the external benefit of power in China by Zhao and Guo (2015). Murata *et al.* (2015) evaluate the effectiveness of the co-benefits of reducing air pollutant emission for renewable energy CDM projects in China by modifying the corresponding values obtained under Japanese conditions basis. Additionally, the papers about Cost-Benefit analysis of renewable energy sources worldwide help inspire thinking and discussion. Zhao *et al.* (2014) assess the environmental, energy security, technological innovation, economic development benefit of renewable energy power subsidy in China. Margarita and Pablo (2016) found that the benefit of renewable energy electricity is highly sensitive to the CO_2 price used in the calculations of the CO_2 emissions reductions as a result of renewable energy deployment. Atanasoae *et al.* (2019) use several financial indicators when performing cost-benefit analysis to investigate small scale renewable energy electricity generation in Romania. And Liang *et al.* (2019) examine the relationship between capacity factors of renewable energy electricity and the cumulative CO_2 abatement from 2015 to 2050 in China. The thesis here implements the traditional Cost-Benefit method to analyze the wind and hydro CDM projects in China and use the Monte Carlo simulation to evaluate the impact from uncertain factors (Yang *et al.*, 2010; Atanasoae *et al.,2019*). When comparing two power projects, the Cost-Benefit ratio is used as the index to analyze which project performs better.

3 Methodology

This section introduces the method applied in this thesis, that is Cost-Benefit Analysis. Then it briefly discusses the Monte Carlo simulation analysis to assess the uncertainty factor. It also states the deterministic model to calculate the private net benefit and social net benefit for wind and hydro power CDM projects in China.

3.1 Cost-benefit Analysis

Cost-Benefit analysis is a policy assessment methodology to predict outcomes of policy in monetary terms. The process of analysis includes the systematic collecting and exam the final impact as cost (negative) and benefit (positive) of object policy, valuating such pros and cons in monetary term according to the time and location of the policy, then calculating the net social benefit (total social benefits minus total social costs). The Cost-Benefit Analysis can be implemented widely to business or government policies, programs, projects, regulations, and interventions. The purpose of this method is to allocate scarce resources efficiently after making the rational comparative analysis based on optional projects or policies (Boardman *et al.*, 2006).

A few types of Cost-Benefit Analysis are available for the researcher to choose. *Ex ante* Cost-Benefit Analysis, which is conducted before the decision to judge whether or not social resources should be allocated to a particular project or specific policy that is under consideration. While *Ex post* Cost-Benefit Analysis is made after the project has ended. This method contributes to learning the success or failure experienced by the social decision-maker. Cost-Benefit Analysis studies are performed ongoing project or policy, which is known as the *in medias res* analysis, which can provide useful information to predict the cost and benefit. Both the *ex ante* and *in medias res* analysis can be used for decision-making purposes since these methods have the potential possibilities to relocate the social resource (Boardman et al., 2006). This thesis chooses *in medias res* analysis because almost all the targeted registered wind and hydro CDM projects are already in operation.

3.2 Monte Carlo Simulation Analysis

The core of *Monte Carlo Analysis* is playing games lots of times to elicit a probability distribution of consequences. It plays an important role in the estimation of a statistical factors whose properties cannot be decided by mathematical techniques alone. Comparing to other sensitivity analyses, *Monte Carlo sensitivity analysis* makes the investigation more comprehensive and effective and practical. The method can apply with lots of uncertainty in the form of assumed parameters, and state the variance. When alternative policies show the close expected value of the net benefit, decision-makers will consider the policy with smaller variance owing to the larger risk of uncertainty to reach the expected net benefit (Boardman *et al.*, 2006). The program such as Crystal Ball, DATA, and R have commonly applied to analyses the data.

3.3 Theoretical model

The CDM projects in developing countries can earn monetary revenue by selling generated electricity to domestic grid companies, at the same time gain extra income from selling CERs after achieving the target amount of carbon dioxide emission reductions. The two main costs of renewable energy CDM project is annualized total investment and the operation and maintenance cost. The net benefit equals revenues minus cost. So the PNB and SNB of each wind or hydro CDM project in China are calculated by the deterministic equation 1 and 2:

$$PNB_i = \sum_{t=0}^{T} \rho^t [PG_{it} * TA_{it} + P * ER_{it} - (AC_{it} + OM_{it})] \ldots\ldots\ldots\ldots 1$$

$$SNB_i = \sum_{t=0}^{T} \rho^t [PG_{it} * TA_{it} + P * ER_{it} - (AC_{it} + OM_{it}) + AB_{it}] \ldots\ldots\ldots\ldots 2$$

i: Each project
t: Time in year
T: Life spam of project
ρ : Discount factor

PNB_i: Private net benefit for project i
SNB_i: Social net benefit for project i
PG_i: Annual power generation of project i
TA_i: Tariff of electricity listed in each power project

P: Deterministic price of CERs
ER_i*: Expected annual CO2 emission reduction of each project*
AC_i*: Annualized fixed cost for every project*
OM_i*: Annual operation and maintenance cost*
AB_i*: Ancillary benefit of project i*

Here, both PNB and SNB is expected annual value in monetary term taking account the time value. The Discount factor (ρ) is obtained according to the Table of Present Value of Annuity Factors (Ordinary Annuity) The ER is the estimated emission reductions in metric tons of CO_2 equivalent per year stated by the project participants. The revenue of selling the CERs is equal to the ER multiply by the price of CERs. Annual fixed cost is calculated from total static investment, and the average fixed cost, which only considers the lifespan of each project. The OM cost obtains from each project design documents of wind or hydro CDM projects.

Equation 3 below is the ancillary benefit, which assesses the economic value of avoided premature mortality resulting from the implementation the renewable CDM projects in China. The total amount of life saved is equal to CAD multiply by ER. And the ancillary benefit obtains from multiple the total amount of life saved multiply by statistical life in monetary term.

$AB_i = (CAD * ER_i) * VSL$ ……………………………..3

AB_i*: Ancillary benefit of each renewable energy project*

CAD: Cases of avoided death per million tons of carbon dioxide reduction

ER_i*: Expected annual* CO_2 *emission reduction of each project*
VSL: Value of a statistical life in monetary term

A lot of ancillary benefits result from air quality improvement by substitution of the fossil-fuel energy projects with renewable energy CDM projects (Bell *et al*., 2008), here only focuses on its impact on economic valuation of human life saved. This is because the economic valuation of life occupies a large proportion of total social benefits. The Clean Air Act in the U.S. reports that it brings $100 billion annually for reduced premature mortality out of $120 billion in total benefits when air quality improved. The proportion is 83.3 percent of all the social benefits after the clean air carry on (Bell *et al.,* 2008). The amount of citizen premature death will decrease as the result of the implementation of renewable energy CDM projects in China. Its economic value accounts for 62 percent of total social welfare rescued from air pollution in 2005 (Matus *et al.,* 2012). The cases of avoided death per million tons of carbon dioxide reduction in this thesis adopts a figure synthesized from Vennemo *et al.* (2006) to both wind and hydro CDM projects in China. The process of how to obtain this figure is stated in detail in section 4.2. Besides, it is difficult to obtain the data of the economic value of citizen disease avoided in China, which will lower the real ancillary social benefit to some extent.

To calculate the overall private and public net benefit for wind and hydro CDM projects in section 5.2, it is necessary to present an equation to separate the uncertain variable from certain variables. After modifying equations 1, 2, and 3, equations 4 and 5 address certain and uncertain variables.

$$PNB = \sum_{i=1}^{N} \sum_{t=0}^{T} \rho^t [PG_{it} * TA_{it} + \tilde{P} * ER_{it} - (AC_{it} + OM_{it})] \ldots\ldots\ldots\ldots\ldots\ldots 4$$

$$SNB = \sum_{i=1}^{N} \sum_{t=0}^{T} \rho^t \left[PG_{it} * TA_{it} + \left(\tilde{P} + \widetilde{CAD} * \widetilde{VSL}\right) * ER_{it} - (AC_{it} + OM_{it})\right] \ldots\ldots 5$$

N: number of projects

In equations 4 and 5, the certain variables include the monetary value of electricity generation ($PG_{it} * TA_{it}$), the annual fixed cost (AC_{it}), annual operation and maintenance cost (OM_{it}), and the annual carbon dioxide emission reduction (ER_{it}). The only uncertain variable of PNB is the price of CERs ($\tilde{P}$) in equation 4. And there are three uncertain variables related to SNB in equation 5, which is $\tilde{P}$; the value of case of avoided deaths ($\widetilde{CAD}$) and a statistical life vale ($\widetilde{VSL}$). Discussion about finding probability distribution for three uncertain parameters is presented in the following section.

