Clean Development Mechanism Project Opportunities in China

Pre-Feasibility Report for a Tri-Generation of Cooling, Heat and Power Project Using Natural Gas–Steam Turbine Combined Cycle

Wei Zhihong
Global Climate Change Institute
Tsinghua University
Beijing, China

August 2002

Contents

1 Introduction **1**
2 Background of Combined Heat, Power, and Cooling Development **1**
3 Project Objectives **2**
4 Project Description **3**
 4.1 Basic Situation 3
 4.2 Project Design 4
5 Energy Conservation and Environmental Protection Benefits of the Project **5**
 5.1 Energy Conservation Benefits 5
 5.2 Environmental Protection Benefits 6
6 Social Benefits **7**
7 Project Sustainability **7**
8 Experience and Lessons Learned from Other Projects **7**
9 Project Financial and Economic Analyses **8**
 9.1 Project Financial and Economic Analyses 8
 9.2 Sensitivity Analysis 8
10 Project Risks **11**
11 CO_2 Emission Reduction Analysis **12**
 11.1 Selection of Baseline Project 12
 11.2 System Boundary Determination 12
 11.3 Emission Leakage 12
 11.4 Credit Period for Emission Reductions 13
 11.5 Certified Emissions Reduction (CER) Production 13
 11.6 Calculation of Incremental Cost of Emission Reduction 15
Annex **16**

Tables and Figures

Table 1 Coal Consumption Intensity of Space Heating Systems (g/kW(heat)) 2
Table 2 Comparison of Various Pollutant Emission Levels 6
Table 3 Impacts of Uncertain Factors on F-NPV (,000 US$) 9
Table 4 Impacts of Uncertain Factors on F-IRR (%) 10
Table 5 Impacts of Uncertain Factors on E-NPV (,000 US$) 10
Table 6 Impacts of Uncertain Factors on E-IRR (%) 11
Table 7 Emissions Reductions Calculations 14
Table 8 CER Production from the CDM Project 14
Table 9 Incremental Cost of Emissions 15

Annex Table 1 Original Data 16
Annex Table 2 Sources of Investment 16
Annex Table 3 Annual Operation Cost (Million US$) 16
Annex Table 4 Financial Analysis (,000 US$) 17
Annex Table 5 Economic Analysis (,000 US$) 19

Figure 1 The Principle of the Tri-generation of Cooling, Heat and Power 5
Figure 2 Impacts of Uncertain Factors on F-NPV 10
Figure 3 Impacts of Uncertain Factors on E-NPV (,000 US$) 11

Preface

The Pembina Institute for Appropriate Development and the **Tata Energy Research Institute** are exploring the application of the Clean Development Mechanism (CDM) in Asia. This multi-year project is being undertaken in collaboration with:

- **The Bangladesh University of Engineering and Technology;**
- **The Global Climate Change Institute at Tsinghua University, China; and**
- **The Centre for Research on Material and Energy at the Technology University in Bandung, Indonesia**.

The following publications have been produced by the project partners:

- *Canada's Potential Role in the Clean Development Mechanism* (2000)
- *Negotiating the CDM: A North–South Perspective* (2000)
- Reports on CDM activities and potential CDM project opportunities in Bangladesh, China, India and Indonesia (2001)
- *A User's Guide to the CDM* (2002)
- Reports on individual CDM project opportunities in Bangladesh, China, India and Indonesia (2001)

For more information on this project visit the following Web sites:

- www.teriin.org
- www.pembina.org/international_eco3.asp

The project is being undertaken with the financial support of the Government of Canada provided through the **Canadian International Development Agency (CIDA)**, online at www.acdi-cida.gc.ca, and is being implemented in collaboration with the **International Institute for Sustainable Development (IISD)**, online at www.iisd.ca.

This report was produced by the Global Climate Change Institute at Tsinghua University, China. The views expressed in this report are entirely those of the authors.

1 Introduction

Beijing is the capital of China, as well as the country's political and cultural center. With a population of 120 million and a large heavy industrial sector, Beijing consumes a huge quantity of energy each year. Much of the city's energy is derived from coal combustion, which results in serious air pollution. Research shows that 90 percent of the SO_2 and 80 percent of the total suspended particulates (TSP) in Beijing's air pollution are due to coal combustion. Air quality worsens in winter, when between six and seven million tonnes of coal are used for space heating, making this the biggest source of air pollution. The average daily amount of pollutants in the atmosphere, such as TSP, SO_2 and NO_x, exceeds the Second or even the Third Grade of National Air Quality Standard. A sustainable development strategy for Beijing would contribute to improved air quality and protect economic viability by shifting the energy structure away from coal to a cleaner type of fuel such as natural gas. Attention should also be paid to energy supply and consumption technologies that can enhance energy efficiency.

The project of tri-generation of natural gas-steam turbine combined cycle provides Beijing with an advanced pattern of natural gas utilization, and accords with the principle of using energy for purposes compatible with its quality. It offers benefits in energy savings, environmental protection, and economic development. The project can also reduce air pollution in the Beijing area and reduce CO_2 emissions, thus contributing to the mitigation of global climate change.

2 Background of Combined Heat, Power, and Cooling Development

The steam produced from power plant boilers propels turbines to generate electricity. However, the exhaust gas transferred by cooling water and then emitted as "waste" still contains a lot of heat. Under these conditions, the thermal efficiency of coal-fired power plants is only 30 to 40 percent. If the exhaust gas could be recovered, the original energy source could produce both heat and power (co-generation). Co-generation produces heat by utilizing the exhaust gas—a lower quality of thermal energy that has a lower temperature and pressure after driving the turbines to generate electricity. Co-generation can achieve a thermal efficiency as high as 80 percent, which is twice that of power generation alone. Co-generation can improve energy efficiency, reduce air pollution, and provide a range of integrated benefits by saving energy, protecting the environment, improving space heating quality, and increasing electricity supply.

