A Modelling Assessment of the Impact of Clean Development Mechanism on Electricity Generation Systems: Case of Shandong Province, China

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The electricity generation sector is broadly cited among the most promising domains for implementation of greenhouse gases (GHG) abatement measures intended to achieve the targets set up in the Kyoto Protocol. Meanwhile, considered through the perspective of the Clean Development Mechanism (CDM), the electricity sector offers attractive business opportunities for investment in GHG mitigation projects which may be beneficial for both industrialised and developing countries. This work aims to identify such GHG emissions reduction projects within the electricity sector that can be eligible for CDM. It is assumed that revenues from sale of the certified emission reductions (CERs) would increase competitiveness of the power generation technologies with lower carbon emission rates, thereby altering economically efficient load order and capacity deployment. Possible range of CDM projects as well as economical and environmental benefits from their implementation were estimated using a least cost electricity system expansion planning model PLANELEC-Pro. It is found that in a reference Chinese province of Shandong the Clean Development Mechanism may contribute to the reduction of CO_2 *emissions by 46.8 million tons (1.64%) compared to the baseline case through the deployment of wind power and advanced clean coal technologies. The total cost of the electricity generation system can be decreased by up to US$ 86 million (0.24%) due to sale of CERs in the international market. Sensitivity analyses were made on the price of CERs which is the main factor having effect on the economical benefits from CDM and the resulting structure of the power generation mix.*

Key words: Energy Systems Modelling, Electricity, Clean Development Mechanism, China

1. INTRODUCTION

Securing safe and reliable electricity supply while protecting natural environment from degradation are among the most crucial problems faced by the public authorities in developing countries in their strive for sustainable economic and social development. Supporting economic growth and enhancing the quality of life requires more and more electrical energy that should be supplied in economically viable and environmentally sound manner. Meanwhile, rising electricity production is often accompanied by the atmospheric air pollution due to combustion of coal – most abundant and accessible fossil fuel. Furthermore, there is an increasing concern about potential contribution of the anthropogenic emissions of greenhouse gases (GHG) to the global climate change. This demonstrates the necessity for implementation of appropriate energy policies with practical emphasis on the adoption of cleaner or preferably "zero-emission" technologies in the power generation sector.

From the strategic point of view, such policies should insure timely expansion and refurbishment of the existing power generation capacities in order to meet the constantly growing electricity demand. On the other hand, they should provide economic incentives and / or mandatory legal framework favouring the power generation technologies with less environmental impact. In light of the recent entering in to force of the Kyoto Protocol these policies also should take into account the opportunities emanating from the international emission trading market and the Clean Development Mechanism (CDM). In fact, the emission constraints imposed on the industrialised countries listed in the Annex-I to the Kyoto Protocol ought to create demand for emission reductions originating from developing countries, where they can be accrued at lower cost. In practice, it means that the construction of new power plants and renovation of the existing ones in developing countries should be considered as potential CDM projects that could bring about additional revenues through the sale of certified emission reductions (CERs).

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Several international studies aiming to assess potential impact of GHG abatement policies and CDM on the developing countries' economies have been accomplished in recent years (ADB, 1998; ADB, 2004; UNEP, 2004; WB, 2004). These studies generally recognise the importance of power generation sector in supplying low cost GHG emissions reductions. However, they are not able to provide a detailed evaluation how CDM projects will fit into the future power generation systems, unless a bottom-up engineering-economic model is used in the analysis. Besides, feasibility of particular CDM projects in the electricity sector and the exact volume of achievable certified emission reductions will depend greatly on the specific market conditions and the characteristics of existing and projected power plants. Therefore, it is important to apply an integrated energy–economy–environment model in order to determine the optimal ways for implementation of CDM projects and to assess their potential benefits.

The present paper elaborates such an integrated modelling approach based on the electricity system expansion planning model PLANELEC-Pro. The main objective of the proposed methodology is to identify the optimal technological solutions for expansion of the existing electrical utilities park subject to the CDM revenues and taking in to account the progress achieved so far in the development of advanced power generation technologies. The study starts with a review and analysis of available documentation regarding CDM and the modalities of its application in electricity sector. Then current trends in the international emission trading market and estimates of future carbon prices are considered. Next chapter describes the proposed methodology for assessment of CDM impact on the power generation systems. An in-depth study of the electricity sector in Chinese province of Shandong is carried out in Chapter 4, and the results in terms of possible impact of the Clean Development Mechanism on the structure of electricity generation mix, total carbon dioxide emissions, total cost of the power generation system and the benefits from implementation of CDM projects are drawn in Chapter 5. Chapter 6 concludes with the main findings and policy recommendations.