4 Empirical data

4.1 Description of deterministic variables

The data about wind and hydro power CDM comes from the project design documents, which are available on the United Nations Framework Convention on Climate Change (UNFCCC) website. This thesis analyzes the CDM projects that register prior to the act-off date of 30 November 2012 (UNFCCC). The total amount of wind power and hydro-power CDM project in China was 1077 and 1020, respectively. Among them, 21 wind and 26 hydro projects lack the critical data needed for analysis in this thesis. Therefore, the sample of wind and hydro projects is 1056 and 994 projects, respectively. The sample projects state the annual amount of electricity delivered to the grid, the expected tariff of specific project, annual expected emission reduction of CO_2, total static investment, annual operating and maintenance costs (OM), and expected life year in each CDM project design documentary. The statistical analysis of wind and hydro power CDM projects in Tables 1 and 2 respectively states mean and total level, the minimum and maximum, and standard deviation.

The life span of each project and operating and maintenance costs need to make some adjustments. The life span of the project consists of construction and operation year. Normally the average year of construction is around one year. Therefore, the life span of each renewable projects is equal to operation year plus one-year construction. Besides, 351 wind projects and 179 hydro projects lack annual maintenance costs. Therefore, this study uses the method of empirical results to calculate CDM project maintenance cost, which is a proportion of operating and maintenance cost to annual fixed cost. The empirical mean proportion is 25 percentage and 24 percentage for wind and hydro projects, respectively. The slash in Table 1 and 2 mean it is useless to sum the per price for electricity tariff and year.

Table 1 The statistical data of wind power CDM projects in China

	Mean	Min	Max	Total	Stand dev
Annual output (MWh）	123,157.06	103.50	995,254.00	130,053,853	102,117.55
Electricity tariff (Yuan[1]/kWh)	0.58	0.23	1.14		0.07
Reductions（million ton）	0.12	0.02	0.89	124.58	0.09
Total static investment	54.06	9.99	431.29	57,091.55	37.57
OM (million €)	1.35	0.03	10.24	1422.95	0.94
Total year	21.15	10	30		0.86
Annual cost (million €)	5.5	1.01	40.96	5809.67	3.78

Source: own calculation based on data from project design documents (PDDs) on UNFCCC.

Table 2 The statistical data of hydro power CDM projects in China

	Mean	Min	Max	Total	Stand dev
Annual output (MWh）	154,075.00	357.80	3,763,090.00	153,150,054	276,226.95
Electricity tariff Yuan/kWh	0.25	0.14	0.55		0.06
CO_2 Reductions （million ton）	0.13	0.01	2.95	127.25	0.21
Total static investment	30.39	0.71	763.30	30,212.10	59.94
OM (million €)	0.66	0.02	22.79	651.77	1.36
Total year	25.57	20.50	50		4.72
Annual cost (million €)	2.81	0.07	64.41	2794.58	5.41

Source: own calculation based on data from project design documents (PDDs) on UNFCCC.

By comparing the mean total year of wind and hydro CDM projects, the hydro projects show a longer period (25.57 years) than wind projects (21.15 years). The mean electricity tariff of wind is much higher than the hydro project. In addition, wind power projects indicate higher fixed and operating and maintenance cost. Coincidently, the annual emission reductions of wind projects are 124.577 million tons, which is very close to hydro 127.248 million tons. It indicates wind and hydro CDM projects paly an almost equal role for reducing the CO_2 emission in China.

The private and public net benefits in equations 1, 2, 4, and 5 are calculated, taking account of

---

[1] Yuan is Chinese basic currency.

time value. Selecting the appropriate discount rate is crucial for cost-benefit analysis. Boardman *et al*. (2006) recommend using a single discount rate rather than multiple to calculate the net social benefit of the project whose life span is less than 50 years. Almost 94% of wind projects with 21 years of life length and none beyond 30 years. The hydro projects show quite diverse in life span, but all the hydro projects are within 50-years length. Therefore, this thesis assumes a constant (time-invariant) discount rate to calculate both PNB and SNB. Besides, usually the social discount rate is recommended to estimate the value of government policy and public projects. Hao and Zou (2009) used the social discount rate of 8 percent to evaluate medium and long-term projects in China. So, this thesis adopts 8 percent discount rate to calculate PNB and SNB for each wind and hydro CDM project. According to the Table of Present Value of Annuity Factors (Ordinary Annuity), I can obtain the corresponding discount factor for different CDM projects with different life span.

4.2 Specify distributions for uncertain variables.

The only uncertain parameter related to PNB in equation 4 is the price of CERs (P). However, there are three uncertain variables related to SNB in equation 5, which are P, case of avoided deaths (CAD) and the value of a statistical life (VSL). Before making Monte Carlo simulation, these three uncertain parameters need to find probability distributions for stochastic calculation of the net benefit for CDM projects.

The price of CERs is determined by demand and supply relationships in the carbon trade market. Generally, normal distribution is often assumed in natural and social sciences to represent real-valued random variables whose distributions are not known. The thesis here assumes that the distribution of CERs price follows a normal distribution. According to the estimated figures made Bellassen *et al*. (2014), the CERs price is expected to be around €8.5/t CO_2 over the next decade. Therefore, it feasible to apply the normal distribution with a mean of €8.5/t CO_2 and a standard deviation of €3.45/t CO_2 to the parameter price of CERs (Bellassen *et al.*,2012) when making private and social benefit valuation. In reality, CERs price in October 2012 is only around 1€/ton, which is much lower than the expected price. The strategies of increasing the demand for CERs or decreasing the supply by postponing the registration of CDM projects will be adopted to trigger the low CERs price. So, it is more reasonable to use the annual average CERs price to calculate the annual net benefit than use spot price at a specific time.

For the parameter case of avoided death (CAD), epidemiological researches studied the impact on the amount of mortality from CO_2 emission deduction. The factory and industry will release fewer air pollutants when there is emission abatement. The total amount of population who are exposed to harmful pollutants, such as SO_2 and total suspended particles, is measured using local air quality monitoring data in China. Exposure-response functions from Chinese epidemiological studies are usually applied to estimate population health status resulting from CO_2 abatement measures or policies. The amount of pollution-induced fatal and non-fatal outcomes, such as acute respiratory symptoms, chronic respiratory symptoms, asthma attack, cough, mortality death, is calculated. And its economic evaluation of reduced health is measured based on the willingness-to-pay approach (Vennemo *et al.*,2006). Vennemo *et al.* synthesized a large number of researches about CDM projects in China; then it shows a conclusive estimation of life saved based on all relevant. The mean and standard deviation of CAD is estimated with 68 percent confidence interval. Boardman *et al.* (2006) suggested it allows approximating the unknown parameter of the normal distribution with mean and standard deviation given by their empirical estimates. Therefore, this thesis applies normal distribution to CAD with a mean (μ=73 person) and standard variance (σ=3.8 person) per million tons CO_2, which is listed by Vennemo *et al.* (2006). However, use the same CAD for both wind and hydro CDM projects will bring controversy in accurately estimating the ancillary benefit and social net benefit, which will be discussed in section 6.

For VSL, no theory or empirical data shows a specific distribution for it, but Boardman *et al.* (2006) suggested it is reasonable to apply a uniform distribution for such unknown variables. The assumption of this distribution is that the valuation between the upper and lower bound have an equally probability (Boardman *et al.*, 2006). So, this thesis assumes the VSL shows the uniform distribution with maximum and minimum value. Here the method used to determine the bound value of VSL is synthesizing the empirical result, then adopting the lowest and highest value among all researches methods.