Development of co-generation in China began in the early 1950s. By the end of 1998, China had 1,313 sets of combined heat and power (CHP) generators with a capacity of about 25 GW—12.3 percent of total national capacity of thermal power generation. The total heating supply ability of co-generation had reached 320 TJ/h (110 tonne-steam/hour, or ts/h).

In China, space heating in winter focuses on residential buildings in the north, northeast, and northwest of the country. As of the end of 1999, total central heating area in China's urban regions was about 968 million m^2, 60 percent of which was heated by co-generation.

As shown in Table 1, coal consumption intensity of co-generation for space heating is less than other heating systems due to its higher efficiency. Co-generation plants are often built in or near heating load centers, which means that the electricity they produce can be used locally. In comparison, if electricity is supplied by large, more remote power plants, long distance power transmission is usually needed, resulting in transmission line losses. Data from the period of 1985-1999 revealed that the loss rate of long distance power transmission lines (above 500 KV) and transformers was 8.1-8.4 percent, confirming the considerable economic benefits of building local co-generation plants.

Table 1 Coal Consumption Intensity of Space Heating Systems (g/kW(heat))

Small boiler heating system	Central boiler heating system	District heating system	Co-generation system
225	190	165	133

In 1982, the State Planning Commission designated co-generation projects as one of the "Important Energy Conservation Projects" and allocated funding to them, spurring rapid development of the co-generation industry during the 1980s. In the last decade, as global climate change has captured increased attention from countries around the world, the Chinese government has implemented a sustainable development strategy, which includes policies, regulations, and laws to support further development of co-generation.

Article 39 of "The Energy Conservation Law of China," put into effect on January 1, 1998, points out that development of co-generation for heat and power as well as central space heating is encouraged by the State to improve utilization efficiency of thermal power turbines. At the same time, development of tri-generation of heat, power (electricity), and cooling (THPC) should also be encouraged by adopting technologies that support an increase in the integrated utilization efficiency of thermal energy. Documents and policies prepared by the Beijing Municipal Authority encourage the development and diffusion of ordinary energy saving technologies in urban areas, including co-generation.

Among all the thermal power plants currently operating in China, Jilin Thermal Power Plant in Jilin Province is the largest, with a capacity of 750 MW. Large-scale generators that combine steam extractors and condensers and have capacities of 200 MW and 300 MW are operating in many large cities, including Beijing, Shenyang, Tianjie, Taiyuan, and others.

Because the load of thermal power plants, especially those heating residential buildings, is greatly reduced in the non space-heating period each year, the energy efficiency of the plants decreases and they typically incur large economic losses. On the other hand, with recent improvements in the standard of living in urban areas, demand for summer air conditioning is increasing rapidly. If the superfluous steam produced from the power plant during the summer could be used for lithium-bromide absorption central cooling, both thermal load and integrated benefits of thermal power plants could be increased. This is why THPC development is actively encouraged in many large cities.

3 Project Objectives

The proposed tri-generation project described in this report has four main objectives:

- To study the development potential of natural gas (NG)-steam turbine tri-generation in large cities in China, especially the applicability of tri-generation for residential districts constructed in the patterns of "small districts" and "large buildings."

- To study the energy conservation potential and contribution of NG-steam turbine tri-generation projects to greenhouse gas emission reduction and environmental protection, compared with baseline projects.
- To study the major problems and obstacles in developing NG-steam turbine tri-generation and make suggestions to overcome these obstacles under the current market and economic conditions in China.
- To learn about and summarize experiences in developing NG-steam turbine tri-generation through this case study project, and to provide a basis for establishing future NG-steam turbine tri-generation in China.

4 Project Description

4.1 Basic Situation

Beijing's climate is described as temperate and semi-humid with monsoons. The continental weather pattern features cold winters with little snow, and hot rainy summers. The city's winter space heating period lasts four to five months, with district heat provided mainly by coal-fired boilers in the following four categories: small boiler district heating, large boiler-group district heating, city district heating, and small coal-stove heating; respectively, they provide 54 percent, 21 percent, 17 percent, and 8 percent of the total heating supply.

Window air conditioners and split unit wall air-conditioners are widely used in residential and service sectors in Beijing. These appliances consume a lot of power, and the growth in air-conditioning demand has increased the pressure on electricity supply. If the steam (or hot water) from thermal power plants could be used for cooling in summer by lithium-bromide (Li-Br) absorption cooling technology, the thermal load could be better balanced throughout the year, the economic benefits of thermal power plants could be increased, and the cooling cost would be decreased.[1]

One district, a science park in one of Beijing's High and New Technology Zones, is being recommended as the location for the natural gas tri-generation CDM project. The tri-generation project will provide this location with district heating for all buildings and with central cooling for office buildings. The heating period is intended to cover five months from November 1 to March 31, and the cooling period to cover three months from June 15 to September 15.

In 2000, total electricity consumption of Beijing reached 33 TWh, a 48-percent increase over 1995. A small part of the electricity supply comes from local power plants in Beijing, but the city depends largely on the North China Power Grid. For this case study, power supply to the district is presumed to come from local power plants.

