DETAILED ECONOMIC ANALYSIS OF THE SUBPROJECTS

I. WEST JINAN WASTE HEAT UTILIZATION AND CLEAN ENERGY SUBPROJECT

1. **Project objective.** The subproject will (i) retrofit West Jinan's existing district heating network to deliver industrial waste heat using efficient large-temperature difference heat exchange technology; (ii) build a 2×75 tons plus 2×15 megawatt (MW) biomass combined heat and power (CHP) plant that uses nearby agricultural waste as feedstock; (iii) install distributed air source, water source, and ground source heat pumps for residences; (iv) build deep well geothermal systems for residential areas; and (v) deploy distributed gas-fired boilers for four new residential communities. The subproject's five components will displace coal-based centralized heat and power generation as well as individual residential coal-fired boilers. The subproject will result in in energy savings of about 1,167,533 tons of coal equivalent (tce) per year and avoid 3,290,792 tons of carbon dioxide (CO_2), 3,771 tons of sulfur dioxide (SO_2), 3,595 tons of nitrogen oxides (NO_x), 425 tons of particulate matter less than 10 micrometers in diameter (PM_{10}), and 394 tons of particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$).

2. **Project rationale.** Jinan City is the economic center of Shandong and an important provincial capital in northern People's Republic of China (PRC). Its size and density, however, presents a challenge because it is highly dependent on coal for electricity and heating.[1] Coal burning releases many pollutants into air, causing haze and increasing the risk of cardiovascular and respiratory problems among the population. In 2016, Jinan city had the highest concentration of $PM_{2.5}$ attributable to coal use among 74 major cities in the PRC and ranked ninth in the province for the poorest air quality. West Jinan has indigenous geothermal and biomass resources and can tap on waste heat capacity from areas outside the city and from neighboring provinces. By drawing on these alternative energy resources, Jinan City can reduce its coal consumption, its associated emissions, and thereby improve air quality in the province.

3. The technologies deployed under this subproject can provide substantial cost savings and reductions in pollution emissions through the displacement of coal use in electricity and heat production and load shifting. The project will retrofit West Jinan's existing district heating network to deliver industrial waste heat using efficient large-temperature difference heat exchange technology. Long distance district heating networks are considered 4th generation district heating technologies; they often require lower network temperatures and or use advancements in materials for pipes and fluids used in heat exchanges to deliver heat supply efficiently across long distances.[2] More specifically, the large temperature differential technology for long distance district heating proposed in this project can supply 50% more heat than traditional district heat networks. The biomass CHP plant proposed for this subproject will use agricultural waste (straw) from farms surrounding Jinan city (at a 50 kilometer [km] radius) as feedstock.[3] The agricultural waste will be converted into straw pellets and briquets at collection and production centers to maximize the energy density of the fuel, as well as facilitate transport and storage. Farmers and small business owners will receive a boost to their incomes because surrounding farms and collection centers will be the source of the agricultural waste. Where feasible, the subproject will

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[1] 79.3% of Jinan province's primary energy consumption is attributable to coal.

[2] OCED/IEA. 2016. *District Heating Business Models and Policy Solutions; Unlocking the Potential from Low-Grade Industrial Excess Heat in China,* Paris.

[3] The surrounding farms produce 1.6 million tons of waste a year, of which 283,000 tons can be used for the CHP plant.

construct deep well geothermal systems to supply heating to communities. Where it is not technically or economically feasible for geothermal development or expansion of the district heating network, cleaner and more efficient technologies such as distributed air source, water source, ground source heat pumps, and distributed gas boilers will be constructed.

4. Several alternatives to deep well geothermal development such as shallow-ground source heating and solar thermal heaters were considered for the project. Shallow-ground source heating has relatively lower capital costs and has minimal impact on groundwater resources. When compared to a deep well geothermal system, more shallow wells are needed to serve the same heating area. Shallow well systems also require more electricity to heat water than deep well systems. For these reasons, a deep well system with reinjection wells and a tail end water filtration system (to improve well sustainability) was chosen for the subproject. Jinan City has already developed solar thermal systems in apartment blocks and hotels. Solar thermal systems are, however, less reliable and effective for winter heating.