Although no formal method found to evaluate the avoided death resulting from better air quality in the environmental economics field, there are various optional approaches for estimation. One of these is to carry out a questionnaire to ask people randomly how much wealth they will give up for reducing the risk of premature death caused by air pollution. However, no such kind of empirical data can be obtained to apply in the wind and hydro CDMs projects. One alternative method is to adjust according to the benchmark VSL obtaining from other countries. The thesis uses the mean value of statistical life and contingent valuation studies in the United States as a benchmark economic value. The range of statistical life value is estimated from $7.4-8.9 million (in 2006$) in America (The benefits and costs of the Clean Air Act from 1990 to 2020). Since the Gross National Income per capita of China in 2012 is ten times lower than the United States (World Bank, 2012). It is feasible to obtain VSL in China by downscale the VSL in the U.S. ten times. Therefore, the range of VSL in China is between $0.74 and $0.89 million. The reason for such adjustment is that numerous reliable studies have applied on assessment of the monetary value of VSL in the United States, in addition, the Gross National Income per capita is positive and linear correlated with the value of VSL (Vennemo *et al.* 2006). Besides, Miller (2000) proposed another method to evaluate VSL, which is approximately equal to 120 multiples of Gross Domestic production per capita of that country. By multiplying the related factor 120 to the average value of GDP per capita of China in 2012, which is $6,093(Word Bank$_2$, 2012). The estimated value of Chines statistical life in this method can be obtained by multiplying $6,093 by 120, which is approximately $0.731million. By combination results of two methods, the range of VSL varies from $0.731million to $0.89 million, which from € 0.511 to € 0.623 million in Euro.

The two approaches stated above are widely used and bring useful measurement to measure VSL value. However, when converting the benchmark VSL based on wage-level in the U.S. to China, there exist deviation by adopting the Gross National Income per capita per capital ratio between two countries as the converting factor. Besides, the component for income for each human being in two countries is different, as the proportion of salary income, realized capital income, dividends, interests, and inheritance. Therefore, the deviation will be high when converting the VSL. In addition, the monetary value of people’s life is significantly related to their education level. Typically, individuals who receive a good education is tend to get high-wage work opportunities and have high life evaluations. As the developing country, the average national education level in China is not as good as the U.S. There exists the risk of overestimating the VSL value in China when ignoring the education level difference between the two countries. The other approach of calculating the VSL by multiplying 120 of GDP per capital proposed by Miller is a crude method. Because the correlation between GDP and VSL is not perfectly simple linear.

In conclusion, here applies the normal distribution to the parameter price of CERs with mean €8.5/t CO_2 and deviation €3.45/t CO_2. The amount of avoided death (CAD) is also used the normal distribution with mean 73 person per million tons CO_2 reduction and deviation of 3.8 person. The third uncertainty factor is the value of a statistical life (VSL), which is applied the uniform distribution with €0.511-€0.623 million as its boundary.

5 Analysis and results

The statistic results are shown in the form of corresponding Figures and Tables after running the theoretical equations in section3.The distribution of deterministic calculation of net benefit for each wind and hydro CDM projects is shown in the corresponding histogram. Then Monte Carlo simulation is used to determine how uncertainty factors will impact the total private and social benefit of wind and hydro CDM projects, respectively. Sensitivity analysis is made to exam the impact of discount rate on net benefit and benefit-cost ratio.

5.1 Deterministic calculation the PNB and SNB of each wind and hydro CDM projects

In this section, it calculates the private and social benefit for each wind and hydro projects under certainty. The expected average price of CERs is €8.5/t CO_2 (Bellassen *et al.*, 2012). PNB is calculated by the expected price of CERs and all other variables stated in the CDM documentary. In addition, the expected average CERs price will be used when calculating the social net benefit. The mean of VSL and CAD estimated in section 4.2 is used to do the deterministic valuation of SNB for both wind and hydro CDM projects.

After running the data analysis function in Excel to equations 1 and 2, the histograms of private and social net benefit for 1056 wind projects are shown in Figure 3 and Figure 4, respectively. The histograms of the private and social benefit of 994 hydro CDM projects is showed in Figure 5 and Figure 6. In each Histogram, the horizontal axle is the increment in the unit of million € and the height of each bar is proportional to the number of projects falling in the corresponding net benefits range. According to Figure 3, most PNB of wind projects is between € 0.5 and 2.00 million, while SNB is more diverse, showing in Figure 4. For hydro power projects, both PNB and SNB histogram shows a long right tail, which means it not centralized as wind projects. Furthermore, the statistic results of net benefits for wind and hydro CDM projects are demonstrated in Table 3 and Table 4, respectively.