To address the serious air pollution in Beijing, a program to replace coal with natural gas is now being implemented. Natural gas has higher thermal efficiency and creates less pollution than coal, and is thus regarded as a clean energy source. Natural gas consumption in Beijing has increased greatly in recent years, and gas imports amounted to 1.4 billion m^3 in 2000. Natural gas consumption is expected to reach 4 billion m^3 by 2005. China's natural gas is supplied by domestic production, imported Russian natural gas, and foreign liquefied natural gas. Beijing's natural gas comes mainly from the Shaan-Gan-Ning Gas Field. To ensure a safe and reliable

---

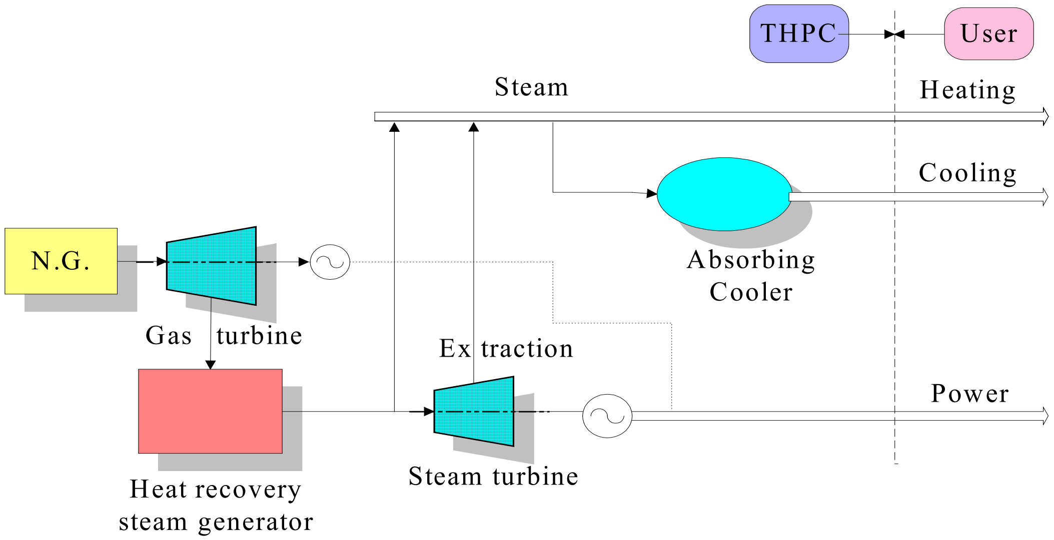
[1] The cost of co-generation central cooling is reduced to about 60 percent of that of absorption cooling of direct-combustion devices, or about 42 percent of that of body-split air conditioning.

natural gas supply to Beijing, to accommodate the expected consumption of 4 billion m^3 by 2005, and to enable the import of natural gas from Russia, Beijing is planning to build a second long-distance pipeline to Shaanxi Province.

4.2 Project Design

The project described in this case study will install two 50-MW units of natural gas-steam combined cycle THPC, which consists of a gas turbine, a non-fuel complemented waste heat recovery boiler, and a steam turbine. Heat is supplied by both extracted steam and exhaust steam from the steam turbine. The steam or hot water produced in summer is used for Li-Br absorption cooling. The principle of THPC is illustrated in Figure 1.

Figure 1 The Principle of the Tri-generation of Heat, Cooling, and Power



A Li-Br absorption cooling system uses water as the cooling agent, Li-Br solution as the absorbing agent, and the low-pressure steam extracted and exhausted from the steam turbine as energy. It can produce cooling water over zero degrees Celsius for central air conditioning in large buildings and other places needing cooling. The Li-Br technology, which uses low-grade steam rather than mechanical energy as a power source for heating the absorption agent, is more thermodynamically efficient than compression cooling systems. This characteristic means that the natural gas-steam combined cycle tri-generation system can produce electricity more cheaply while conserving energy and contributing to environmental improvement.

The gas-steam combined cycle generator selected for this project is designed to produce 0.5 TWh of electricity annually, and provide space heating for an area of 2.5 million m^2 and central cooling for 1 million m^2. The yearly natural gas consumption would be 133 million m^3 in the full load operation period, and the project could be constructed in about two years.

Total investment required is estimated at about 600 million yuan (US$72.6-million), making the unit investment roughly 5,660 yuan (US$685). Funds needed to construct the project could be raised through various channels, and energy conservation loans should be used to the maximum extent to ensure reliability of funding and delivery of the project's economic benefits.

5 Energy Conservation and Environmental Protection Benefits of the Project

5.1 Energy Conservation Benefits

The integrated thermal and power efficiency of co-generation can reach 70-85 percent, with a power generation efficiency of 35-40 percent and heating supply efficiency of 35-45 percent. However, due to inevitable thermal losses in the cooling process, the efficiency of common condenser power generation is more like 30-40 percent (i.e., thermal losses are 60-70 percent). Although the efficiency of natural gas boilers can reach 85-90 percent, the energy consumed by independent heat and power production is still double that of co-generation to generate the same quantity of electricity and heat. Therefore, a tri-generation CDM project can save about 0.8 million tonnes of carbon-equivalent every year.

5.2 Environmental Protection Benefits

Because natural gas-steam tri-generation technology is a clean and highly efficient way to supply energy, its application could effectively mitigate the winter air pollution in Beijing caused by coal-fired boilers. The main environmental advantages of clean natural gas-steam tri-generation technology are: (a) greatly reduced emissions of SO_2, NOx, dust, and other pollutants; (b) lower total levels of pollution per unit of energy consumed due to the high efficiency of gas turbine and co-generation technology and to the rationalization of energy use; and (c) reduced emissions of CO_2 as a result of the lower carbon content of the fuel source and the high efficiency of the combined cycle system. The various pollutant emission levels are compared in Table 2.