2. KYOTO PROTOCOL'S CLEAN DEVELOPMENT MECHANISM AND THE ELECTRICITY SECTOR

2.1 GHG Emissions in the Electricity Sector and the Role of CDM

According to the International Energy Agency, the electricity generation accounted for 39 % of global carbon emissions in 2000 (IEA, 2002). This puts the electricity sector in the front line of the biggest sources of anthropogenic emissions of greenhouse gases along with transports and certain industrial processes. Continuous expansion of the power generation systems through the construction of new power plants and refurbishment of existing ones is vitally needed, especially in developing countries, for supporting economic growth. Considering that fuel of primary choice for most part of new projects is coal – abundant and easily accessible primary energy resource, it is expected that carbon emissions from electricity sector will continue to grow. On the other hand, recent progresses made in the fields of cleaner power generation technologies and renewable energy create opportunities for reduction of GHG emissions as compared to the business-as-usual projections. Already implemented in different industrialized countries, these technical options are capable to generate considerably higher amounts of GHG emission reductions in developing countries, where they will substitute to low efficiency / high pollution technologies. Moreover, they are likely to be at lower cost while bringing numerous fringe benefits. The essential condition for making those emission reductions feasible is that appropriate technologies should become accessible for developing countries which often lack financial resources and institutional capacities.

Different international capacity building initiatives and official development aid programs partially facilitate the task of transferring the environmentally sound energy technologies towards developing countries. However, a real boost in the deployment of low or zero- carbon emitting technologies can be expected with the help of Clean Development Mechanism – one of the Kyoto Protocol's financial flexibility instruments. Originating from the text of Article 12 of the Protocol, the Clean Development Mechanism has the main purpose to assist developing countries not included in Annex I in achieving sustainable development, and to assist Parties included in Annex I in achieving compliance with their GHG quantified emission limitation and reduction commitments. The Protocol stipulates that the emission reductions resulting from each CDM project activity in order to be certified shall represent real, measurable, and long-term benefits related to the mitigation of climate change and shall be additional to any that would occur in the absence of the certified project activity.

2.2 Key Issues in the Implementation of CDM Projects in Electricity Sector

Finding appropriate methodology for reliable estimation of the expected GHG emission reductions represents one of the most critical issues in the lifecycle of any CDM project. In order to meet this, so-called, environmental additionality criterion the project proponents must chose a transparent, accurate and practically applicable emission baseline as well as to define the project boundary and to estimate the potential "leakage" of GHG emissions outside this boundary. In practice, the choice of the methodology for setup of emission baseline and monitoring of actual emission reductions depends on the type and characteristics of particular CDM project. This choice should be justified, and the methodology itself should be explicitly described in the CDM Project Design Document. Kartha & Lazarus (2002) proposed practical baseline recommendations for GHG mitigation projects in the electric power sector. According to them, the fundamental condition for baseline methodology choice is whether the avoided generation is on the "build margin" (i.e. CDM project is replacing a facility that would have otherwise been built) or on the "operating margin" (i.e. CDM project is affecting the operation of current and/or future power plants). Since most CDM projects in power generation sector are likely to affect both the operating margin (in the short run) and the build margin (in the long run), emission baselines should reflect a combination of both these effects. Hence, the combined margin approach (i.e. an average of the operating margin and build margin) can be recommended as the standardised baseline methodology for most electricity projects. An effective combined margin method consists of

- the *average emissions rate of the operating margin baseline* (system average minus lowcost / must-run resources, OM_{year1}) and
- the *build margin baseline* (based on the cohort of 20% most recently built or under construction, $BM_{historical}$) for the first 7 years of project crediting (or 10 years for projects electing 10 year credit lifetime), per the following equation:

$$CM_{1stCreditingPeriod} = \frac{OM_{year1} + BM_{historical}}{2}$$

- the *build margin baseline* calculated based on new construction during the years 1 – 7 and 8 – 14

$$CM_{2ndCreditingPeriod} = BM_{years1-7} \;\; ; \;\; CM_{3dCreditingPeriod} = BM_{years8-14}$$

Besides the environmental additionality in terms of GHG emission reductions, potential CDM projects have to demonstrate their investment, technological and financial additionality. Meeting the investment additionality criterion consists in proving that implementation of potential CDM project will require additional investments compared to the existing technical options of the first choice and, hence, it is less economically attractive under the business-as-usual scenario. Practical approaches to define investment additionality were investigated by Greiner & Michaelowa (2003). Having reviewed the methodologies proposed in various studies, they have identified the set of criteria which differed considerably depending on the character of benchmark assessment. Some of them are purely qualitative, for example, those focusing on the existing barriers to project implementation. The other criteria are of quantitative nature comparing economic performance of CDM project either to the reference case, or to the certain threshold value. For the electricity sector, considering the large size of potential projects and the existence of sound alternatives among conventional technologies with transparent cost structure, it was suggested to perform the investment additionality check on the basis of financial indicators, such as IRR or NPV.