5. **Economic benefits.** The economic analysis of the project was conducted in accordance with the Asian Development Bank's Guidelines for the Economic Analysis of Projects.[4] The economic benefits for the subproject include (i) coal fired heat and electricity generation savings, which is estimated as the net amount of energy saved to heat about 8.4 million square meters (m^2), based on the coal consumption intensity (0.014 tce/m^2) of the implementing agency's coal fired boilers during the 2017–2018 heating season; (ii) incremental benefits of deploying distributed gas boilers to four newly built communities (980,000 m^2) where there is currently no district heating network; and (iii) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

6. The subproject will result in energy savings (non-incremental benefit) of about 1,167,533 tce per year. The energy saved per year was valued at the average 2018 delivered heat fuel cost of (CNY1,310/tce), accounting for boiler efficiency.[5]

7. The incremental benefit associated with the expansion of heat supply in four new residential communities through the construction of gas fired boilers is CNY0.98 million per year. The benefits were valued at Shanghe County households' willingness to pay above the current tariff (CNY1/m^2) for centralized heating supply.[6]

8. Global environmental benefits from CO_2 abatement are valued at the 2016 global social cost of carbon of $36.30 per ton of CO_2, adjusted to 2018 price levels (CNY241/ton), and increased annually by 2% to reflect the potential increase in marginal social costs of climate change over time. Local environmental benefits from local pollutant emissions abatement are valued by estimating the cost of premature mortality and reduced productivity (labor loss) associated coal burning. The cost of premature mortality was calculated using the value of life years lost from an higher pollution concentrations in Ningbo, and then accounting for differences in working population between Ningbo and Jinan.[7] The impact of reduced productivity was

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[4] ADB. 2017. *Guidelines for the Economic Analysis of Projects*. Manila.

[5] OCED/IEA. 2017. *District Energy Systems in China: Options for Optimization and Diversification,* Paris. Coal fuel cost based on mid-point value in Table 4 on the heat fuel price of coal fired generation. 2017 prices were adjusted to 2018 prices, converted from United States dollars using historic exchange rates and inflation rates.

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

[7] Taifeng He et al. 2016. Ambient Air Pollution and Years of Life Lost in Ningbo, China. *Scientific Report. 6. Pp. 22485*

calculated using a comprehensive study covering many manufacturing firms across several years in China, that measured the effect of a one μ/m^3 increase in pollution on output.[8] The cost of pollution also included the cost of pneumonia treatment among children associated with coal burning as well as including parents' productivity loss.[9] These costs were converted into a social cost of coal by comparing the average pollution concentrations above the WHO standard in Jinan with the amount of coal that was burned in 2016. The social cost of coal in Jinan is CNY 595.29 per ton. Finally, local pollution included physical damages such as building damages caused by SO_2-induced acid rain.[10] The cost of building damage is valued at CNY3,260 per ton of SO2.Table 1 shows the expected energy savings and pollution mitigated from the proposed retrofits.

Table 1: Estimated Energy Savings and Pollutant Mitigation[11]

Energy Savings (tce)			1,167,533		
	CO_2	**SO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Total reference case emissions (ton)	3,350,118	3,814	3803	641	572
Project emissions (ton)	59,326	43	208	216	178
Emission reduction(ton)	3,290,792	3,771	3,595	425	394

CO_2 = carbon dioxide, NO_x = nitrogen oxides, PM= particulate matter, SO_2 = sulfur dioxide, tce = ton of coal equivalent.

9. **Economic costs.** The project lifespan is expected to last 25 years with a construction period of 5 years for urban and township components of the project and 1 year for the rural component. The residual value of the project is 5% of civil works, equipment and materials. 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 the appropriate conversion factors. All prices and costs are expressed in 2018 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 8.3%. The shadow exchange rate factor of 1.03 was used to estimate the shadow price of tradeable goods.[12] Eighty percent of the subproject's inputs was assumed to be tradable. 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). Skilled labor is assumed to account for 90% of labor inputs while unskilled labor accounted for 10%.

