ECONOMIC ANALYSIS

A. Introduction and Background

1. The Air Quality Improvement in the Greater Beijing–Tianjin–Hebei (BTH) Region—Shandong Heating and Cooling Project is the fourth in a set of multiyear projects supported by the Asian Development Bank (ADB) that seek to support air quality improvement in the greater BTH region.[1] The project will invest in clean heating and cooling technologies to reduce energy consumption and air pollution from existing coal-based heating and cooling and electricity generation. The project will demonstrate the economic and financial viability of a comprehensive heating and cooling package that deploys diverse technologies to exploit Shandong Province's abundant renewable energy resources.

2. Shandong Province is the largest coal consumer in the People's Republic of China (PRC), with 79.3% of its primary energy consumption attributable to coal. Although coal consumption in the PRC peaked in 2013 and started to decline, in Shandong Province, coal use increased substantially from 364.7 million tons in 2011 to 409.3 million tons in 2015.[2] Heating and cooling demand in the province has been increasing in line with the rise in the population's economic welfare and a desire for improved comfort in the form of higher indoor temperatures during the winter and lower indoor temperatures during the summer. In the PRC, district cooling demand in buildings has increased by 9% per year since 2010. County- and city-level district heating networks have expanded by more than 10% a year since 2013. In Shandong Province, heating demand is expected to increase by about 9% during 2015–2020.[3]

3. High levels of coal consumption contribute to poor air quality in the province. In 2016, the annual average concentration of major air pollutants, such as particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$), was 73 micrograms per cubic meter (μg/m^3), or more than double the category II national ambient air quality standards.[4] Jinan city, the provincial capital, had the highest concentration of $PM_{2.5}$ attributable to coal use among 74 major cities in the PRC that year. The annual concentration of $PM_{2.5}$ in Jinan city specifically attributable to coal is 52 μg/m^3, or about 70% of total $PM_{2.5}$ concentration levels. During winter, driven by a demand for heating, the contribution of coal to $PM_{2.5}$ levels is even higher, at 61 μg/m^3, or 84% of total $PM_{2.5}$. Exposure to high levels of particulate matter and other air pollutants is associated with health risks such as cardiovascular and respiratory disease.

4. Considering the public health risks associated with severe air pollution, the Shandong Provincial Government has made air quality improvement a provincial-level priority, in line with national government priorities, and views restructuring its energy mix as key to realizing this objective. In 2012, the provincial government published the Action Plan for Air Pollution Control, 2013–2020. The plan targets a reduction in annual average $PM_{2.5}$ concentration levels to 49 μg/m^3 by 2020. The provincial government has implemented end-of-pipe measures, such as desulphurization, denitrogenation, and dust management of heavy industrial processes, in the effort to reduce $PM_{2.5}$ emissions. $PM_{2.5}$ emissions have steadily decreased since 2013, but further

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[1] The greater BTH region refers to Beijing and Tianjin municipalities; Hebei, Henan, Shandong, Shanxi, and Liaoning provinces; and Inner Mongolia Autonomous Region.

[2] Y. Zhang, C. Liu, K. Li, and Y. Zhou. 2018. Strategy on China's regional coal consumption control: A case study of Shandong province. *Energy Policy.* 112(X). pp. 316–327.

[3] Organisation for Economic Co-operation and Development and International Energy Agency. 2017. *District Energy Systems in China: Options for Optimisation and Diversification*. Paris.

[4] Jinan Municipal Government Bureau of Environmental Protection. 2016. *The 2016 Bulletin on the Jinan Municipal Air Quality.* Jinan.

efforts to reach the 2020 target will require reductions in coal consumption.

5. Substantial investments must be made to divest the heating and cooling (electricity) sector from coal-based generation and more energy-efficient technologies. Shandong Province can tap its diverse and abundant resources such as geothermal energy (2.3 billion tons of coal equivalent), natural gas, agricultural waste, and waste heat supply from heavy industries and surrounding provinces.

6. The proposed project responds directly to urgent government priorities to reduce coal consumption and improve air quality by (i) introducing more efficient methods and technology for heating and cooling, (ii) substituting coal with cleaner energy sources such as natural gas and renewable energy, and (iii) reducing raw coal burning among households. The three subprojects will deploy advanced clean heating and cooling technologies using business models that have the potential to be scaled-up across Shandong Province and the greater BTH region. The subprojects' economic impact includes (i) reduction of pollutants harmful to health and the human environment from energy savings, and (ii) reduced use of coal for heat and electricity production. The three subprojects are as follows.

7. **West Jinan Waste Heat Utilization and Clean Energy Subproject (Subproject 1).** The subproject will deploy four key types of clean heating technologies to help West Jinan transition to a coal-free heating supply by 2020. The project will (i) retrofit and expand an existing district heating network using large temperature difference waste heat exchange technology to enable long-distance transport of industrial waste heat for winter heat supply; (ii) construct a biomass-based combined heat and power plant that uses straw pellet feedstock to supply heat to an industrial park; (iii) develop and construct geothermal heating systems for residential areas; and (iv) deploy air and water heat pumps to deliver an efficient heating supply to residential areas without geothermal sources. These clean heating technologies will displace coal-based centralized heat and power generation.