Another eligibility filter for potential CDM project is the technological additionality. According to Thorne & Raubenheimer (2000), in order to qualify for CDM, the proposed project activity must achieve a level of performance with respect to reductions in GHG emissions that is significantly better than average compared with recently undertaken and comparable activities or facilities within an appropriate geographical area. UNIDO (2003) describes the same criterion as checking whether the project components include elements of innovation beyond conventional practice and what is their impact on maintenance and / or supply chain. From the above definitions it can be concluded that practical implication of the technological additionality criterion for electricity industry will result in ensuring that potential CDM project leads to implementation of the state-of-the-art high performance environmentally sound power generation technology which otherwise, in the absence of CDM, is not accessible to the host country.

Finally, the financial additionality indicator assumes that international funding for the CDM project activities in host developing countries shall not result in a diversion of and shall not be counted towards the financial obligations of industrialised countries included in Annex II to the UNFCCC as well as to the official development assistance (ODA) flows. It means that funds from existing programs such as administered by GEF or other ODA activities shall not be used to finance CDM projects.

2.3 Projection of CERs Prices and Transaction Costs

The price of Certified Emission Reduction (CERs) which is an official accounting unit of the Clean Development Mechanism will have a decisive impact on the feasibility and economic performance of potential CDM projects in the electricity sector. The study of Springer (2003) reviewing outcomes of different models identifies average price of US$ 27 and median price of US$ 19 per ton of CO_2. According to Grütter (2002) a market price of US$ 7 – 17 per ton of carbon (equivalent to US$ 2 – 5 per ton of CO_2) is considered as most probable under current conditions. The study of Chen (2003) throughout broader scope of sensitivity analyses estimated carbon price within diapason US$ 3.26 – 27.73 / t C corresponding to US$ 0.89 - 7.56 per ton of CO_2. The similar price range is given in Point Carbon (2003) study: US$ 3 – 6.5 / t CO_2. On the other hand, the IETA survey of 116 carbon market participants predicted the median carbon price in the end – 2010 at US$ 10.5 / t CO_2 , the mean was US$ 14.3 / t CO_2, and the 75 per cent responses were in the range US$ 6 – 20 / t CO_2 (IETA, 2003).

Considerable risks and transaction cost inevitably will be associated with implementation of CDM projects due to their international and long-lasting nature. In electricity sector, potential CDM projects, besides standard transaction costs incurred throughout the construction of new power generation facilities, shall bear additional expenses related to different stages of CDM project development and issuance of the certified emission reductions. Actual amount of transaction costs and its repartition among the project stakeholders will depend greatly on the specifics of project activity and the choice of investment model for CDM project implementation. From the study of Michaelowa et al. (2003) it can be concluded that the impact of transaction costs will be as bigger, as smaller will be the size of potential CDM project as shown in Table 2.

Table 2. CDM project size and transaction costs

Size	Reduction (tCO_2/ year)	Transaction cost (€ / tCO2)
Very large	> 200,000	0.1
Large	20,000 – 200,000	0.3 – 1
Small	2,000 – 20,000	10
Mini	200 – 2,000	100
Micro	< 200	1000

Source: Michaelowa et al. (2003)

3. DESCRIPTION OF THE PROPOSED INTEGRATED MODELLING APPROACH FOR EVALUATION OF THE CDM PROJECTS IN THE ELECTRICITY SECTOR

Considering the specific rules and conditions of the Clean Development Mechanism depicted in the above chapter, this study proposes an integrated methodology for assessment of possible CDM impact on the evolution of electricity generating system in a given region or country. This methodology assumes that low or zero carbon emitting technologies eligible for CDM can reduce their production cost through selling the certified emission reductions in the international market. Thereby, the competitiveness of these technologies vis-à-vis conventional ones is being enhanced, and their share in total electricity generation and capacity deployed can be increased. The core element of the proposed approach consists in the application of a least cost electricity system expansion planning model, such as PLANELEC-Pro, that allows to estimate which technology qualifies for CDM by meeting additionality criteria; how much power capacity of specific technology should be added and when; what is the practically achievable level of CO_2 emission reductions and corresponding CDM revenue; what would be the electricity production cost of the power plants of specific type and the cost of the whole power generating system adjusted to the potential income from CDM. Optimal ways to introduce “low emission” or “carbon free” technologies can be determined in this methodological setting through the sensitivity analyses regarding availability and prices of primary energy resources, international market price and demand for CERs, discount rate and other factors. The flowchart of the methodology is given in Figure 1 and the peculiarities of individual modules are described hereunder.

- ***Scenario Assumptions Module***

Different economic factors having direct impact on the operation and development of the power generation system are being analysed in this module, and the assumptions regarding evolution of main factors are made. These assumptions concern: forecasting of electricity demand; definition of load duration curves; projection of future prices of main power generation fuels; estimation of possible price range of the certified emission reductions; fixing of escalation ratios for fuel prices, investment and operation & maintenance costs of power plants.