10. **Economic internal rate of return calculation.** The economic internal rate of return (EIRR) and the economic net present value (ENPV) for the project are shown in Table 2. The subproject has an ENPV at a 6% social discount rate of CNY13,634 million when global environmental benefits (CO_2 reduction) are included. The EIRR is well above the 6% threshold at 43%. The main benefit of this subproject is the substantial reduction in coal use for heating as well as incremental heat supply for newly-built residential areas.

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[8] Shihe Fu et al. 2017. Air Quality and Manufacturing Firm Productivity: Comprehensive Evidence From China.

[9] Chenguang 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, DOI: 10.1080/10962247.2016.1265026

[10] Zhang Fenglin, and Yang Xiao. 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.

[11] Base case emissions result from coal and natural gas burning as well as electricity generation. The amount of pollution for every ton of coal is 2.62 tons of carbon dioxide, 3.12 kilograms of sulfur dioxide, 3.12 kilograms of nitrogen oxides, 0.52 kilograms of PM10, and 0.46 kilograms of PM2.5. Extra emissions are avoided by more efficient use of natural gas and electricity.

[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.

Table 1: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Incremental and non-incremental benefits	Avoided Pollution (local)	Avoided Pollution (global)	Net Economic Benefits
2019	-605.74	0.00	0.00	0.00	0.00	-605.74
2020	-267.33	0.00	0.00	0.00	0.00	-267.33
2021	-172.90	0.00	0.00	0.00	0.00	-172.90
2022	-423.41	0.00	0.00	0.00	0.00	-423.41
2023	-243.65	0.00	0.00	0.00	0.00	-243.65
2024	0.00	(773.62)	1530.49	707.31	874.52	2338.69
2025	0.00	(1061.55)	1530.49	707.31	892.01	2068.26
2026	0.00	(1349.48)	1530.49	707.31	909.85	1798.17
2027	0.00	(1637.41)	1530.49	707.31	928.05	1528.44
2028	0.00	(1637.41)	1530.49	707.31	946.61	1547.00
2029	0.00	(1637.41)	1530.49	707.31	965.54	1565.93
2030	0.00	(1637.41)	1530.49	707.31	984.85	1585.24
2031	0.00	(1637.41)	1530.49	707.31	1004.55	1604.94
2032	0.00	(1637.41)	1530.49	707.31	1024.64	1625.03
2033	0.00	(1637.41)	1530.49	707.31	1045.13	1645.52
2034	0.00	(1637.41)	1530.49	707.31	1066.03	1666.43
2035	0.00	(1637.41)	1530.49	707.31	1087.35	1687.75
2036	0.00	(1637.41)	1530.49	707.31	1109.10	1709.49
2037	0.00	(1637.41)	1530.49	707.31	1131.28	1731.67
2038	0.00	(1637.41)	1530.49	707.31	1153.91	1754.30
2039	0.00	(1637.41)	1530.49	707.31	1176.99	1777.38
2040	0.00	(1637.41)	1530.49	707.31	1200.53	1800.92
2041	0.00	(1637.41)	1530.49	707.31	1224.54	1824.93
2042	0.00	(1637.41)	1530.49	707.31	1249.03	1849.42
2043	82.53	(1637.41)	1530.49	707.31	1274.01	1956.93
ENPV (CNY million) – with global environment benefits						13,633.57
ENPV (CNY million) – without global environment benefits						4,865.77
EIRR (%) – with global environment benefits						42.96
EIRR (%) – without global environment benefits						28.23

() = negative, EIRR = economic internal rate of return, ENPV = economic net present value.
Social discount rate = 6%
Source: Asian Development Bank estimates.

11. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in CAPEX and OPEX, and to decreases in the marginal cost of climate change of CO_2. Table 3 indicates that the EIRR remains well above the 6% social discount rate under all sensitivity scenarios.

Table 2: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 10%	2- year delay
EIRR – with global environment benefit	42.96	38.77	41.43	36.74
EIRR – without global environment benefit	28.23	24.62	25.07	24.44

CAPEX = capital expenditure, EIRR = economic internal rate of return, OPEX = operational expenditure.