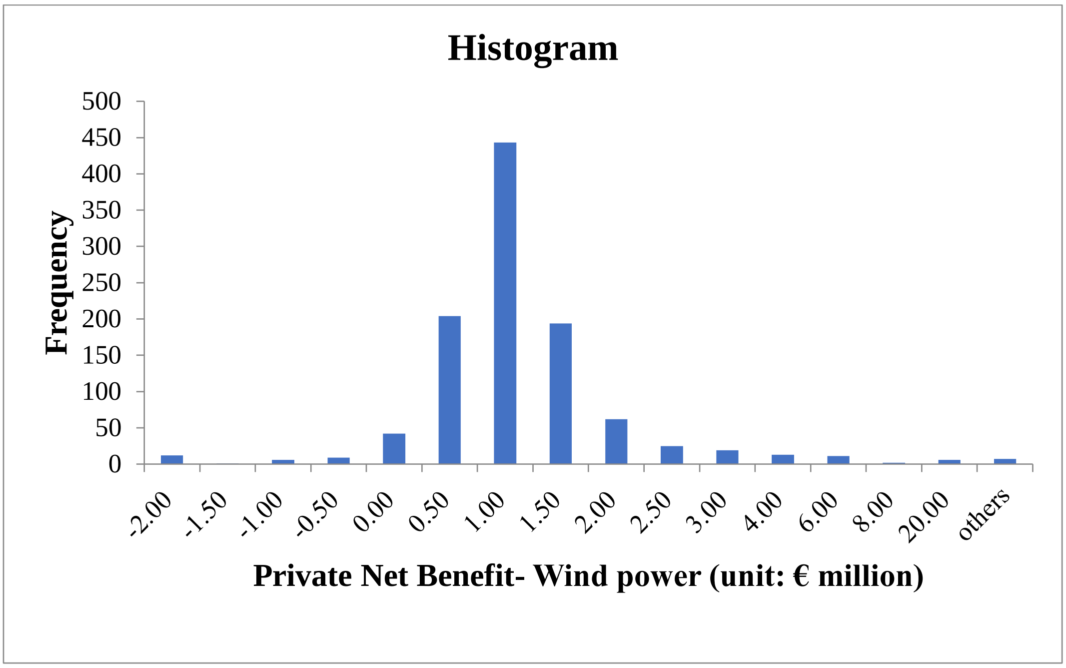


Figure 3 Histogram of PNB for per wind power CDM project

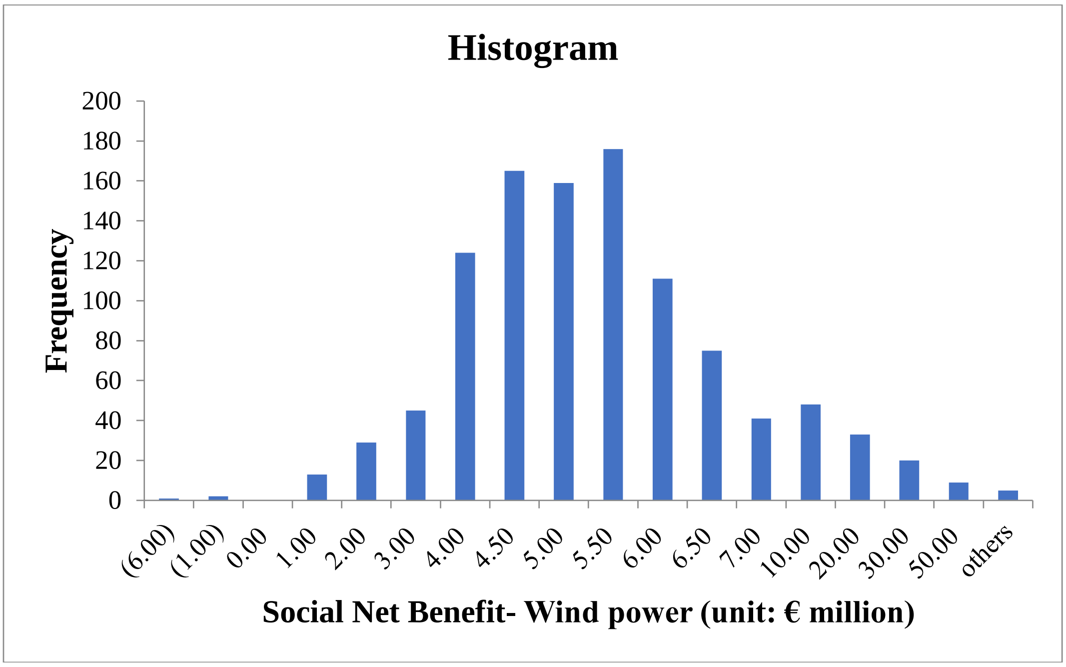


Figure 4 Histogram of SNB for per wind power CDM project

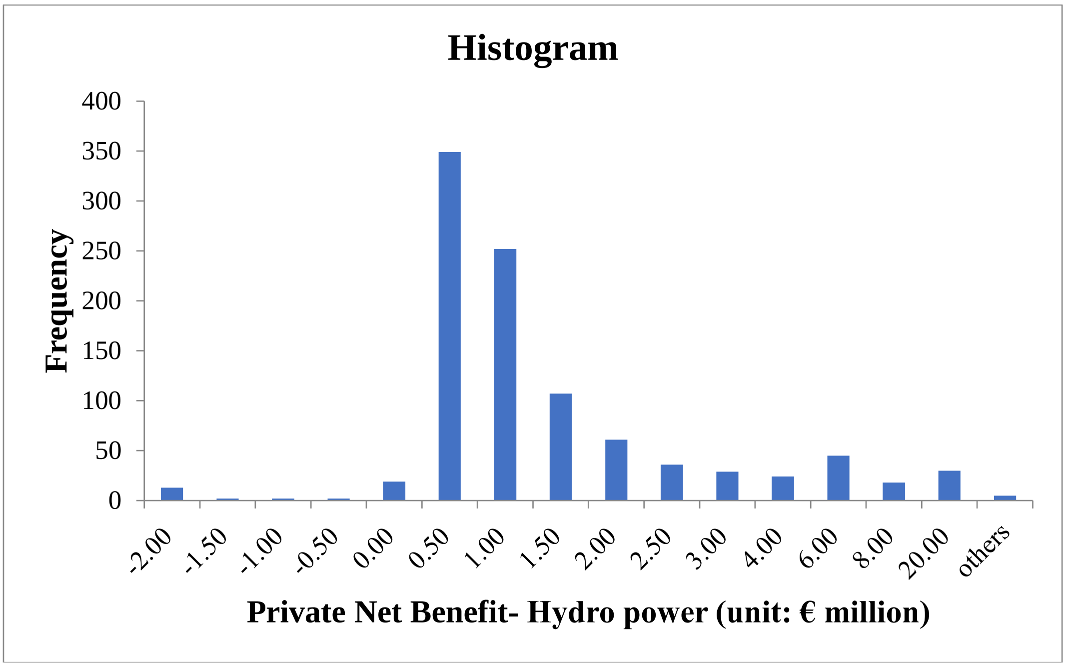


Figure 5 Histogram of PNB for per hydro power CDM project

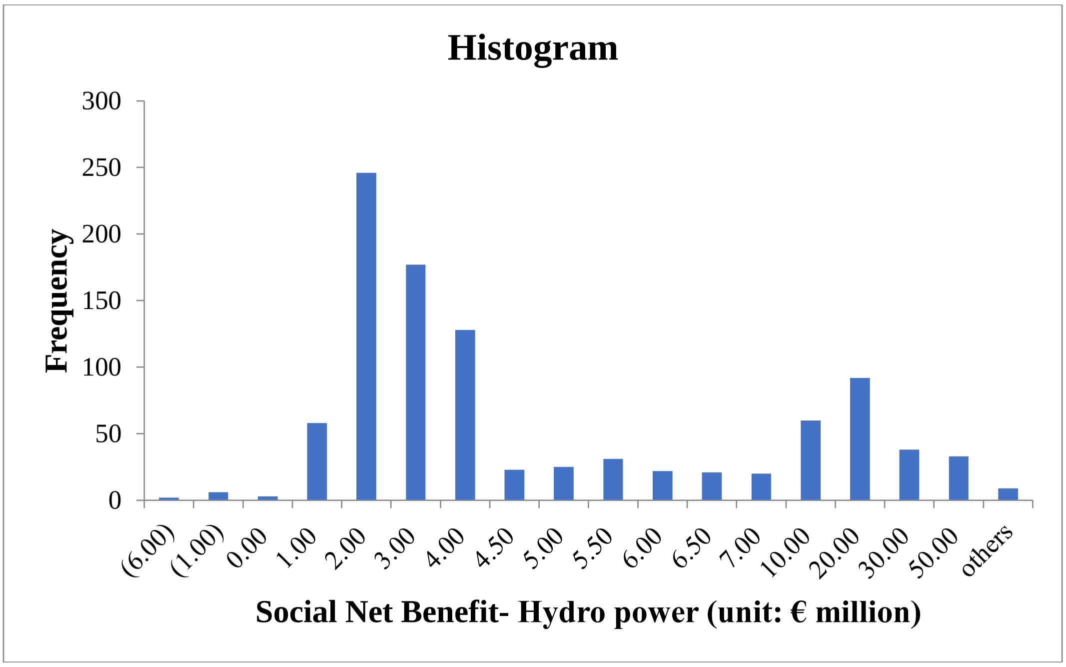


Figure 6 Histogram of SNB for per hydro power CDM project

Table 3 indicated the amount of negative PNB and SNB and its proportion to the total amount of CDM projects. For wind power projects, 70 projects show negative private benefits, while only 38 hydro projects are negative. When including the impact of ancillary benefit to SNB, the amount of negative SNB wind CDM projects decrease to 3 projects. For hydro CDM project, the amount falls to 11.

Table 3 The amount of negative PNB and SNB to wind and hydro power projects

	quantity of negative PNB	Percentage	quantity of negative SNB	Percentage
Wind (1056 projects)	70	6.63%	3	0.28%
Hydro (994 projects)	38	3.82%	11	1.11 %

Source: own calculation based on data from project design documents (PDDs) on UNFCCC

Table 4 The statistical results of PNB and SNB for wind and hydro power CDM

Unit (€ million)	PNB			SNB		
	Mean	Standard dev	Total	Mean	Standard dev	Total
Wind	1.124	3.443	1,187.325	6.133	6.007	6,343.704
Hydro	1.510	3.380	1,501.303	6.810	11.553	6,768.872

Source: own calculation based on data from project design documents (PDDs) on UNFCCC.

It is calculating the total private benefits for wind and hydro CDM projects by aggregating each PNB of two renewable projects respectively. The total amount of private benefit for the wind and hydro project is €1187.325 and €1,501.303 million, respectively, showing in the forth column of Table 4. And the overall social benefit for two energy projects is € 6,343.704 and €6,768.872 respectively, showing in the seventh column of Table 4. By comparing these two columns, it states that total SNB is much larger than the total PNB. And the hydro power projects show higher PNB and SNB than the wind projects. However, the SNB of hydro projects shows a relatively higher standard deviation (€11.553 million) comparing to wind projects (€6.007million).

When applying Cost-Benefit analysis, the Benefit-Cost ratio is used as an indicator to determine which type of CDM project performs better in China. Benefit-Cost ratio is equal to the monetary benefit gained by the project divided into its costs. The higher the ratio, the better the projects given the budget is constrained. And these projects should be chosen to carry on priority.