- ***Technology Selection Module***

This module specifies the existing electricity generation system: its composition, retirement of old and commissioning of committed facilities, technical characteristics of individual power plants (number, unit capacity, fuel type, heat rate) and economic parameters (capital, maintenance & operation costs). The same data as well as on-line availability year are collected on the candidate power plants. This module also decides about the technology mix that corresponds to the emission baseline.

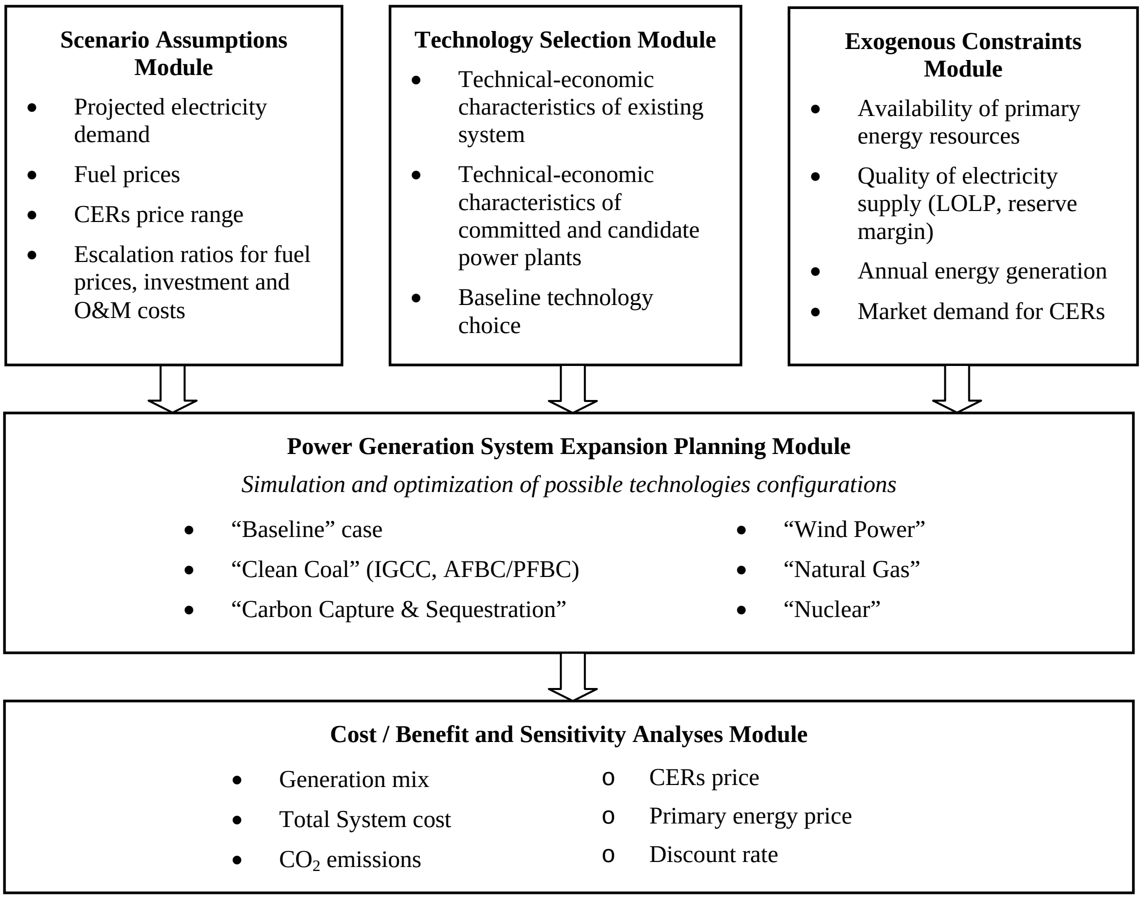
- ***Exogenous Constraints Module***

The constraints set up in this module normally include: availability of primary energy resources, required quality of electricity supply (LOLP, reserve margin), unit and total system annual energy generation (subject to scheduled maintenance and forced outage rate), volume of CERs market, and upper bound on CO_2 emissions.

- ***Power Generation System Expansion Planning Module***

This module is derived from PLANELEC-Pro v. 3.2 which is a least-cost probabilistic simulation and dynamic programming model of the electricity sector (Gnansounou & Rodriguez, 2003). Having determined technological configuration of the system and CERs price, possible system expansion strategies are optimized in order to meet the electricity demand with a given quality of service. The model uses probabilistic simulation to estimate generating system production cost and dynamic programming to determine the optimal expansion plan. The present worth of total costs including investment costs, operating and maintenance costs, fuel costs and the cost of un-served energy is used as an objective function to be optimized and to be used when comparing alternative expansion strategies (Gnansounou & Dong, 2003).