II. ECONOMIC ANALYSIS OF SHANGHE COAL-FREE CLEAN HEATING DEMONSTRATION SUBPROJECT

12. **Project objective.** The subproject will: (i) retrofit existing residential buildings by adding thermal insulation to walls, rooftops, and windows; (ii) construct a new geothermal district heating system for new and rebuilt residential areas; (iii) distributed air source heat pumps in areas that cannot be served by the geothermal heating system; (iv) introduce ground source heating and cooling for commercial buildings; (v) replace a coal-fired boiler with a 42 MW gas boiler to provide peaking adjustments for the geothermal district heating system; (vi) deploy modular gas boilers in areas that cannot be served the geothermal district heating system, and (vi) distribute various clean heating technologies for rural households and kindergartens, such as air source heat pumps, gas heaters, electric radiators, and carbon crystal electric heating plates. The subproject will transform Shanghe to a coal-free county by demonstrating the economic and financial viability of a comprehensive package of clean heating projects at the county level. The subproject will result in in energy savings of about 113,718 tce per year and avoid 476,806 tons of CO_2, 1,306 tons of SO_2) 645 tons of NO_x, 1,303 tons of PM_{10}, and 996 tons of $PM_{2.5}$.

13. **Project rationale.** Air pollution in Shandong province, largely attributed to coal, is severe. In 2016, the annual average concentration of $PM_{2.5}$ (73 μg/m³) and PM_{10} (144 μg/m³) was more than two times the category II national air quality standards. Particulate matter emissions are exacerbated during winter by heat production from coal fired boilers and from the use of inefficient traditional stoves and household level boilers that use coal or straw as feedstock. The burning of raw coal burning is associated with increased health risks such as cardiovascular and respiratory disease due to the coal's high sulphur content and direct inhalation of particulate matter borne from incomplete combustion. Shanghe is a county in Shandong province that has experienced rapid rural growth and increasing living standards. Its urban center currently relies on a district heating network served by two 58 MW coal fired boilers for heat supply, while surrounding township areas rely on distributed coal-fired boilers. In the rural areas of Shanghe County, most of its households still rely on traditional stoves that use raw coal or loose straw.

14. The subproject will modernize Shanghe County's heating supply to reduce air pollution and improve energy efficiency by (i) distributing energy efficient heat technologies to rural households, (ii) integrating the use of abundant local energy resources (geothermal) in the county's heating mix and systems, and (iii) substituting coal for natural gas.

15. The subproject will demonstrate the health and heat quality benefits of energy efficient heating technologies to rural households. Current heating options in Shanghe County include bee hive stoves, loose straw burning, and raw coal burning. Rural households are at considerable risk of developing cardiovascular and respiratory diseases from prolonged exposure to the fumes from inefficient and highly polluting traditional stoves and least likely to be able to afford cleaner heating technologies or have lower awareness of their availability.

16. The subproject will construct "geothermal heat plus" systems, exploiting Shanghe County's vast geothermal and natural gas resources. These systems will utilize geothermal energy to meet heating base load and gas boilers to meet peak demand. Geothermal systems require high initial capital outlays, but have relatively low operations cost, low to no emissions, and can provide baseload heat supply. Natural gas boilers have relatively low capital costs, high efficiency, relatively low emissions when compared to coal boilers, and can serve as peaking plants because they can adjust quickly to changes in load. The combination of these technologies will increase the energy efficiency, reduce emissions, and improve the heat quality of district heating services in Shanghe County. Since geothermal resources are highly site specific,

advanced heating technologies will be deployed in areas that cannot be feasibly served by geothermal systems. The specific technical advantages of these technologies—air source heat pumps, gas heaters, carbon crystal electric heating plates, shallow-ground source heating and cooling and electric radiators—are described in the technical due diligence report.