Table 2 Comparison of Various Pollutant Emission Levels

	SO_2	Smoke and dust	NOx	CO_2
Emission factor – coal-fired boiler	11.69 kg/t	3.15 kg/t	7.61 kg/t	1.88 kg/kg
Emission factor – natural gas co-generation	0	0.17 g/m^3	1.825 g/m^3	1.77 kg/m^3

Split units are currently the most widely used air conditioners in Beijing. These not only waste energy but also introduce a new problem to the city— the "heat-island effect." Natural gas THPC can use the steam from the power plant in summer to provide central cooling through Li-Br absorption cooling technology, thus easing the heat island effect.

Replacing electrical air conditioners with Li-Br absorption cooling technology also eliminates any need to use chlorofluorocarbons (CFCs), which destroy the ozone layer and contribute to global warming.

6 Social Benefits

Beijing’s increasingly hot summers have raised demand for air conditioning and placed a great burden on the power industry, with summer loads reaching 6.5 GW. Tri-generation can smooth out the seasonal load peaks and valleys for the power generation system. Shifting from electrical air conditioning to central Li-Br absorption cooling reduces the amount of electricity required for direct cooling and increases the amount of thermal energy available for cooling.

Tri-generation can provide stable and reliable space heating in winter, central cooling in summer, and ample hot water for daily use, thereby improving the quality of life for Beijing residents.

7 Project Sustainability

To a large extent, Beijing’s air pollution is caused by an irrational energy structure and low efficiency of energy utilization. To improve air quality and achieve the goal of holding “green” Olympic Games in 2008, Beijing’s municipal government has implemented several active and effective measures; these include encouraging the use of cleaner natural gas, banning the use of high sulphur-content coal, speeding up the establishment of no-coal districts, retrofitting district space heating boilers, and actively promoting urban co-generation. Because natural gas-steam THPC is an effective way to use natural gas and it has obvious environmental and social benefits, its application is strongly supported by relevant departments and agencies.

Funding for this project is reliable, with 70 percent of the total required investment coming from various loans and the other 30 percent from equity capital.

As mentioned, natural gas, the fuel of the project, is available from several sources. Besides Shaan-Gan-Ning Gas Field, increasing gas reserves have been found in recent years in west China (e.g., Qinhai Province and Xinjiang Autonomous Region), and plans to transport domestic natural gas from west to east China will be completed. With imported natural gas also available, Beijing will have a long-term stable and reliable natural gas supply.

This project has the close cooperation of technical research institutes so that good technical advice and support can be obtained.

8 Experience and Lessons Learned from Other Projects

Utilization of natural gas should follow the principle of “reduction of emissions and pollution, high efficiency and rationality.” Replacement of coal by natural gas is the most effective, rational and direct measure for controlling environmental pollution, and it is being adopted throughout the world. “High efficiency” means that the conversion of natural gas to useful energy should be high. “Rationality” means that the energy should be used for purposes that are appropriate to its quality. Co-generation is one of the most advanced and mature technologies available to satisfy this principle.

For several reasons, co-generation has not become well-established in China and has not been used to its full potential. Presently, in urban areas natural gas is often simply burned in boilers, which is not in accordance with the principle of grade-utilization of energy and does not contribute to reduction of NOx emissions. Thus, it can be concluded that, to some extent, natural gas resources are being wasted. With its high efficiency and low pollution, gas turbine co-generation can save energy and has led to the development of some reliable low-NOx combustion technologies.

In June 1999, the Orient Energy Development Corporation of Beijing Initiate Group proposed a program, entitled "Blue Sky in the Capital - Thermal Energy System Engineering," to install 20 co-generation units around Beijing with a capacity of 56 MW each and total annual natural gas consumption of 1.8 billion m^3. The program can supply space heating for 40 million m^2 of residential buildings, phase out a number of existing coal-fired boilers, and reduce air pollution—bringing back natural blue sky to Beijing. In addition, to meet the requirements for holding the 2008 Olympic Games, some hotels and restaurants in Beijing now intend to use mini gas turbine and heat recovery Li-Br air conditioners for THPC. However, little experience is available so far because all related projects are still in the development stages.

As a mature and advanced technology, tri-generation is applied broadly in the US, the UK, Japan, and a few other countries. Tri-generation projects for heating, power, and cooling are in place at Manchester Airport in England, and Tokyo, Japan has a district heating and cooling system. In the US, the more than 100 gas turbine co-generation units in universities have shown good environmental and economic benefits. As gas turbine technology continues to develop, co-generation systems will also improve. At the present time, the power industry around the world is moving toward miniaturization and dispersion. Developed countries are pursuing the transition from individual space heating boilers to medium- and small-size gas turbine co-generation and tri-generation, and China can learn from these experiences. Demonstration projects should be encouraged to help China acquire more experience with co-generation and tri-generation technologies.

9 Project Financial and Economic Analyses

9.1 Project Financial and Economic Analyses

Basic data, detailed calculations, and results of financial analysis are shown in Annex Tables 1-4. The financial cash flow table shows that: (a) the financial net present value (F-NPV) of the project is US$1.05-million; (b) the financial internal rate of return (F-IRR) is 8.32 percent, which exceeds the basic discount rate of 8 percent in this industry; and (c) the payback period is 16.8 years. These three indexes all indicate that investment in this project is viable.