Figure 1. Outline of the integrated methodology for assessment of CDM impact



- ***Cost / Benefit and Sensitivity Analyses Module***

For a given system expansion strategy, the indicators of benefit are defined as the absolute and relative benefit from introduction of low or zero carbon emission technology. It can be calculated from the difference of the objective function value (discounted total cost of power system) of the baseline expansion case and specific GHG abatement technology introduction cases. The calculation of the indicators of benefit is as following:

$$B_i = TC_{BL} - TC_i \quad ; \quad b_i = \frac{TC_{BL} - TC_i}{TC_{BL}} * 100\%$$

where: B_i is absolute benefit of introduction of specific technology case at a given price of CERs compared to baseline case;

b_i is relative benefit of introduction of specific technology case at a given price of CERs compared to baseline case;

TC_i is the objective function value (discounted total system cost) of expansion plan with introduction of specific technology at a given price of CERs;

TC_{BL} is the objective function value of the expansion plan corresponding to the baseline case.

Considering that economic performance of technologies qualifying for CDM will depend greatly on future price of certified emission reductions, which is actually uncertain, a sensitivity analyses to the different levels of CERs price should be carried out in order to determine magnitude of potential impact of the Clean Development Mechanism. Another important variable is the price of primary energy, especially fuel oil and natural gas. Power generation mix, total system cost and corresponding CO_2 emissions should be monitored throughout these sensitivity analyses. Finally, different level of discount rate may also have significant influence on the results. Even more, according to IEA (2001), high capital costs of energy projects and their long lifetimes often make the setting of the discount rate a determining factor in the choice between energy options.

Basing on the model application within a realistic regional / country setup it is possible to identify an optimal system expansion plan that would allow introduction of low or zero carbon emitting technologies through the implementation of CDM projects. Potential impact of the Clean Development Mechanism on the electricity system might be evaluated on the basis of several variables including configuration of the power generation mix, emissions of carbon dioxide and benefit indicators. Since potential revenues from individual CDM projects are expected to be relatively modest compared to the total capital and operation costs of national or regional electricity systems, major impact of the Clean Development Mechanism will be revealed through the changes in power capacity and generation mix. It is assumed that sale of certified emission reductions would increase competitiveness of power generation technologies with lower carbon emission rates, thereby altering economically efficient load order and capacity deployment. Hence, the share of the technologies qualifying for CDM in total newly built capacity may be increased, as well as its share in total annual electricity generation. Structural changes in technology mix can be further assessed through a number of qualitative and quantitative indicators such as security of electricity supply, dependence on imported primary fuel, environmental fringe benefits, contribution to local employment and others.

4. CONTEXT OF SHANDONG PROVINCE AND MAIN DATA ASSUMPTIONS

4.1 General Overview

Shandong is one of China’s most populated and economically productive provinces. It is located in the East of China and constitutes one of several China’s free-trade zones along eastern coast. Shandong has maintained rapid economic growth over past decade at average annual rate above 10% (SDinternet, 2003). In 1999 Shandong had the third largest GDP in the country with 766.2 billion Yuan or 9.4% of total GDP (CSY, 2001). Being a model for Chinese economic development, Shandong province typifies also main energy and environmental challenges faced by China as a whole. These include a historically overextended power system (Connors, 2002), reliance on coal and poor air quality. Shandong has relatively abundant primary energy resources. The proven reserve of primary energy in Shandong province includes 29 billion ton of coal, 3.42 billion ton of oil and 29.94 billion m^3 of natural gas. There is little hydropower. Total power generation capacity in 2000 was 19.7GW including 16GW owned by Shandong Electrical Power Corporation (SEPCO) and 3.7GW owned by the Prefectures and customers (Gnansounou & Dong, 2003). All the power plants are fuelled with local coal and coal from the neighbouring Shanxi province. The capacity of units over 300 MW is 45% of the total capacity, while units smaller than 50 MW represent 16% of total capacity. In 2002, the total power generation in Shandong was 124,175 GWh (Sepco, 2003).

Great efforts had been made in recent years in Shandong province to assure sustainable development of the power generation sector. The interconnection between Shandong Power Grid and North China Power Grid has started and the West-East electricity transmission project is in steady progress. The 9x600KW wind farm project in Changdao was put into operation in September 1999. Tai'an Pumped Storage Power Station with a capacity of 4x250MW generating units is now under construction. The IGCC pilot project in Yantai and construction of Haiyang Nuclear Power Station are being greatly promoted (Sepco, 2003). This long term strategy aimed and technological renovation, energy saving, decreasing of costs and enhancing environmental protection results in gradual reduction of harmful emissions from power plants, while keeping the rapid growth of generating capacity. There are all evidences that implementation of CDM projects perfectly fits into this strategy, and it have all chances to contribute to the attainment of Shandong province’s sustainable development goals.