Table 5 The Benefit-Cost ratio of wind and hydro CDM

€ million	Benefit	Cost	Private ratio	Benefit	Cost	Social ratio
Wind	8,402.229	7,214.904	1.1646	13,558.608	7,214.904	1.8792
Hydro	4,944.772	3,443.470	1.4360	10,212.341	3,443.470	2.9657

From Table 5, all four indicators in column fourth and seventh are larger than 1, which indicate the benefit achieved by implement the CDM projects is exceed costs. Among them, the social Benefit-Cost ratio for hydro power project is much higher than others, and it is approximate to 3. Generally, the Benefit-Cost ratio of hydro is higher than wind projects in both private and social aspects. Therefore, the hydro CDM project should be recommended to carry on priority.

5.2 Stochastic calculation the PNB and SNB of total wind and hydro CDM projects

Based on equation 4 and 5 and the assumed distribution for three uncertain parameters in section 4.2, the thesis uses the software Crystal Ball to perform the Monte Carlo simulation for estimation the total PNB and SNB for wind and hydro CDM project respectively. It takes a random draw from the distributions for each uncertain parameter to reach a set of specific values. Then, when repeating the trials thousands of tens of times to get a large number of the corresponding net benefit of two renewable energy techniques. With the faith in the law of large numbers, the frequencies will cover the accurate underlying probabilities when the number of trials large enough. (Boardman *et al*., 2006)

The *histogram* in Figure 7 to 10 is the distribution of net benefit for wind and hydro CDM projects, since more trials run, the higher the probability that the resulting histogram can give a full representation of the distribution. (Boardman *et al.*, 2006) This thesis executed 10,000 times trials to form the net benefit distribution. The *histogram* provides a visual picture of the net benefit distribution, and its spread and symmetry can be easily investigated. The height of each horizontal bar shows the proportion of trial results that falling in the corresponding vertical increment net benefits. Table 6 listed the statistic results from Figure 7 to 10. The stochastic mean private and social benefit of the wind CDM project is €1,186.22 and €6,343.08 million, respectively. The hydro project gains a higher private and social benefits, which is €1,500.44 and €6,767.87 million. Comparing statistic results in Table 6 to Table 4, there is no significant difference between the stochastic mean level and the deterministic result for both two renewable technologies. The reason is that the assumed distributions for uncertain factors are all symmetry.

However, the stochastic analysis shows the total net benefit for wind and hydro projects vibrate more the deterministic analysis. The minimum and maximum PNB of wind CDM project are € -398.63 and € 2,829.13 million under stochastic analysis. It is a zero probability of total PNB falls to negative under deterministic for wind projects. The result of simulation shows 31 trials are negative benefit under stochastic analysis, according to Figure 11. However, when study SNB derived from the stochastic calculation of wind projects in Figure 8, it shows all projects can bring positive benefits.

Meanwhile, according to Figure 12, it shows four trials of hydro CDM projects face negative PNB under stochastic analysis. And all the stochastic distribution of total SNB of hydro CDM projects locate in the positive range. Comparing the probability of negative net benefits for two renewable CDM projects, it is certain that the hydro project with 0.04 percent probability negative benefit is better than wind project with 0.31 percent probability.

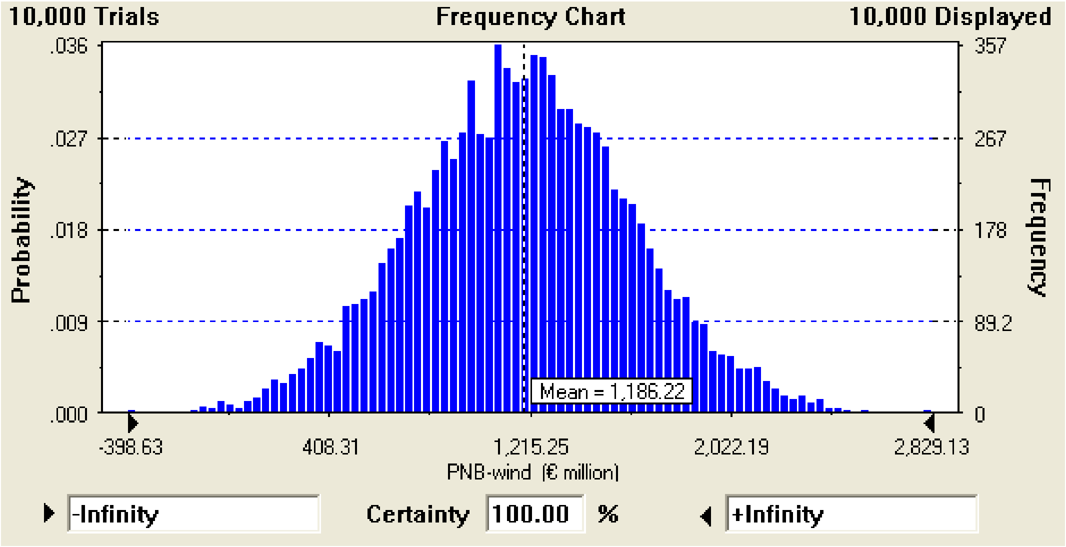
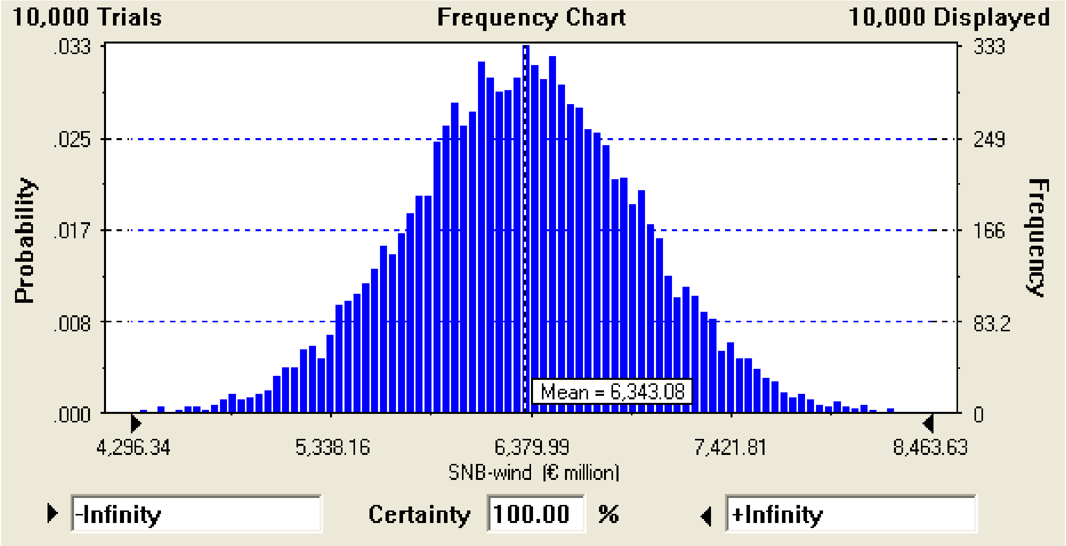
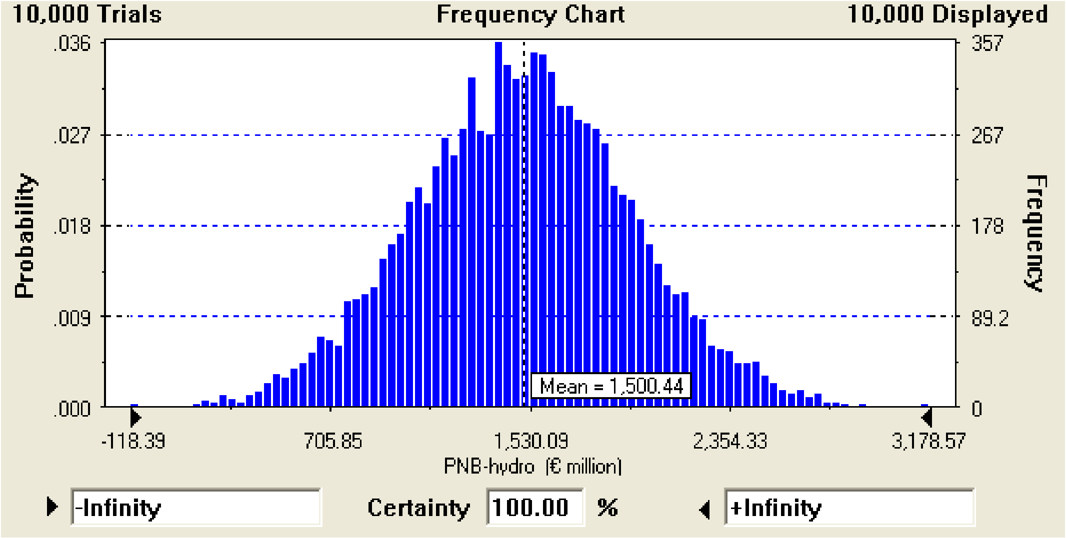