Annex Table 5 shows the economic analysis for the project. Most of the items in this table are the same as the financial cash flow table. Because taxes and subsidies are moved from external income and expenditures to internal items when doing the national economic evaluation of projects, all tax items are excluded from the economic cash flow table. Analysis shows that economic net present value (E-NPV) of the project is US$67.38-million, and economic internal rate of return (E-IRR) is 26.11 percent.

9.2 Sensitivity Analysis

Results of the project's sensitivity analysis are summarized in Tables 3-6 and illustrated in Figures 2 and 3. They show the impacts on net present value and internal rate of return when key parameters, such as total investment, operation cost, and others are varied from -10 percent to 10 percent. For this project, both operation cost (mainly the price of natural gas) and the grid-in electricity price are the most sensitive, and also the most important, factors in deciding whether the project is financially viable. More detailed forecasts and analysis are needed for future natural gas price and grid-in electricity price.

Table 3 Impacts of Uncertain Factors on F-NPV (,000 US$)

	-10%	-5%	0	5%	10%
Total investment	5,892.99	3,472.14	1,051.28	-1,136.75	-3,796.94
Operation cost	14,950.28	8,014.38	1,051.28	-5,934.14	-13,045.53
Natural gas price	13,694.70	7,384.02	1,051.28	-5,299.52	-11,736.48
Grid-in electricity price	-18,975.61	-8,714.63	1,051.28	10,751.77	20,425.08
Heating price	-411.26	320.01	1,051.28	1,782.55	2,513.82
Cooling price	-296.03	377.63	1,051.28	1,724.94	2,398.59

Figure 2 Impacts of Uncertain Factors on F-NPV

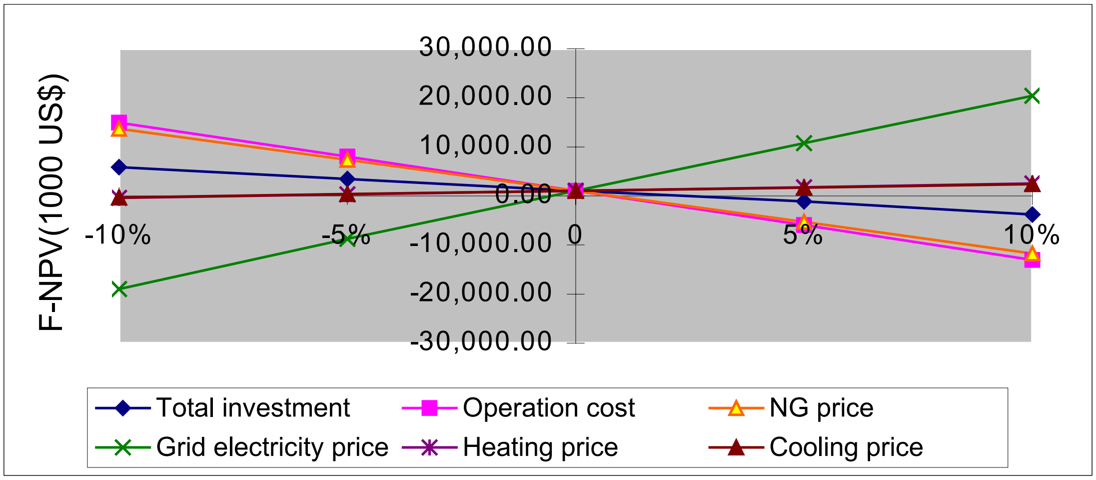


Table 4 Impacts of Uncertain Factors on F-IRR (%)

	-10%	-5%	0	5%	10%
Total investment	10.00%	9.12%	8.32%	7.60%	6.93%
Operation cost	12.53%	10.45%	8.32%	6.15%	3.90%
Natural gas price	12.15%	10.26%	8.32%	6.35%	4.32%
Grid-in electricity price	2.05%	5.27%	8.32%	11.27%	14.14%
Heating price	7.87%	8.10%	8.32%	8.55%	8.77%
Cooling price	7.91%	8.12%	8.32%	8.53%	8.74%

Table 5 Impacts of Uncertain Factors on E-NPV (,000 US$)

	-10%	-5%	0	5%	10%
Total investment	73,543.39	70,463.02	67,382.64	64,302.27	61,221.89
Operation cost	88,051.56	77,717,10	67,382.64	57,048.18	46,713.72
Natural gas price	86,181.07	76,781.86	67,382.64	57,983.43	48,584.21
Grid-in electricity price	38,057.27	52,719.96	67,382.64	82,045.32	96,708.01
Heating price	65,174.36	66,278.50	67,382.64	68,486.78	69,590.92
Cooling price	65,348.35	66,365.49	67,382.64	68,399.79	69,416.93

Figure 3 Impacts of Uncertain Factors on E-NPV (,000 US$)