4.2 Main Assumptions and Projections

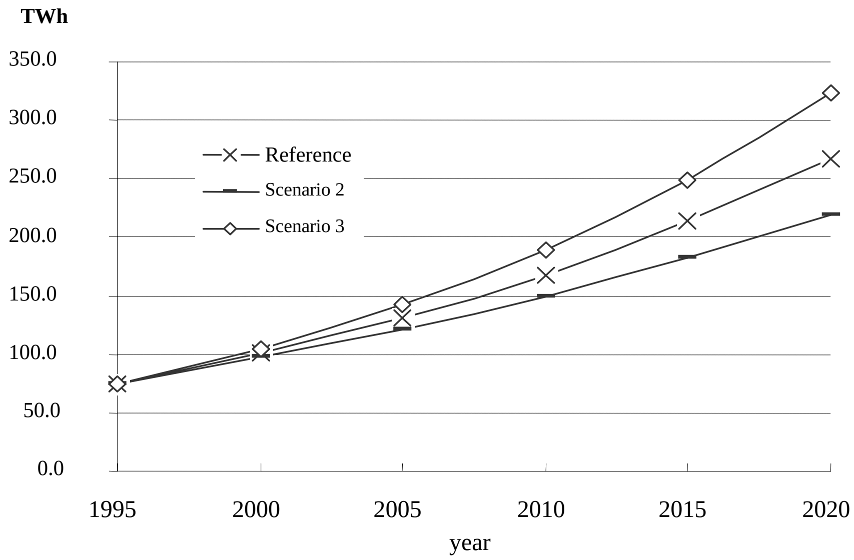
In recent years power generation system in Shandong became an object of thorough and cutting-edge scientific investigation within the framework of China Energy Technology Program (CETP). According to Eliasson (2003) this program has united the efforts of dozens of scientists, engineers and academics from three continents, but also producers and consumers of electricity in China with ultimate objective to analyse the true, life cycle impact of a range of power generation options focusing on the needs of Shandong province. The major components of the program included: (1) data collection and database development; (2) energy & electricity demand forecasting; (3) energy - economy modelling; (4) electric sector simulation and energy transportation modelling; (5) life cycle, environmental impact and risk assessment; (6) multi-criteria decision aiding; and (7) outreach.

Although being comprehensive and targeted on environmental issues, the investigations carried out within CETP program did not consider the issue of CDM as potential economic instrument capable of fostering the deployment of environmentally sound technologies. The analysis related to the policies for control of carbon emissions, performed within the energy economy modelling task, was limited to the hypothetical introduction either of taxes or caps on carbon emissions. However, the environmental policies of this kind are hardly plausible to be introduced in China in the nearest future considering its actual economical and political priorities. Bearing in mind that one of the main ideas of the CETP program consisted in ensuring widespread dissemination of the results, it was found reasonable to use the dataset from CETP study in order to investigate potential impact of CDM on the power generation system in Shandong province.

Electricity demand

Projection of future electricity demand in Shandong province is required for performing simulations of possible expansion paths of the existing power generation system subject to possible implementation of CDM projects. Estimation of future electricity demand (Figure 2) until 2020 (time horizon of the study) is taken from Gnansounou & Dong (2003), who also contributed to the "Demand forecasting" task within CETP program. The intermediate path is chosen to represent reference scenario of electricity demand growth. Estimation of future annual load duration curves also was taken from Gnansounou & Dong (2003).

Figure 2. Shandong electricity demand forecasting



Source: Gnansounou & Dong (2003)

Primary energy availability and prices

Assumptions on primary energy availability and prices might have a significant impact on the results of assessment of potential share of CDM technologies in future power generation mix, because considerable reductions of carbon emissions are possible through the fuel switch to primary energy sources with lower carbon content (such as natural gas or fuel oil) and use of renewable energies (wind, solar radiation, hydro etc). Estimation of available wind power resource in Shandong was taken from Connors et al. (2002) who were responsible for electric sector simulation within CETP. According to them, with reference to other studies, total Shandong land-based wind power resource at 10 m height corresponds to 3940 MW. It is concluded that if off-shore wind energy resource is taken in to account, the real wind power generation capacity in Shandong may exceed by far 4000 MW.

Another primary energy resource for fuelling new power generation capacity, which potentially may be eligible for CDM, is the natural gas. At present, availability of natural gas for electricity sector in Shandong is characterised by high degree of uncertainty. It is assumed that own natural gas resource will be used, foremost, to serve industrial processes needs and households consumption. Hence, in order to meet growing demand from peak and base load power generation, importation of natural gas will be required. This may be done either in form of liquefied natural gas or in form of pipeline supplies from gas fields. Both supply options will need large capital investments and time for construction of necessary infrastructure. Considering these facts, Connors et al. (2003) assume that some modest amount of natural gas for peak load combustion turbines will be available staring from 2008 and larger supplies of natural gas for base load applications will reach Shandong by 2012 – 2015.