17. **Economic benefits.** The economic analysis of the subproject was conducted in accordance with the Asian Development Bank's Guidelines for the Economic Analysis of Projects.[13] The economic benefits for the subproject include (i) coal-fired heat and electricity generation savings, which is estimated as the net amount of coal saved to heat an area of around 7.8 million square meters (m^2); (ii) the incremental benefit of supplying heat to 60,000 households, in which a WTP survey in Shanghe County found respondents were willing to pay CNY900 for installation; (iii) the energy saved through energy efficiency retrofits, such as wall, window and roof insulation for 100 urban buildings (totaling 660,400 m^2) and for 30,000 households in rural areas (covering 1.5 million m^2); and (iv) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

18. The subproject will result in energy savings (non-incremental benefit) of about 113,718 tce per year. The energy saved per year was valued at the average 2018 delivered heat fuel cost of coal (CNY 1,310/tce), accounting for boiler efficiency, and electricity generation (CNY 0.23/kWh) in the PRC, adjusted to 2018 prices and excluding VAT.[14]

19. Global environmental benefits from CO_2 abatement are valued at the 2016 global social cost of carbon of $36.30 per ton of CO_2, adjusted to 2018 price levels (CNY241/ton), and increased annually by 2% to reflect the potential increase in marginal social costs of global warming over time. Local environmental benefits were calculated using the same methodology for Subproject 1, however affects of pollution on productivity are adjusted for rural wages and output, and the cost of SO2 includes damages to crops. The social cost of coal is calculated at CNY225.57 per ton and the cost of SO2 is calculated at CNY4,409 per ton. Table 7 shows the expected energy savings and pollution mitigated from the proposed subproject.

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[13] ADB. 2017. *Guidelines for the Economic Analysis of Projects*. Manila.

[14] OCED/IEA. 2017. *District Energy Systems in China: Options for Optimization and Diversification,* Paris. Coal fuel cost based on mid-point value in Table 4 on the heat fuel price of coal fired generation. 2017 prices were adjusted to 2018 prices, converted from United States dollars using historic exchange rates and inflation rates.

Table 7: Estimated Energy Savings and Pollutant Mitigation

Energy Savings (tce)	113,718				
	CO_2	**SO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Total reference case emissions (ton)	810,210	1,463	885	1,342	1,020
Project emissions (ton)	333,314	156	240	38	24
Emission reduction(ton)	476,806	1,306	645	1303	996

CO_2 = carbon dioxide, NO_x = nitrogen oxides, PM= particulate matter, SO_2 = sulfur dioxide, tce = ton of coal equivalent.

20. **Economic costs.** The project lifespan is expected to last 25 years including a construction period of five years. The residual value of the project is 5% of civil works, equipment and materials. 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 the appropriate conversion factors. All prices and costs are expressed in 2018 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 8.3%. The shadow exchange rate factor of 1.03 was used to estimate the shadow price of tradeable goods.[15] 90% of the subproject's inputs was assumed to be tradable. 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). 80% of labor inputs were assumed to come from skilled labor and 10% from unskilled labor.

21. **Economic internal rate of return calculation.** The economic internal rate of return (EIRR) and the economic net present value (ENPV) for the project are shown in Table 8. The subproject has an ENPV at a 6% social discount rate of CNY1,956 million when global environmental benefits (CO_2 reduction) are included. The EIRR is well above the 6% threshold at 33%. The main benefit of this subproject is the substantial reduction in CO_2 compared to the reference scenario.

[15] 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.