Figure 7 Stochastic distribution of total PNB of wind CDM projects



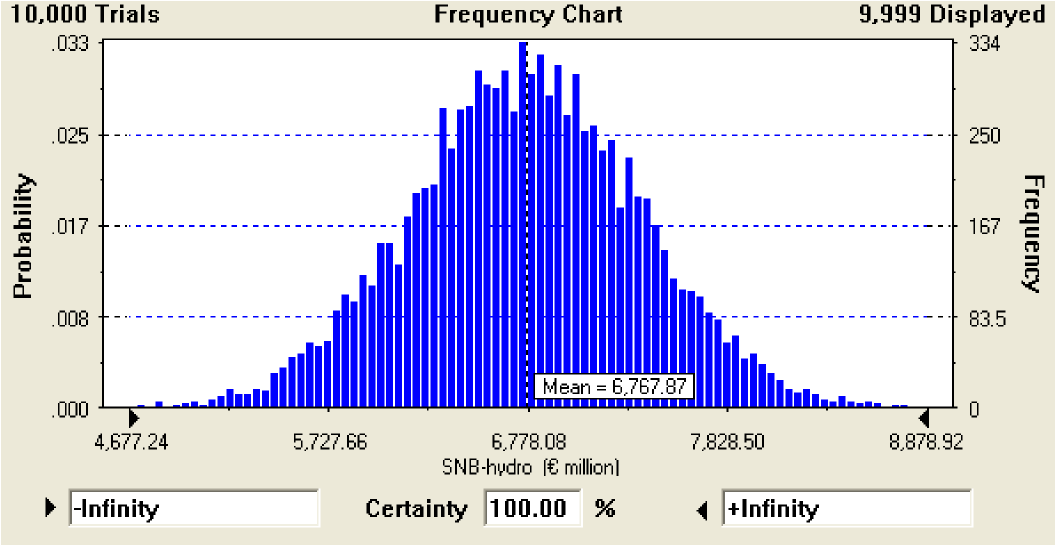
-Infinity Certainty 100.00 % +Infinity

Figure 8 Stochastic distribution of total SNB of wind CDM projects



-Infinity Certainty 100.00 % +Infinity

Figure 9 Stochastic distribution of total PNB of hydro CDM projects



-Infinity Certainty 100.00 % +Infinity

Figure 10 Stochastic distribution of total SNB of hydro CDM projects

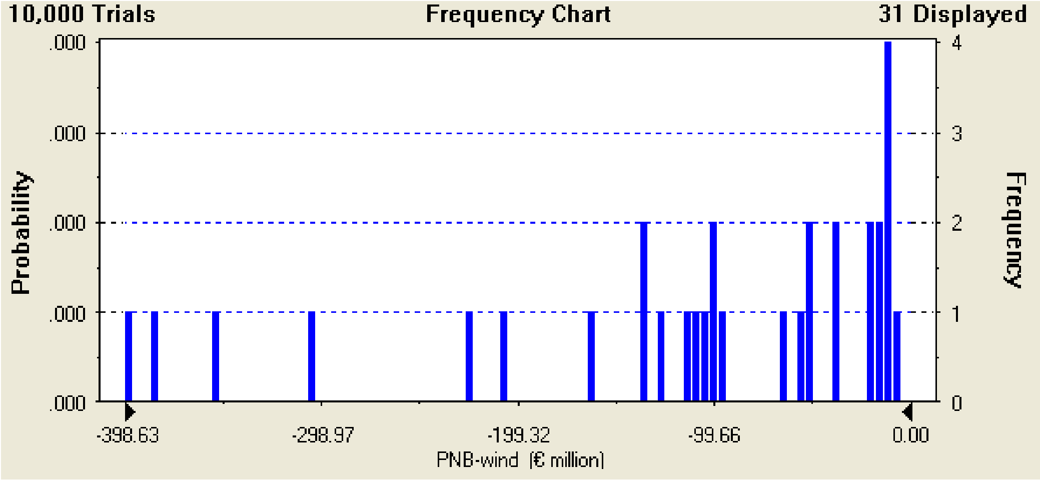


Figure 11 Stochastic distribution of negative PNB of wind projects

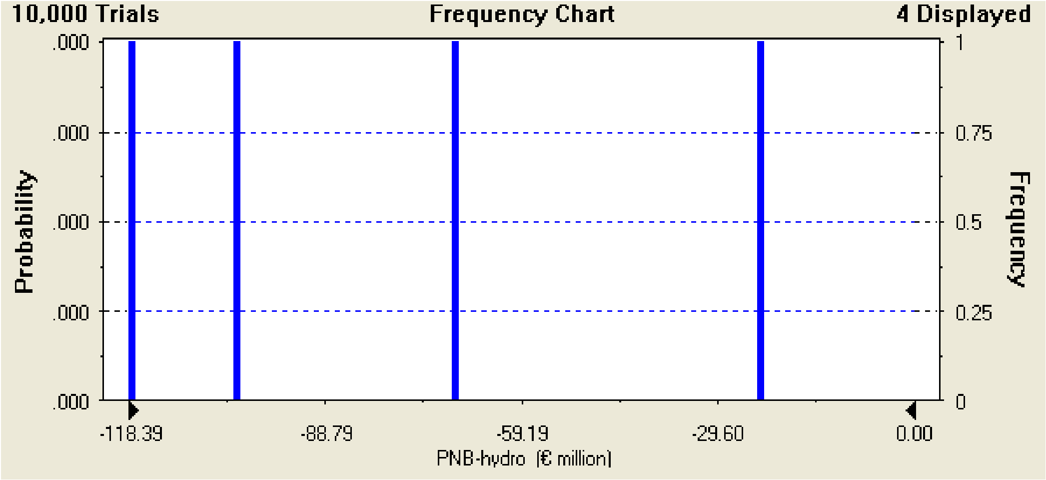


Figure 12 Stochastic distribution of negative PNB of hydro projects

According to the decision rule of Cost-Benefit analysis mentioned by Boardman et al. (2006), when an alternative project shows the close expected value of the net benefit, the decision-maker should consider the project with smaller variance or standard deviation due to the larger probability to reach the expected net benefit. And when an alternative project undertakes similar risk, that is, close variance or standard deviation, the project produces high profits is recommended. According to Table 6, both the private and social benefits of hydro CDM projects gain higher expected value comparing with wind projects. The SNB, including the monetary value of the ancillary benefits, is always higher than PNB in both deterministic and stochastic analysis. Therefore, the wind and hydro CDM projects become economically attractive, given the social co-benefits can make real. As a developing country, China faces high energy consumption with high carbon emission. The Chinese environmental and sustainable policymaker should consider the overall social benefit when examining the CDM project.