As far as other types of power generation fuels are concerned (fuel oil, coal, nuclear fuel), it is supposed that there would not be any limitation on their availability. The prices of all fuels (Table 3) roughly correspond to the CETP data. Three different levels of natural gas prices conforming to the China State Power Corporation estimate (Jingru, 2003) were considered in order to perform sensitivity analyses under uncertain future conditions. Assumed escalation ratio for fuel prices is 1% per year.

Table 3. Assumptions on Prices of Power Generation Fuels

Coal		Natural Gas		Fuel Oil		Nuclear Fuel	
\$/Gcal	\$/t	\$/Gcal	\$/m^3	\$/Gcal	\$/toe	\$/Gcal	\$/GJ
4.24	29.68	14.00	0.127	19.80	211.83	2.60	0.62

Price of Certified Emission Reductions

In order to simulate introduction of CDM technologies under variable international carbon market conditions, the expected price of certified emission reduction was assumed to be within the range \$5.00 - \$20.00 reflecting the findings from chapter 3. Simulations of Shandong electricity system expansion and sensitivity analyses were performed with four different levels of CERs price: \$5.00 ; \$10.00 ; \$15.00 and \$20.00 per ton of CO_2. To ensure consistency of the study results, volumes of emission reductions obtainable through the implementation of CDM projects in Shandong were compared with potential China's share in meeting international market demand for CERs estimated at the level 53 – 55% of total CDM market volume (Chen, 2003).

Technology options

The methodology developed throughout this study requires a thorough assessment of the existing power plants, since the choice of prospective CDM technologies will depend on operational characteristics of the whole electricity generating system. In this case study, a comprehensive data base of Shandong electricity generation system was used covering main technical-economic characteristics of existing and committed power plants as well as their retirement and commissioning order. Based on CETP study, the scope of prospective power generation technologies was determined. The details of their technical-economic characteristics are given in Table 4.

Table 4. Technical-Economic Characteristics of Candidate Power Generation Technologies

Technology	Unit Capacity	Thermal Efficiency	CO_2 intensity	Forced outage	Sched. Mainte-nance	1st year available	O&M fixed	O&M variable	Capital cost	Econo-mic life
	MW	%	tCO2/MWh	%	days/yr		\$/kW* month	\$/MWh	\$ / kW	yrs
CCGT 250	*250*	*58%*	*0.330*	*5*	*21*	*2005*	*1*	*0.5*	*600*	*25*
CCGT 500	*500*	*58%*	*0.330*	*5*	*21*	*2005*	*0.92*	*0.5*	*600*	*25*
GT	*155*	*38%*	*0.504*	*8*	*10*	*2005*	*0.08*	*3*	*400*	*25*
HFOil	*50*	*34%*	*0.787*	*5*	*21*	*2003*	*0.44*	*2.53*	*500*	*30*
Nuclear ALWR-1000	*1000*	*33%*	*-*	*5*	*28*	*2010*	*3.42*	*0.5*	*1400*	*40*
Pulverized Coal 300	*300*	*35%*	*0.961*	*5*	*49*	*2003*	*1.83*	*2*	*624*	*30*
Pulverized Coal 600	*600*	*36%*	*0.934*	*5*	*56*	*2003*	*1.67*	*2*	*574*	*30*
AFBC	*300*	*38%*	*0.885*	*5*	*35*	*2008*	*2.5*	*4*	*900*	*30*
IGCC	*500*	*45%*	*0.748*	*8*	*35*	*2010*	*2.5*	*2*	*1200*	*30*
Wind on-shore	*25*	-	*-*	*75*	-	*2003*	*1.25*	*5*	*650*	*30*
Wind off-shore	*50*	-	*-*	*65*	-	*2010*	*1.67*	*5*	*800*	*30*

5. RESULTS AND ANALYSES OF ELECTRICITY TECHNOLOGIES' ELIGIBILITY FOR CDM

5.1 Least Cost Baseline

In order to perform analysis of the costs and benefits resulting from introduction of low or zero carbon emitting technologies, first, baseline case corresponding to the least cost system expansion plan was considered. It is assumed that availability of natural gas is limited to supply of two combustion turbine units totalling 310 MW and two combined-cycle turbine units with total capacity of 1000 MW. These natural gas-fired power plants are introduced into the system in the beginning of the study time period, i.e. in 2004 – 2007, and they are not considered as CDM candidates. Assumed natural gas price in baseline case is \$3.34 / GJ (\$0.127 / m^3) that corresponds roughly to the projections of Chinese State Power Corporation (Jingru, 2003).

It is observed that in order to meet the projected electricity demand and to replace decommissioned capacity, in least cost baseline system expansion plan, 14 pulverized coal units of 300MW and 47 units of 600MW should be put in operation, equivalent to the total newly built capacity of 32.4 GW. This results in a steady growth of total CO_2

emissions from 96.2 million tons in 2003 to 235.0 million tons in 2020. Carbon intensity slightly increases from 0.833 tCO_2 / MWh to 0.897 tCO_2 / MWh due to replacement of old heavy fuel oil-fired units by new pulverized coal-fired power plants. With assumed 8% discount rate for baseline case, total system present worth cost throughout study period 2003 – 2020 equals to $ 35,891 million.