8. **Shanghe Coal-Free Clean Heating Demonstration Subproject (Subproject 2).** This subproject will deploy five types of energy efficiency and clean heating technologies in Shanghe County to demonstrate the viability of a comprehensive clean heating program at the county level. The subproject will (i) retrofit exterior walls and windows in 100 urban residential buildings, and retrofit roofs and install insulation curtains for 30,000 residents living in rural areas; (ii) develop and construct deep-well geothermal district heating systems in urban Shanghe County and 10 semi-urban towns; (iii) deploy air, water, and ground source heat pumps; electric radiators; and carbon crystal electric heating plates to deliver efficient heating supply to urban and rural residential areas with no geothermal potential or heating network; (iv) replace a 58-megawatt (MW) coal boiler with a 42 MW gas boiler; and (v) deploy modular gas boilers to serve a heating area of 10.2 million square meters in areas with a central heating network but no geothermal potential. These clean heating technologies will displace raw coal burning and coal-based centralized heat generation.

9. **East Jinan Low-Emission Combined District Heating and Cooling Subproject (Subproject 3).** The subproject will (i) expand and retrofit Jinan city's district heating network to use waste heat in place of coal; (ii) install a 30 MW electrode boiler that delivers heat in the evenings during off-peak hours for electricity; and (iii) construct a district cooling system that uses highly efficient large-scale chilling facilities (lithium bromide absorption chillers, ice storage air conditioning, and electric cooling equipment) that use off-peak electricity for cool storage and provide centralized cooling during peak hours. The efficient heating and cooling network and

facilities will displace coal and natural gas use in boilers and result in coal-based electricity cost savings by replacing individual air conditioning units in the building stock.

10. A complete description of the subprojects can be found in the Technical Due Diligence Report.[5]

11. ADB and the implementing agencies (the Jinan Thermal Power Company and the Jinan Heating Group) agreed on various subproject economic viability criteria, including (i) the total economic benefits must exceed the total economic costs; and (ii) the economic internal rate of return (EIRR) must be greater than the discount rate of 6%—the assumed social opportunity cost of capital—and must be viable under adverse sensitivity scenarios.

B. Quantifying Project Benefits

12. **Economic benefits.** The economic benefits of the subprojects are incremental, nonincremental, and external. Incremental benefits included in the economic analysis are attributed to improved quality and reliability of heat supply newly expanded areas of heat supply. ADB conducted willingness-to-pay studies in Jinan city and Shanghe County to estimate the value of incremental benefits. The incremental benefit of installing an improved heating supply in new residential buildings in Shanghe County is valued at CNY900. Respondents in Jinan city were willing to pay CNY1 more than the current tariff for clean heat supply.[6] Nonincremental benefits included in the economic analysis are savings from coal use and the external benefits of reducing carbon dioxide emissions and local pollutants, including emissions of sulfur dioxide, nitrogen oxides, and particulate matter including $PM_{2.5}$. Detailed supplementary materials that describe the economic analysis conducted for each subproject are included in a linked supplementary document.[7]

13. **External benefits from pollution abatement.** The subprojects reduce the amount of pollution that would otherwise have been emitted from burning raw coal and coal-based heat and electricity generation. These pollutant savings have considerable benefits to human health and the environment. Local environmental benefits from local pollutant emissions abatement are valued by estimating the cost of premature mortality and reduced productivity (labor loss) associated with coal burning. The cost of premature mortality was calculated using the value of life years lost from an increase in local pollution concentrations in Ningbo city, and then accounting for differences in the working population between the cities of Ningbo and Jinan.[8] The impact of reduced productivity was calculated using a comprehensive study of many manufacturing firms across several years in the PRC that measured the effect on industrial output of a 1 microgram per cubic meter increase in pollution.[9] The cost of pollution also included the cost of pneumonia treatment among children associated with coal burning and parents' productivity loss.[10] Finally, local pollution externalities included physical damage such as agriculture productivity losses and

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[5] Technical Due Diligence Report (accessible from the list of linked documents in Appendix 2 of the Report and Recommendation of the President).

[6] Social Survey Report (accessible from the list of linked documents in Appendix 2 of the Report and Recommendation of the President).

[7] Detailed Economic Analysis of the Subprojects (accessible from the list of linked documents in Appendix 2 of the Report and Recommendation of the President).

[8] T. He, et al. 2016. Ambient Air Pollution and Years of Life Lost in Ningbo, China. *Scientific Reports.* 6(1). pp. 22485.

[9] S. Fu, B. Viard, and P. Zhang. 2017. *Air Quality and Manufacturing Firm Productivity: Comprehensive Evidence from China*. Hongkong.

[10] C. Lv, et al. 2017. The Impact of Airborne Particulate Matter on Pediatric Hospital Admissions for Pneumonia among Children in Jinan, China: A Case-Crossover Study. *Journal of the Air & Waste Management Association*. 67(6). pp. 669–676.

building damage caused by acid rain.[11] Table 1 shows the amount of pollution avoided by subproject.