Table 6 Statistics result from Monte Carlo simulation

Unit (€ million)	PNB		SNB	
	Mean	Standard deviation	Mean	Standard deviation
Wind	1,186.22	434.94	6,343.08	590.65
Hydro	1,500.44	444.26	6,767.87	603.32

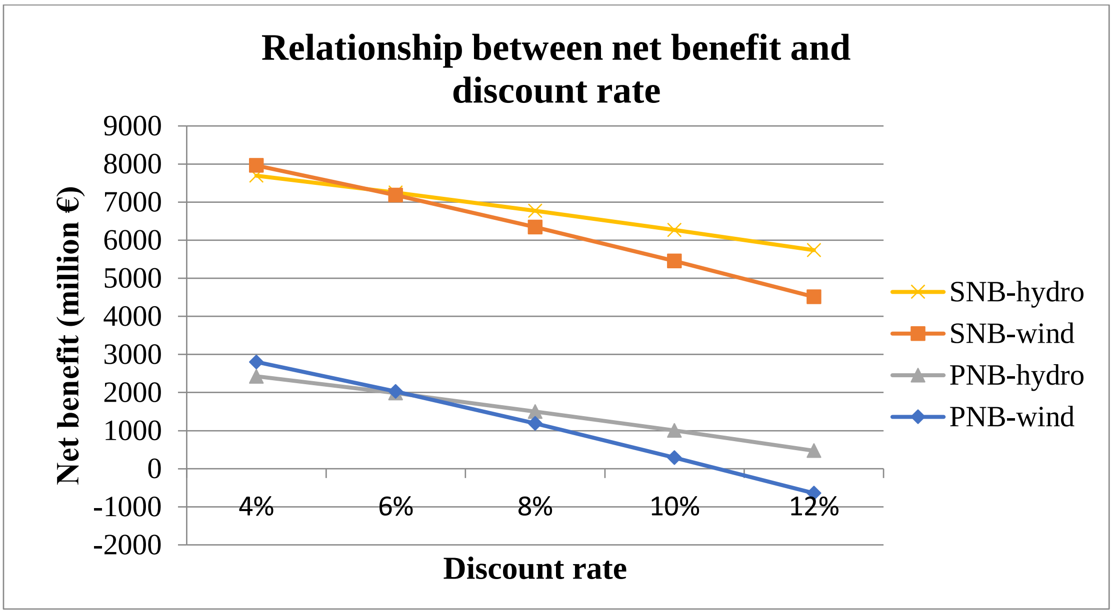


Figure 13 Impact on the net benefit from changed the discount rate

Boardman *et al*. (2006) state that the choice of an appropriate discount rate when making policy or evaluating the projects is essential. Therefore, this thesis makes the sensitive analysis of the discount rate to see the impact on the net benefit of CDM projects. It assumes that all other factors constant, the impact on the net benefit is illustrated in Figure 13. The discount rate applies in both deterministic and stochastic analysis in this thesis is 8 percent. The only parameter related to the discount rate is the annual fixed cost, and they are positively related to each other. When the discount rate increases, the fixed cost of CDM projects increase, resulting in the net benefits falling correspondingly. Figure 13 shows a downward sloping. When the discount rate is below 5 percent, the SNB of wind projects is large than hydro ones. And the hydro CDM projects show high SNB when the discount rate is above 5 percent. When the discount rate is below 6 percent, the SNB of wind projects is large than hydro ones. And the hydro CDM projects show high SNB when the discount rate is above 6 percent. According to Figure 13, the discount rate of 10.7 percent is the breakeven point for wind CDM projects. It indicates that implement both wind and hydro CDM project when the discount rate is below 10.7 percent given another factor constant. And wind CDM projects confront the risk of cancel if the discount rate rises to 10.7 percent. Because the PNB of wind CDM projects will be negative given the discount rate is above the breakeven point.

Table 7 Impact on the BCR when discount rate changes

BCR / Discount rate	Private BCR		Social BCR	
	Wind	Hydro	Wind	Hydro
4%	1.5011	1.9638	2.1334	3.6883
6%	1.3185	1.6722	1.9955	3.2891
8%	1.1646	1.4360	1.8792	2.9657
10%	1.0363	1.2545	1.7824	2.7173
12%	**0.9289**	1.1056	1.7013	2.5135

The different Benefit-cost ratio is calculated when the discount rate varies for wind and hydro CDM projects in Table 7. Comparing column four to column two in Table 7, the social BCR is higher than private BCR in every discount rate. The same is for hydro CDM projects. When comparing column three to column two, the hydro projects indicate higher private Benefit-Cost ratio than wind. Therefore, hydro CDM projects show better economic valuation. The same is for the hydro project when considering the social Benefit-Cost ratio. Besides, the private Benefit-Cost ratio for wind is below 1 when the discount rate rises to 12 percent, Because the ratio of wind is less than 1 and indicates negative economic evaluation. It is advisable to give up wind projects to avoid private economic loss. However, the social Benefit-Cost ratio for wind is still above one at a 12 percent discount rate, indicating the worth of investment.

6 Discussion and conclusions

According to the results in section 5, the hydro CDM projects perform better than wind both in deterministic and stochastic analysis of net benefit, so it is more valuable for investing in this type of renewable energy CDM project. However, in real situation, establishing renewable energy projects is significantly affected by natural resource regional allocation. The wind and hydro resources are distributed unevenly in China. Southwest area has plentiful rainfall the whole year, and the national longest and largest Yangtze River flows through south region. Therefore, hydro power project is highly recommended to build in this area. However, some regions have very rich wind resource like Inner Mongolia Autonomous region, and wind CDM project is more practical to build there. The discussion about renewable energy resource allocation in China is also mentioned in the study by Murata *et al* (2015). When investigating the co-benefit of renewable power CDM projects in China, it found that massive ancillary benefit exist in North and Northwest Chian Grid, where have tremendous wind energy resouces than other Chinese areas (Murata *et al.*,2015).

The assumed distributions for uncertain variables, VSL and, CAD, are debated. First, in section 4.2, the assumed uniform distribution range for VSL in China is from €0.511to €0.623 million per person. However, according to studies by Chinese researchers, the estimation is between € 0.024-0.117 million (assume the exchange rate of € to RMB is 10) (Vennemo *et al.* 2006). When tacking into account of economic inflation factor in China, the VSL data proposed by Chinese researchers will undoubtedly be higher than the level in 2006, but still lower than the data adopted in this thesis. The estimated ancillary and net benefit for CDM projects will be much lower in the stochastic analysis given the low VSL in Monte Carlo simulations analysis. In addition, whether or not the ethical judgment should be made when estimating the VSL is controversial. This thesis assumes all lives have the same economic valuation, but every human being is a unique individual. In reality, age, health condition, income, education level, working skills are all different for every person. There is a lot of uncertain variables affecting the VSL evaluation, so it is difficult to deal with this issue in reality. Second, applying the same CAD for wind and the hydro project will bring some problems to accurately calculate ancillary benefit for each renewable CDM project. The amount of people affected by air pollution is correlated to the population density in the area where they live. One-third of wind CDM projects in China are established in Inner Mongolia province, where the population density is much lower than other provinces in China. At the same time, one-fourth of hydro CDM projects is built in Sichuan provinces where the population concentration is high. Considering the impact of population density, the data of hydro CAD will be higher than the wind in China.

Another parameter which is worth be discussed is the expected price of CERs in the life-cycle of wind and hydro CDM projects in China. Margarita and Pablo (2016) revealed that benefits of deployment the renewable energy electricity in Europe is highly sensitive to CO_2 price used when calculating of the CO_2 emissions reduction. The thesis here also finds that the price of CO_2 will affect the CERs revenue directly, then correlate to the total private and social benefit of CDM projects. This thesis uses the normal distribution for CERs with mean €8.5/t CO_2 and standard deviation €3.45/t CO_2 for the parameter price of CERs (Bellassen *et al.,*2012). Wang *et al.* (2016) point out that the CERs revenue is a significant benefit when the price of CERs is about \$10/t CO_2 before 2011. However, the revenue decreases a lot when the price of CERs drops below \$1/t CO_2 in 2013. And CERs revenue benefit will minimize in 2015. It is certain that the total private and social benefit of wind and hydro CDM projects in China will shrink given the expected CERs price is \$1/t CO_2 instead of €8.5/t CO_2 (Wang *et al.,*2016). It is controversial to obtain the accurate CERs revenue given the mean level of it is underestimated or overestimated in reality. Therefore, the expected private and social benefit for wind and hydro CDM projects which are affected by the price of CERs will be underestimated or overestimated correspondingly in both deterministic and stochastic conditions.