5.2 Assessment of Technical Options

In order to estimate potential overall impact of the Clean Development Mechanism on the power generation system in Shandong province, the energy - economic performance and achievable levels of CO_2 emission reductions of each candidate technology were compared. Then, integrated case was simulated, which presumed deployment of several CDM technologies simultaneously. Finally, an expansion plan based on nuclear power generation was simulated, and its performance in terms of CO_2 emission reductions and incremental CO_2 abatement cost was compared with other technologies. Results of these calculations are summarized in Table 5.

Table 5. Total emission reduction and CO_2 abatement cost

Candidate CDM technology	Capacity added (MW)	Energy generated (GWh)	CO_2 emission reduction (Million t)	CO_2 abatement cost ($/t CO2)
Wind on-shore	1500	30,879	29.2	9.99
Wind off-shore	900	22,667	21.8	5.79
IGCC	1500	76,507	14.4	30.73
ABFC	1500	791	0.3	609
Integrated Case*	4025	110,754	46.8	14.04
Nuclear Power	9678	541,475	506.2	7.64

* Include wind on-shore (41 x 25MW), wind off-shore (18 X 50MW), IGCC (3 x 500MW), and AFBC (2 x 300MW)

Economic benefits from implementation of CDM projects of specific technology under different levels of CERs price were compared to evaluate economic impact of CDM on the power generation system in Shandong in terms of absolute and relative benefit (Table 6).

Table 6. Absolute and Relative Economic Benefits from CDM (Million $)

Candidate CDM technology	CERs Price			
	$10	***$15***	***$20***	***$40***
Wind on-shore	*< 0*	*< 0*	*73 (0.20%)*	-
Wind off-shore	*18 (0.05%)*	*90 (0.25%)*	*161 (0.45%)*	-
IGCC	*< 0*	*< 0*	*< 0*	*26 (0.07%)*
ABFC	*< 0*	*< 0*	*< 0*	*5 (0.01%)*[1]
Integrated Case	*< 0*	*< 0*	*86 (0.24%)*	-

According to the study results, the Clean Development Mechanism has a good potential to promote deployment of state-of-the-art environmentally sound technologies in China that not only reduce GHG emissions, but also bring numerous economic and other fringe benefits. The most attractive opportunities for implementation of CDM projects can be offered by on-shore and off-shore wind power generation. This technology is capable to generate economic benefits already at relatively low levels of CERs price: $5 - $10 per ton of CO_2 avoided. Advanced clean coal technologies, such as integrated coal gasification combined-cycle and fluidised bed combustion also may qualify for CDM, but higher level of CERs price ($37 - $40 / tCO_2) will be required to achieve any perceptible economic benefit.

6. CONCLUSIONS AND RECOMMENDATIONS

An Integrated Case assuming introduction of several potential CDM technologies and representing most probable course of system expansion under CDM regime allows estimation of potential overall impact of the CDM on a given power generation system. It is found that, in a representative Chinese province of Shandong, approximately 4GW capacity (8.27% of total system capacity in 2020) could qualify for CDM and generate throughout 2003 – 2020 the amount of certified emission reductions equalling 46.8 million tons of CO_2 (1.64% of total system emissions). At the CERs price $20 / tCO_2 this emission reduction may bring economic benefit of $86 million. However, at lower CERs prices $10 and $15/ tCO_2 only off-shore wind power is able to yield benefit ($18 million and $90 million respectively) producing about 21.8 million tons of CO_2 emission reductions with total capacity reaching 900 MW in 2020.

[1] Economic benefits from AFBC technology were estimated on the basis of predefined load factor, which was considerably higher than that resulting from the model application. In practice, it means that if AFBC technology is to be introduced into the power generation system as CDM project, it should be considered as "must run" power plant in order to achieve the expected levels of emission reductions and CDM benefits.

The prerequisite condition for achieving these performances is that necessary institutional capacity should be established to allow implementation of GHG abatement projects conforming to the CDM rules, methodologies and project development requirements. The study also has demonstrated the importance of non-standardized project-specific approach to the setting of emission baseline for potential CDM projects within electricity sector. Considering the large size of individual electricity installations and the modalities of operation of the existing power generation systems, the expected level of emission reductions may vary significantly depending on the choice of emission baseline and commitment order of the electricity generation facilities.

The results of this work generally correspond to the findings from other studies (e.g. Wei, 2000; World Bank, 2004) dedicated to the analysis of potential CDM projects in China. As a final conclusion it can be resumed that, although implementation of CDM projects results in smaller amount of CO_2 emission reductions as compared, for example, to the nuclear power, nevertheless, it allows receiving additional revenues which reduce total cost of the electricity system, while bringing substantial fringe benefits contributing to the sustainable development.

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