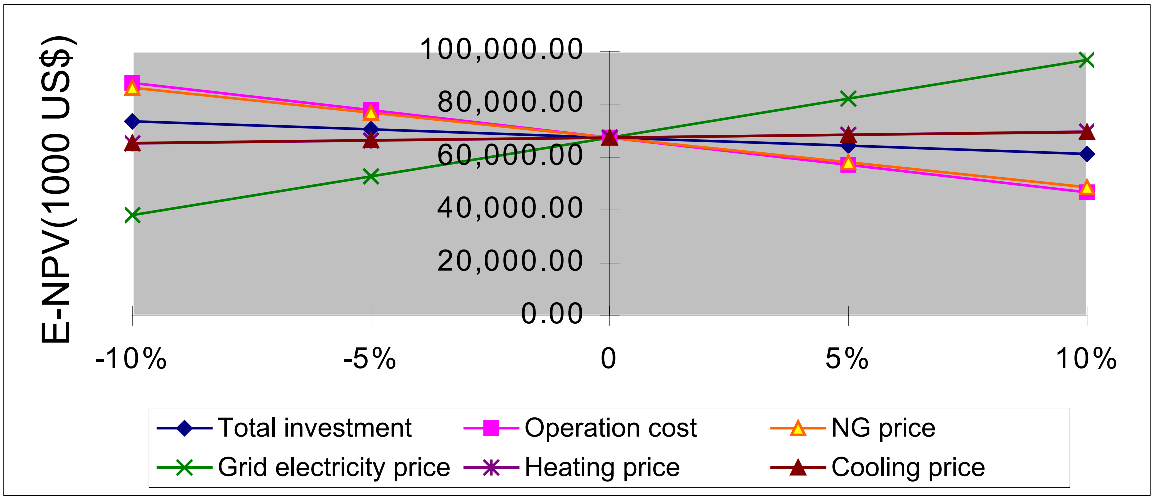


Table 6 Impacts of Uncertain Factors on E-IRR (%)

	-10%	-5%	0	5%	10%
Total investment	29.68%	27.82%	26.11%	24.55%	23.11%
Operation cost	31.24%	28.71%	26.11%	23.46%	20.76%
Natural gas price	30.78%	28.47%	26.11%	23.17%	21.26%
Grid-in electricity price	18.47%	22.34%	26.11%	29.77%	33.31%
Heating price	25.55%	25.83%	26.11%	26.39%	26.67%
Cooling price	25.60%	25.85%	26.11%	26.37%	26.63%

10 Project Risks

From the sensitivity analysis, it can be seen that natural gas price is an important factor influencing the economic viability of the project. In the calculation, the natural gas price is assumed to be 1.4 yuan/m^3 (US$0.169/m^3). If this price were to increase, the viability of the project would worsen. However, according to projections the long-term natural gas price will gradually decline. This is due mainly to economies of scale that are expected to result from expanded gas field production. As production expands, natural gas production costs will decrease, even though pipeline costs will more than double. Furthermore, international natural gas suppliers tend to offer more favourable prices to large industry users, especially power plants. Chinese regulations also note that because gas-steam turbine combined cycle tri-generation stabilizes natural gas consumption and helps meet peak grid demand, the price of natural gas should be rationalized for this use. Thus it is expected that the natural gas price in Beijing will decrease in the future and, for the tri-generation project, might be less than 1.4 yuan/m^3 (US$0.169/m^3).

The grid electricity price is another important factor. However, the current price does not reflect the environmental benefits of clean energy. If no relevant policies emerge to ensure a favourable grid electricity price for clean energy power generation projects, the economic benefits of these projects will be greatly compromised.

11 CO_2 Emission Reduction Analysis

11.1 Selection of Baseline Project

The project-specific approach was adopted for selecting baseline projects in this case study to ensure credibility, transparency, and operability of the selections. For the natural gas combined cycle tri-generation project, the baseline projects consist of three parts:

(a) As mentioned above, power supply in Beijing depends mainly on the North China Power Grid. Electricity for this grid is generated in Shanxi Province and Inner Mongolia Autonomous Region. Power plants selected as baseline projects should be newly built or expansions of existing plants in these regions, and they should fall within certain categories of coal-fired thermal power plants. The capacity of the CDM project is about 100 MW, which corresponds to a medium sized coal-fired plant. To improve energy efficiency, new coal power plants for 300 MW and 600 MW are being given priority in China. Data for the power supply baseline project in this study is mainly referenced to 300 MW coal-fired thermal power plants.

(b) Beijing's heating supply depends on various sizes of coal-fired boilers with capacities of 4 tonne-steam/hour, or ts/h (3.7 MW), 6.5 ts/h (6.0 MW), and 10 ts/h (9.2 MW). The heating supply baseline is calculated using average data of 4 ts/h, 6.5 ts/h and 10 ts/h industrial boilers in Beijing.

(c) Residential electrical air-conditioning, which is now widely installed in Beijing, was selected as the baseline case for cooling supply.

11.2 System Boundary Determination

In general, the system boundary of the CDM project involves all greenhouse gas emission sources related to the CDM project and the baseline projects. The usual approach is to choose the project's physical boundary as the system boundary. For this case study, before implementing the CDM project, space heating in the chosen district relied mainly on centralized coal-fired boilers, while electricity for residential and office air conditioning came mainly from the Beijing city grid. Therefore, the system boundary should be extended to cover CO_2 emissions associated with the fuels burned in the heating network and power grid. Electrical air conditioning used in houses and offices in Beijing relies on the city power grid. If only the CO_2 emissions from electricity end uses are considered in the cooling supply of the baseline project, the emission effect of direct electricity use would be near zero, leading to a lower total emissions level of the baseline project, and thus not reflecting the real emissions reduction of the CDM project. Therefore, the system boundary should be extended outward to include the CO_2 emissions of the coal-fired power plants that provide power to the Beijing grid.

11.3 Emission Leakage

Given the system boundary described above, emissions from the production of large amounts of energy-intensive material (such as steel and cement) used for constructing CDM and baseline projects, as well as emissions from extraction, transportation, and processing of natural gas and coal, are defined as indirect emissions outside the system and are treated as carbon leakage. The indirect emissions during project construction occur only once, and the emission difference between the CDM project and the baseline project is quite small. Furthermore, if the indirect emissions are allotted to the 25-year lifetime, the leakage amount can be ignored. Analysis shows that the sum of carbon leakage in various fuel processes amounts to only one percent of annual emissions reductions from the CDM project. Thus, impacts on the incremental cost of emissions reductions by this part of overall carbon leakage can also be ignored.