Besides, the CDM projects generate transaction costs when registration, verification, and certification of the project. When calculating the total cost for wind and hydro CDM projects, this thesis takes account of only average static fixed cost and the operating and maintenance cost per year. The reason for not including the transaction cost is no reliable data available, which means lack the transaction cost in each project design documents. Transaction costs will increase the total cost of CDM projects and result in reducing the economic attraction of CDM projects comparing to Chinese domestic greenhouse gas abatement policy (Schroeder, 2009). Because the total net benefit of wind and hydro CDM projects will decrease when the CDM transaction cost is taken account. So CDM project can be established in various countries and areas where CERs revenue is higher than transaction cost. The number of CDM projects depends significantly on regional transaction costs (Michaelowa and Jotzo, 2005).

The renewable energy electricity generation will bring social benefits, such as improving the environment, guaranteeing energy security, advancing technology innovation, and promoting economic development. Zhao *et al.* (2014) calculated the environmental benefit of renewable energy power subsidy reached to 17.88 billion RMB. However, other benefits cannot be calculated due to a lack of corresponding data. The thesis here confronts the same problem of insufficient data, so when calculating the social ancillary benefit, it only focuses on human health improvement. Other co-benefits, such as generation local employment opportunities and regional poverty alleviation, cannot be calculated here. Most small-size wind and hydro CDM projects locate in the underdeveloped regions in China. Constructing and operating the CDM projects can create work opportunities for local citizens and raise their income correspondingly. The economic benefits of increasing work opportunity already list in some CDM project documents, but not all of them. Therefore, another ancillary benefit of CDM wind and hydro power projects cannot be calculated comprehensively. However, all these co-benefits mentioned above are difficult to measure in monetary terms. Besides, renewable energy projects can bring higher agricultural yields, less corrosion on building, and ancient architecture and reservation of the ecology system and biodiversity, which even more challenging to obtain the date and evaluate corresponding ancillary benefits in monetary terms.

Bibliography

Aunan, K., Fang, J., Vennemo, H., Oyd, K. & Seip, H. M., (2004). Co-benefit of climate policy-lessons learned from a study in Shanxi, China. *Energy Policy,*vol. 32(4), pp.567-581. Available at: https://doi.org/10.1016/S0301-4215(03)00156-3

Atanasoae, P., Pentiuc, D.R., Milici, L.D., Olariu, D.E., & Poienar, M., (2019) The Cost-benefit analysis of the electricity production from small scale renewable energy sources in the conditions of Romania. Procedia Manufacturing, vol. 32, pp385-389. Available at: https://doi.org/10.1016/j.promfg.2019.02.230

Boardman, A. E., Greenberg, D.H., Vining, A. R. & Welmer, D. L. (2006). *Cost Benefit Analysis: Concepts and practice.* 3ed. New Jersey: Prentice Hall.

Bell, M.L.,Davis,D.,Cifuentes.L.A, Krupnick.A.J, Morgenstern.R.D., & Thurston.G.D., (2008). Ancillary human health benefits of improved air quality resulting from climate change mitgation. *Environmental Health,* vol. 41(7) Available at: https://doi.org/10.1186/1476-069X-7-41

Bellassen, V., Stephan, N. & Leguet, B., (2012). Will there still be a market price for CERs and ERUs in two years time? Available at: http://www.cdcclimat.com/IMG/pdf/12-05_climate_brief_no13_-_supply_demand_for_cer_eru_in_the_ets.pdf

Hao, Q., & Zou, X., (2009). The influencing factors of social discount rate in BRICs. *World Economy Study*, 2009(10). Available at: http://en.cnki.com.cn/Article_en/CJFDTOTAL-JING200910006.htm

Liang, Y., Yu, B., & Wang, Lu., (2019). Costs and benefits of renewable energy development in China's power industry. *Renewable Energy*, vol. 131, pp.700-712. Available at: https://doi.org/10.1016/j.renene.2018.07.079

Michaelowa, A. & Jotzo, F., (2005). Transaction costs, institutional rigidities and the size of the clean development mechanism. *Energy Policy*, vol. 33(4), pp.511-523. Available at: https://doi.org/10.1016/j.enpol.2003.08.016

Matus, K., Nam, K., Selin, N. E., Lamsal, L.N., Reilly, J. M., Paltsev, S., (2012). Health damages from air pollution in China. *Global Environmental Change,* vol. 22(1), pp.55–66. Available at: https://doi.org/10.1016/j.gloenvcha.2011.08.006

Margarita, O., & Pablo, D.R., (2016). Benefits and costs of renewable electricity in Europe. *Renewable and Sustainable Energy Reviews*, vol. 61, pp.372-383. Available at: https://doi.org/10.1016/j.rser.2016.03.044

Morimoto, R., & Hope, C., (2012). Applying a cost-benefit analysis model to the Three Gorges project in China. *Impact Assessment and Project Appraisal*, vol. 22(3), pp. 37–41. Available at: https://doi.org/10.3152/147154604781765888

Murata, A., Liang, J., Eto, R., Tokimatsu, K., Okajima, K., & Uchiyyama, Y.,(2015). Environmental co-benefits of the promotion of renewable power generation in China and

India through clean development mechanisms. *Renewable Energy*, vol. 87 part 1, pp. 120-129. Available at: http://dx.doi.org/10.1016/j.renene.2015.09.046

Partridge, I. & Gamkhar, S., (2010). The role of offsets in a post-Kyoto climate agreement: The power sector in China. *Energy Policy*, vol. 38(8), pp.4457–4466. Available at: https://doi.org/10.1016/j.enpol.2010.03.078

Schroeder, M., (2009). Utilizing the clean development mechanism for the deployment of renewable energies in China. *Applied Energy*, vol. 86(2), pp.237–242.Available at: https://doi.org/10.1016/j.apenergy.2008.04.019

The benefits and costs of the Clean Air Act from 1990 to 2020.Ssecond prospective study (2011). U.S.Environmental Protection Agency Office of Air and Radiation, Available at: http://www.epa.gov/air/sect812/prospective2.html

UNFCCC (United Nations Framework Convention on Climate Change) Available at: https://cdm.unfccc.int/Statistics/Public/CDMinsights/index.html

Vennemo, H., Aunan, K., Fang, J., Holtedahl, P., Hu, T. & Seip, H. M.,(2006). Domestic Environmental Benefits of China's Energy-Related CDM Potential. *Climatic Change*, vol. 75(1-2), pp.215–239. Available at: http://link.springer.com/10.1007/s10584-006-1834-0

Wang, Y.,Geng, S., Zhao, P., Du, H., He, Y.,& Crittenden, J.,(2016). Cost–benefit analysis of GHG emission reduction in waste to energy projects of China under clean development mechanism. Resources, Conservation and Recycling, vol. 109, pp. 90-95. Available at: http://dx.doi.org/10.1016/j.resconrec.2016.02.010

Word Energy Outlook 2017: China. (2017) Available at https://www.iea.org/weo/china/

Word Bank 1 (GNI per capita, Atlas method (current US$)). Available at: http://data.worldbank.org/indicator/NY.GNP.PCAP.CD

Word Bank 2 (GDP per capita (current US$)) Available at: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Yang, M., Nguyen, F., Serclaes, P.D.T'. & Buchner, B., (2010). Wind farm investment risks under uncertain CDM benefit in China. *Energy Policy*, vol. 38(3), pp.1436–1447. Available at: https://doi.org/10.1016/j.enpol.2009.11.024

Zhang, J. & Wang, C., (2011). Co-benefits and additionality of the clean development mechanism: An empirical analysis. *Journal of Environmental Economics and Management*, vol. 62(2), pp.140–154. Available at: http://dx.doi.org/10.1016/j.jeem.2011.03.003.

Zhao, H., Guo, S., & Fu, L., (2014). Review on the costs and benefits of renewable energy power subsidy in China. *Renewable and Sustainable Energy Reviews,* vol. 37, pp.538-549. Available at: https://doi.org/10.1016/j.rser.2014.05.061

Zhao, H., & Guo, S.,(2015). External Benefit Evaluation of Renewable Energy Power in China for Sustainability. *Sustainability*, vol. 7, pp.4783–5805. Available at: https://www.mdpi.com/2071-1050/7/5/4783