Table 8: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Incremental and non-incremental benefits	Avoided Pollution (local)	Avoided Pollution (global)	Net Economic Benefits
2019	-70.19	-26.85	129.33	6.28	22.95	61.53
2020	-207.36	-41.22	153.53	12.56	46.82	-35.66
2021	-514.72	-63.29	177.73	18.85	71.64	-309.80
2022	-406.16	-88.53	201.93	25.13	97.43	-170.21
2023	-388.83	-122.38	226.13	31.41	124.23	-129.44
2024	0.00	-124.48	226.13	31.41	126.71	259.77
2025	0.00	-124.48	226.13	31.41	129.24	262.30
2026	0.00	-124.48	226.13	31.41	131.83	264.89
2027	0.00	-124.48	226.13	31.41	134.47	267.52
2028	0.00	-124.48	226.13	31.41	137.15	270.21
2029	0.00	-124.48	226.13	31.41	139.90	272.96
2030	0.00	-124.48	226.13	31.41	142.70	275.75
2031	0.00	-124.48	226.13	31.41	145.55	278.61
2032	0.00	-124.48	66.13	31.41	148.46	124.49
2033	0.00	-124.48	226.13	31.41	151.43	284.49
2034	0.00	-124.48	226.13	31.41	154.46	287.52
2035	0.00	-124.48	226.13	31.41	157.55	290.61
2036	0.00	-124.48	226.13	31.41	160.70	293.76
2037	0.00	-124.48	226.13	31.41	163.91	296.97
2038	0.00	-124.48	226.13	31.41	167.19	300.25
2039	0.00	-124.48	226.13	31.41	170.53	303.59
2040	0.00	-124.48	226.13	31.41	173.95	307.00
2041	0.00	-124.48	226.13	31.41	177.42	310.48
2042	0.00	-124.48	226.13	31.41	180.97	314.03
2043	75.07	-124.48	226.13	31.41	184.59	392.72
ENPV (CNY million) – with global environment benefits						1,896.19
ENPV (CNY million) – without global environment benefits						332.33
EIRR (%) – with global environment benefits						33.15
EIRR (%) – without global environment benefits						10.23

() = negative, EIRR = economic internal rate of return, ENPV = economic net present value.
Social discount rate = 6%
Source: Asian Development Bank estimates.

22. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in capital expenditure and operating expenditure, and to a 2-year delay in project construction. Table 9 indicates that the EIRR remains above the 6% social discount rate under all sensitivity scenarios when global environmental benefits are included. The EIRR also remains above the social discount rate when global environmental effects are excluded.

Table 9: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 10%	2-year delay
EIRR – with global environment benefit	33.15	22.41	30.28	20.60
EIRR – without global environment benefit	10.23	6.75	8.52	7.29

CAPEX = capital expenditure, EIRR = economic internal rate of return, OPEX = operational expenditure.

III. EAST JINAN LOW-EMISSION COMBINED DISTRICT HEATING AND COOLING SUBPROJECT

23. **Project objective.** The subproject will (i) retrofit and expand Jinan City's existing district heating network to utilize industrial waste heat in place of coal; (ii) install a 30 MW electrode boiler that stores heat using off peak electricity and delivers heat in the evenings during peak heating hours; and (iii) construct a district cooling system that uses highly efficient large scale chilling facilities (lithium bromide absorption chillers for cold water delivery, ice storage air conditioning and electric cooling equipment for air conditioning) that use off peak electricity for cool storage and provides centralized cooling during peak hours of the day. The subproject will result in in energy savings of about 87,754 tce per year and avoid 226,745 tons of CO_2, 269 tons of SO_2, 276 tons of NO_x, 45 tons of PM_{10}, and 40 tons of $PM_{2.5}$.

24. **Project rationale.** Jinan City is the economic center of Shandong and an important provincial capital in northern PRC. Its size and density, however, presents a challenge because it is highly dependent on coal for electricity and heating.[16] Coal burning releases many pollutants into air, causing haze and increasing the risk of cardiovascular and respiratory problems among the population. In 2016, Jinan city had the highest concentration of $PM_{2.5}$ attributable to coal use among 74 major cities in the PRC and ranked ninth in the province for the poorest air quality. Jinan City's central business district (CBD) located in East Jinan is densely populated and highly built-up. During the day, the CBD is a large consumer of electricity for cooling (in summer) and heating (in winter). The CBD's electricity and heating needs are a key driver of daytime peak demand for electricity and heating. Switching to more energy efficient technologies and cleaner resources for the heat and electricity production can contribute towards reducing air pollution and peak energy consumption in the city.