11.4 Credit Period for Emission Reductions

Three claim periods of seven years' each are assumed for the emissions reductions from each phase of the CDM project, for a total of 21 years for each phase.

.

11.5 Certified Emissions Reduction (CER) Production

Emissions reduction information for the baseline and CDM project is shown in Table 7.

Annual Emission Reduction = $AE_{Baseline}$ - AE_{CDM}

where:

$$AE_{Baseline} = (AS_{Electricity} \times CIE + AS_{Heat} \times CIH + AS_{Cooling} \times CIC) \times EF_{ce}$$

$$AE_{CDM} = NGC \times EF_{NG}$$

Table 7 Emissions Reductions Calculations

Symbols	Descriptions	Data
$AS_{Electricity}$	Annual electricity supplied by project	541 GWh/yr
AS_{Heat}	Annual heat supply supplied by project	750315.79 GJ/yr heat
$AS_{Cooling}$	Annual cooling supplied by project	225391.30 GJ/yr cooling
CIE	Baseline coal intensity per unit electricity	0.34 kgce/KWh
CIH	Baseline coal intensity for unit heat supply	42.7 kgce/GJ heat
CIC	Baseline coal intensity for unit cooling supply (electricity used by air conditioners)	94.4 kgce/GJ cooling
EF_{ce}	Emission factor for coal equivalent	0.726 kg-c/kgce
NGC	Natural gas consumption by CDM project	133.4 Mm^3
EF_{NG}	Emission factor for natural gas	0.485 kg-c/m^3
$AE_{Baseline}$	Annual emission of baseline project	1.722×10^8 kg-c
AE_{CDM}	Annual emission of CDM project	0.647×10^8 kg-c

Table 8 shows the expected annual production of certified emissions reductions from the CDM project, and the value of these CERs at different price levels.

Table 8 CER Production from the CDM Project

	CER Price	
CDM Project Emissions (ktonnes CO_2/year)		631
Baseline Plant Emissions (ktonnes CO_2/year)		237
Annual CER production (ktonnes/yr		394
Annual Income from Sale of CERs	US$5	$1,970,000
	US$10	$3,940,000
	US$15	$5,910,000

11.6 Calculation of Incremental Cost of Emission Reduction

The incremental cost of emissions reduction is estimated in Table 9.

$$IC = \frac{AC_{CDM} - AC_{Baseline}}{AE_{Baseline} - AE_{CDM}} \quad \text{where}$$

$$AC_{Baseline} = AC_{Electricity} + AC_{Heat} + AC_{Cooling}$$

$$AE_{Baseline} = (AS_{Electricity} \times CIE + AS_{Heat} \times CIH + AS_{Cooling} \times CIC) \times EF_{ce}$$

$$AE_{CDM} = NGC \times EF_{NG}$$

Table 9 Incremental Cost of Emissions

Symbols	Descriptions	Data
IC	Incremental cost for emission mitigation	US $95.07 /t-C or US$25.93 /t-CO_2
$AC_{Baseline}$	Annual cost of baseline project	19.34 million US$
AC_{CDM}	Annual cost of CDM project	29.56 million USS $
$AE_{Baseline}$	Annual emission of baseline project	1.722×10^8 kg-c
AE_{CDM}	Annual emission of CDM project	0.647×10^8 kg-c
$AS_{Electricity}$	Annual electricity supply	541 GWh/yr
AS_{Heat}	Annual heat supply	750315.79 GJ/yr
$AS_{Cooling}$	Annual cooling supply	225391.30 GJ/yr
CIE	Coal intensity for unit electricity	0.34 kgce/KWh
CIH	Coal intensity for unit heat supply	42.7 kgce/GJ
CIC	Coal intensity for unit cooling supply	94.4 kgce/GJ
EF_{ce}	Emission factor for coal equivalent	0.726 kg-c/kgce
NGC	Natural gas consumption	133.4 Mm^3
EF_{NG}	Emission factor for natural gas	0.485 kg-c/m^3
$AC_{Electricityy}$	Annual cost for electricity supply	14.99 MUS $
AC_{Heat}	Annual cost for heat supply	1.49 MUS $
$AC_{Cooling}$	Annual cost for cooling supply	2.86 MUS $

The natural gas tri-generation CDM project will produce significant environmental benefits. By replacing coal combustion with natural gas and improving energy efficiency, 0.40 million tonnes of CO_2 would be reduced annually during the lifetime of the CDM project.

The cost increase to obtain the CO_2 reduction will be 84.83 million yuan per year (US$10.22-million), making the incremental cost of emissions reductions from the natural gas tri-generation CDM project US$25.93/tonne of CO_2 or US$95.07/tonne of carbon.