Table 1: External Environmental Benefits of the Subprojects
(tons)

Pollutant	Subproject 1	Subproject 2	Subproject 3
Coal savings	1,167,533	113,718	87,754
Carbon dioxide	3,290,792	476,806	226,745
Sulfur dioxide	3,771	1,307	269
Nitrogen oxides	3,615	645	276
Particulate matter	425	1,303	45
Particulate matter 2.5	394	996	40

Note: Base case emissions result from coal and natural gas burning as well as electricity generation. The amount of pollution per ton of coal is 2.62 tons of carbon dioxide, 3.12 kilograms (kg) of sulfur dioxide, 3.12 kg of nitrous oxides, 0.52 kg of particulate matter less than 10 micrometers in diameter, and 0.46 kilograms of particulate matter less than 2.5 micrometers in diameter. Additional emissions are avoided by more efficient use of natural gas and electricity.
Source: Asian Development Bank estimates

C. Economic Costs

14. Financial cost estimates were adjusted to economic costs by eliminating price contingencies and transfer payments, such as taxes and financial charges (interest during construction and working capital), and applying shadow pricing. The operating life of all subprojects is 25 years, consistent with the installations' technical useful life. The residual value at the end of project life is assumed to be 5% of property, plant, and equipment. All prices and costs are expressed in real values at the domestic level in 2018 prices. Physical contingencies are added to each capital expenditure component with an allowance of 8.3%.

15. Most capital costs (80%) and operating costs were assumed to consist of traded goods or services. The financial costs of traded goods were adjusted to economic costs by adjusting domestic prices with a shadow exchange rate factor of 1.03, which is the multiplicative inverse of standard conversion factors used for recent ADB projects in the PRC.[12] Most labor inputs (90%) were assumed to come from skilled labor. A shadow wage rate factor of 0.8 was applied to unskilled labor, given the PRC's surplus of unspecialized labor (a factor of 1 was used for skilled labor).

[11] F. Zhang, and X. Yang. 2015. Social and Economic Loss Assessment of China's Air Pollution during the Transition Period. *Journal of Hebei University of Economics and Business.* 36(4). pp. 87–94.

[12] ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Loan to the People's Republic of China for the Hebei Energy Efficiency Improvement and Emission Reduction Project.* Manila; and ADB. 2011. *Report and Recommendation of the President to the Board of Directors: Proposed Loan to the People's Republic of China for the Shandong Energy Efficiency and Emission Reduction Project.* Manila.

D. Estimation of the Economic Internal Rate of Return

16. Table 3 shows the EIRRs for the subprojects. In each case, the EIRR exceeds the economic opportunity cost of capital of 6% when global environmental benefits are considered. When global environmental effects are excluded, the economic net present value (at 6%) is negative for subproject 1, East Jinan.

Table 3: Net Economic Benefits of Subprojects
(CNY million)

Item	Subproject 1	Subproject 2	Subproject 3
ENPV with global environmental benefits	13,633.6	1,896.19	482.4
ENPV without global environmental benefits	4,865.8	332.33	(261.3)
EIRR (%) with global environmental benefits	43.96	33.2	14.22
EIRR (%) without global environmental benefits	28.23	10.2	0.40

( ) = negative, EIRR = economic internal rate of return, ENPV = economic net present value.
Source: Asian Development Bank estimates.

E. Sensitivity Analysis

17. A sensitivity analysis was conducted to test how robust the EIRRs are to changes in the underlying assumptions. The effect on the subproject EIRRs of an increase in capital costs, operating costs, and a 2-year delay in construction is minor. In the case of East Jinan, a 2-year delay improved the economic viability because construction costs were more spread out, while benefits were still able to be accrued during construction. The subprojects' EIRRs exceed the social opportunity cost of capital under all scenarios (Table 4). When global environmental benefits are excluded, the EIRRs remain robust except in the case of the East Jinan subproject (Table 5).

Table 4: Sensitivity Analysis of the Economic Internal Rate of Return Including Global Environmental Benefits
(%)

Subproject	Subproject Name	Base Case	Case 1: CAPEX +20%	Case 2: OPEX +10%	Case 4: 2-year delay
1	West Jinan	43.0	38.8	37.3	28.8
2	Shanghe Demonstration	33.2	22.4	30.3	20.6
3	East Jinan	14.2	11.2	11.6	14.1

CAPEX = capital expenditure, OPEX = operating expenditure.
Source: Asian Development Bank estimates.

Table 5: Sensitivity Analysis of the Economic Internal Rate of Return Without Global Environmental Benefits
(%)

Subproject	Subproject Name	Base Case	Case 1: CAPEX +20%	Case 2: OPEX +10%	Case 3: 2-year delay
1	West Jinan	28.2	22.6	25.1	24.4
2	Shanghe Demonstration	10.2	6.8	8.5	7.3
3	East Jinan	0.4	(1.2)	(3.9)	0.0

( ) = negative, CAPEX = capital expenditure, OPEX = operating expenditure.
Source: Asian Development Bank estimates.