25. The technologies deployed under this subproject are advanced and provide substantial cost savings through the displacement of coal use in electricity and heat production and load shifting. The subproject will result in an expansion of the recently built long distance heating network, which delivers waste heat from the nearby Zhangqiu Power Plant. Long distance district heating networks are considered 4th generation district heating technologies; they often require lower network temperatures and or use advancements in materials for pipes and fluids used in heat exchanges to deliver heat supply efficiently across long distances.[17] More specifically, the large temperature differential technology for long distance district heating proposed in this subproject can supply 50% more heat than traditional district heat networks. The subproject will also deploy lithium bromide chill stations that produce cold water using waste heat to deliver cold water supply to the CBD, increasing district heating network utilization to include summer time. The subproject also offers cost savings and supports electricity grid demand management by utilizing off-peak electricity for heating (using electrode boilers) and cooling production and by deploying storage technologies (using ice storage air conditioning). The utilization of off-peak electricity for heat and cold storage enables load shifting that reduces the need to generate electricity from highly-polluting (coal-fired) peaking plants.

26. Alternatives to electrode boilers for heat production and storage, a district cooling network, and ice storage air conditioning were considered for the subproject. Heating needs could be served with solar thermal heaters. Jinan City has already developed solar thermal systems in

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[16] 79.3% of Jinan province's primary energy consumption is attributable to coal.

[17] OCED/IEA. 2016. *District Heating Business Models and Policy Solutions; Unlocking the Potential from Low-Grade Industrial Excess Heat in China,* Paris.

apartment blocks and hotels. Solar thermal systems are, however, less reliable and effective for winter heating. The alternative to a district cooling network is building level air conditioning systems. Because of the scale of building level air conditioning systems required to supply Jinan's CBD cooling load, a district cooling network is less energy and water intensive, produces less pollution emissions, noise pollution, and avoids additional contributions to the urban heat island in Jinan (cooling towers on rooftops).[18] Cold storage can be in the form of chilled water or stored ice. Chilled water storage facilities have higher production efficiency than ice storage and can be easily retrofitted. Ice storage facilities by contrast require less than one quarter the size of chilled water storage. This is important in the context of Jinan's density and premium on space. Ice storage is therefore selected as the preferred technology.[19]

27. **Economic benefits.** The economic analysis of the subproject was conducted in accordance with the Asian Development Bank's Guidelines for the Economic Analysis of Projects.[20] The economic benefits for the subproject include (i) avoided of coal fired heat generation, which is estimated as the net amount of coal saved to heat 6.92 million m^2; (ii) the avoided coal fired electricity generation, which is estimated as the net amount of energy to cool 2.2 million m^2 via air conditioning; (iii) the avoided cost of installing cooling towers; and (iv) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

28. The subproject will result in energy savings of about 87,754 tce per year, of which 86,907 tce is attributed to avoided heat generation and 2.7 gigawatt per hour (GWh) (847 tce) from avoided electricity generation. The energy saved per year was valued at the average 2018 delivered heat fuel cost of (CNY1,310/tce), accounting for boiler efficiency, and electricity generation (CNY0.23/kWh) in the PRC, adjusted to 2018 prices and excluding value-added tax (VAT).[21]

29. Global environmental benefits from CO_2 abatement are valued at the 2016 global social cost of carbon of $36.30 per ton of CO_2, adjusted to 2018 price levels (CNY241/ton), and increased annually by 2% to reflect the potential increase in marginal social costs of global warming over time. Local environmental benefits were calculated using the same methodology for Subproject 1. Table 4 shows the expected energy savings and pollution mitigated from the proposed subproject.

[18] The urban heat island effect refers to the condition where the temperature in urban areas are higher than surrounding land areas because of anthropogenic activities such as increasing built environments, transportation, or air conditioning etc.

[19] FVB Energy, Inc. Chilled Water/Ice Storage. http://www.fvbenergy.com/district-energy-expertise/thermal-energy-storage/chilled-waterice-storage/

[20] ADB. 2017. *Guidelines for the Economic Analysis of Projects*. Manila.

[21] OCED/IEA. 2017. *District Energy Systems in China: Options for Optimization and Diversification,* Paris. Coal fuel cost based on mid-point value in Table 4 on the heat fuel price of coal fired generation. 2017 prices were adjusted to 2018 prices, converted from United States dollars using historic exchange rates and inflation rates.