Annex

Annex Table 1 Original Data

Total installed capacity (MW)	2×50
Annual electricity generation (TWh/year)	0.498
Annual utilization hours (Hour)	4700
Annual heat generation (TJ)	712.8
Annual chill generation (TJ)	207.36
Life time (year)	25
Natural gas price (US$/m^3)	0.169
Heating value of NG (kcal/m^3)	8421
Loan interest rate (%)	5.96
Loan repayment term (year)	15
Loan share (%)	70
Income tax rate (%)	33
Standard discount rate (%)	12

Annex Table 2 Sources of Investment

Capital	Loan (million US$)	Equity capital (million US$)
First year	35.42	15.18
Second year	15.18	6.51

Annex Table 3 Annual Operation Cost (Million US$)

Item	Cost
Fuel	21.93
Water	0.24
O&M	1.20
Salary	0.14
Welfare	0.12
Material	0.12
Other	0.34
Total	24.09

Annex Table 4 Financial Analysis (,000 US$)

Fiscal year	Investment				O & M	Gross income	VAT and additional tax plus	Benefit after VAT	Income Tax	Net Benefit after Income Tax
	Capital	Liability	Interest	Depreciation						
2002	15,180.7									-15180.72
2003	6,506.0									-6506.02
2004		3,723.7	3328.97	2,804.8	12,180.7	19,581.8	3,241.1	-1973.77	0.0	-2892.67
2005		3,723.7	3107.04	2,804.8	18,138.5	29,372.6	4,861.6	460.66	0.0	-458.24
2006		3,723.7	2885.11	2,804.8	24,096.4	39,163.5	6,482.1	2895.09	456.05	1520.14
2007		3,723.7	2663.18	2,804.8	24,096.4	39,163.5	6,482.1	3117.02	1028.63	1169.49
2008		3,723.7	2441.25	2,804.8	24,096.4	39,163.5	6,482.1	3338.95	1101.86	1318.19
2009		3,723.7	2219.32	2,804.8	24,096.4	39,163.5	6,482.1	3560.88	1175.1	1466.88
2010		3,723.7	1997.38	2,804.8	24,096.4	39,163.5	6,482.1	3782.82	1248.34	1615.58
2011		3,723.7	1775.45	2,804.8	24,096.4	39,163.5	6,482.1	4004.75	1321.58	1764.27
2012		3,723.7	1553.52	2,804.8	24,096.4	39,163.5	6,482.1	4226.68	1394.81	1912.97
2013		3,723.7	1331.59	2,804.8	24,096.4	39,163.5	6,482.1	4448.61	1468.05	2061.66
2014		3,723.7	1109.66	2,804.8	24,096.4	39,163.5	6,482.1	4670.54	1541.29	2210.35
2015		3,723.7	887.73	2,804.8	24,096.4	39,163.5	6,482.1	4892.47	1614.53	2359.04
2016		3,723.7	665.79	2,804.8	24,096.4	39,163.5	6,482.1	5114.41	1687.76	2507.75
2017		3,723.7	443.86	2,804.8	24,096.4	39,163.5	6,482.1	5336.34	1761	2656.44
2018		3,723.7	221.93	2,804.8	24,096.4	39,163.5	6,482.1	5558.27	1834.24	2805.13
2019				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2020				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2021				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2022				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2023				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2024				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52

Fiscal year	Investment				O & M	Gross income	VAT and additional tax plus	Benefit after VAT	Income Tax	Net Benefit after Income Tax
	Capital	**Liability**	**Interest**	**Depreciation**						
2025				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2026				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2027				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	6677.52
2028				2,804.8	24,096.4	39,163.5	6,482.1	5780.2	1907.48	12496.53

F-NPV = 1051.28
F-IRR = 8.32%

Annex Table 5 Economic Analysis (,000 US$)

Fiscal year	Investment				O&M	Gross income	Net Benefit
	Capital	Liability	Interest	Depreciation			
2002	15,180.7						-15180.72
2003	6,506.0						-6506.02
2004		3,723.7	3328.97	2,804.8	12,180.7	19,581.8	348.43
2005		3,723.7	3107.04	2,804.8	18,138.5	29,372.6	4403.36
2006		3,723.7	2885.11	2,804.8	24,096.4	39,163.5	8458.29
2007		3,723.7	2663.18	2,804.8	24,096.4	39,163.5	8680.22
2008		3,723.7	2441.25	2,804.8	24,096.4	39,163.5	8902.15
2009		3,723.7	2219.32	2,804.8	24,096.4	39,163.5	9124.08
2010		3,723.7	1997.38	2,804.8	24,096.4	39,163.5	9346.02
2011		3,723.7	1775.45	2,804.8	24,096.4	39,163.5	9567.95
2012		3,723.7	1553.52	2,804.8	24,096.4	39,163.5	9789.88
2013		3,723.7	1331.59	2,804.8	24,096.4	39,163.5	10011.81
2014		3,723.7	1109.66	2,804.8	24,096.4	39,163.5	10233.74
2015		3,723.7	887.73	2,804.8	24,096.4	39,163.5	10455.67
2016		3,723.7	665.79	2,804.8	24,096.4	39,163.5	10677.61
2017		3,723.7	443.86	2,804.8	24,096.4	39,163.5	10899.54
2018		3,723.7	221.93	2,804.8	24,096.4	39,163.5	11121.47
2019				2,804.8	24,096.4	39,163.5	15067.10
2020				2,804.8	24,096.4	39,163.5	15067.10
2021				2,804.8	24,096.4	39,163.5	15067.10
2022				2,804.8	24,096.4	39,163.5	15067.10
2023				2,804.8	24,096.4	39,163.5	15067.10
2024				2,804.8	24,096.4	39,163.5	15067.10
2025				2,804.8	24,096.4	39,163.5	15067.10

Fiscal year	Investment				O&M	Gross income	Net Benefit
	Capital	Liability	Interest	Depreciation			
2026				2,804.8	24,096.4	39,163.5	15067.10
2027				2,804.8	24,096.4	39,163.5	15067.10
2028				2,804.8	24,096.4	39,163.5	16758.05

E-NPV = 67,382.64
E-IRR = 26.11%