Table 4: Estimated Energy Savings and Pollutant Mitigation

Energy Savings (tce)	87,754				
	CO_2	**SO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Total reference case emissions (ton)	263,572	289	294	49	43
Project emissions (ton)	36,827	20	18	4	4
Emission reduction(ton)	226,745	269	276	45	40

CO_2 = carbon dioxide, NOx = nitrogen oxide, PM= particulate matter, SO_2 = sulfur dioxide, tce = ton of coal equivalent.

30. **Economic costs.** The project lifespan is expected to last 25 years, including a construction period of 5 years. The residual value of the project is 5% of civil works, equipment and materials. 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 the appropriate conversion factors. All prices and costs are expressed in 2018 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 8.3%. The shadow exchange rate factor of 1.01371 was used to estimate the shadow price of tradeable goods.[22] Ninety percent of the subproject's inputs was assumed to be tradable. 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). 80% of labor inputs were assumed to come from skilled labor and 20%from unskilled labor.

31. **Economic internal rate of return calculation.** The economic internal rate of return (EIRR) and the economic net present value (ENPV) for the project are shown in Table 5. The subproject has an ENPV at a 6% social discount rate of CNY482 million when global environmental benefits (CO_2 reduction) are included. The EIRR is above the 6% threshold at 14.22%. When global environmental benefits are excluded, the ENPV and EIRR are below the threshold of economic feasibility. The main benefit of this subproject is the substantial reduction in CO_2 compared to the reference scenario.

[22] 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.

Table 5: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Avoided Costs of Coal	Avoided Pollution (local)	Avoided Pollution (global)	Net Economic Benefits
2019	-144.14	-28.67	24.52	10.62	10.92	-126.75
2020	-124.24	-57.34	49.04	21.25	22.27	-89.03
2021	-191.47	-86.01	73.56	31.87	34.07	-137.99
2022	-114.95	-114.68	98.08	42.49	46.33	-42.72
2023	-170.22	-143.35	122.60	53.12	59.08	-78.78
2024	-	(143.35)	122.60	55.19	60.26	94.70
2025	-	(143.35)	122.60	55.19	61.46	95.90
2026	-	(143.35)	122.60	55.19	62.69	97.13
2027	-	(143.35)	122.60	55.19	63.94	98.38
2028	-	(143.35)	122.60	55.19	65.22	99.66
2029	-	(143.35)	122.60	55.19	66.53	100.97
2030	-	(143.35)	122.60	55.19	67.86	102.30
2031	-	(143.35)	122.60	55.19	69.22	103.65
2032	-	(143.35)	122.60	55.19	70.60	105.04
2033	-	(143.35)	122.60	55.19	72.01	106.45
2034	-	(143.35)	122.60	55.19	73.45	107.89
2035	-	(143.35)	122.60	55.19	74.92	109.36
2036	-	(143.35)	122.60	55.19	76.42	110.86
2037	-	(143.35)	122.60	55.19	77.95	112.39
2038	-	(143.35)	122.60	55.19	79.51	113.95
2039	-	(143.35)	122.60	55.19	81.10	115.54
2040	-	(143.35)	122.60	55.19	82.72	117.16
2041	-	(143.35)	122.60	55.19	84.37	118.81
2042	-	(143.35)	122.60	55.19	86.06	120.50
2043	35.52	-143.35	122.60	53.12	87.78	155.67
ENPV (CNY million) – with global environment benefits						482.39
ENPV (CNY million) – without global environment benefits						(261.31)
EIRR (%) – with global environment benefits						14.22
EIRR (%) – without global environment benefits						0.40

() = negative, EIRR = economic internal rate of return, ENPV = economic net present value.
Social discount rate = 6%
Source: Asian Development Bank estimates.

32. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in CAPEX and OPEX, and to a 2-year delay in project construction. Table 6 indicates that the EIRR remains above the 6% social discount rate when global environmental benefits are included under all sensitivity scenarios. The EIRR remains below the social discount rate under the sensitivity scenarios when global environmental benefits are excluded.

Table 6: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 10%	2-year delay
EIRR – with global environment benefit	14.22	11.18	11.55	14.13
EIRR – without global environment benefit	0.40	(1.16)	(3.89)	0.04

() = negative, CAPEX = capital expenditure, EIRR = economic internal rate of return, OPEX = operational expenditure.