DETAILED ECONOMIC ANALYSIS ON THE REPRESENTATIVE SUBPROJECTS

A. Advanced Biogas and Organic Fertilizer

1. **Project objective.** The subproject will demonstrate the viability of a business model to convert waste to biogas, which will replace gasoline and diesel in transportation, and to biomass (organic fertilizer), which will replace chemical fertilizers in agricultural production. The subproject will (i) implement a feedstock collection system that ensures abundant supply through entering into acquisition contracts with specialized straw purchasers, in-house listing acquisition, or cooperative acquisition with harvester manufacturers; (ii) adopt Continuous Stirred-Tank Reactor technology and include carbon excipients to optimize biomass generation using mixed feedstock; and (iii) construct compressed natural gas (CNG) and liquid natural gas (LNG) filling stations to bring its products to market.[1] The subproject will produce CNG and organic fertilizer from organic waste such straw, livestock manure, and other agricultural waste sourced from Fengqiu, Yuanyang, and Yanjin counties, major cereal and livestock production centers in the People's Republic of China (PRC).

2. **Project rationale.** The PRC has enjoyed rapid economic growth in the past few decades, especially in the greater Beijing–Tianjin–Hebei (BTH) region. The PRC's industrialization has improved the quality of life for its population. In turn, this has led to increased use of gasoline or diesel run cars and taxis, and increasing local air pollutant emissions such as carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulfur dioxide (SO_2) and volatile organic compounds (VOCs). These pollutants contribute to respiratory diseases such as asthma and bronchitis, smog, and an increased likelihood of premature mortality. Economic development has also led to shifting diets, putting pressure on agro-industries to improve yields and resulting in increasing use of livestock manure and chemical fertilizers in agriculture. Both manure and chemical fertilizers contribute to nutrient run-off into nearby water bodies, leading to eutrophication. The chemicals in these fertilizers also react with the air, creating air pollution. Longer term application of chemical fertilizers acidizes the soil, degrading its quality, which in turn results in lower agricultural productivity.

3. The proposed subproject will divert agricultural waste away from environmentally harmful practices, such as open burning of straw, and reduce manure and chemical fertilizer applications to the soil to produce CNG, a cleaner fuel alternative to gasoline vehicles and organic fertilizer for agricultural use. Fengqiu County—where the project is being proposed—produced 858,500 tons of straw (2013) and 1.57 million tons of livestock manure (2012). According to the Ministry of Agriculture, 1.5 billion tons of agricultural waste are produced a year in the PRC, which could be used to produce 122.7 billion cubic meters of biogas.

4. Biomass plants are not a new and emerging renewable energy industry, but the technology and market has struggled to achieve economies of scale. Issues that affect the biogas industry include an unreliable supply of inputs, the production of biogas slurry by-products and the limited grid connection of biogas-generated electricity. The subproject proposes a new business model that incorporates innovative technology to optimize biogas production and the chemical ratio of the organic fertilizer. The project will be able to collect straw from Fengqiu, Yuanyang, and Yanjin Counties and contracts with straw purchasers and manure collectors to ensure a sustainable supply of feedstock. The subproject can produce liquid and solid fertilizer to cater to different

[1] The Project purchases and resells LNG to increase filling station utilization.

markets. The biogas facility will also have an adjacent filling station to save on CNG transport.

5. **Economic benefits.** The economic analysis of the project was conducted in accordance with the Asian Development Bank's (ADB) Guidelines for the Economic Analysis of Projects.[2] The economic benefits for the subproject include (i) petroleum savings, which is estimated as the net amount of petroleum saved in liters from the substitution of petroleum use in taxis (reference case vehicle) to CNG; (ii) fuel switching costs required to retrofit existing petroleum taxis to run on CNG; (iii) nitrogenous fertilizer savings, which is estimated as the net amount of nitrogenous fertilizer saved in tons from the substitution of chemical fertilizer for organic fertilizer in agriculture; 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).

6. The subproject will produce 4.2 million cubic meters of CNG, 32,400 tons of organic solid fertilizer, and 15,000 tons of organic liquid fertilizer, and purchase and resell 6.81 million tons of LNG. The CNG and LNG will replace over 12.4 million liters of gasoline. The avoided economic cost of petroleum was assumed to be the retail pump price of petroleum in the PRC, which is currently CNY 6.66/liter. Since mandated fuel efficiency improvements (China 6) will come into force in 2020, petroleum savings are constrained by the expected annual efficiency improvements (6% per year), up to 2020 and assumed to continue for the remaining economic life of the project. Cost of retrofitting existing taxis are also included in the economic analysis. The retrofit cost per taxi is estimated at CNY6,000. If an average taxi with a mileage of 100,000 kilometers (km) requires 10,000 liters of petroleum, the number of taxis that need to be retrofitted is 1,240 taxis, bringing the total cost of retrofits to CNY7,440,000. The cost of retrofits is reflected in the first year of the subproject's operation. The avoided economic cost of nitrogenous fertilizer was assumed to be the spot price of urea adjusted for the Shadow Exchange Rate Factor (SERF), amounting to CNY1,589 per ton.[3]

7. 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 2017 price levels, 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 is valued by estimating the cost of premature mortality (labor loss) associated with SO_2, VOC, $PM_{2.5}$, NOx, and CO emissions.[4] Local pollution abatement is estimated by subtracting the expected emissions from CNG and LNG use from existing emissions from gasoline taxis. The energy savings from the subproject is presented in Table 1 below.

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

[3] The SERF of 1.01371 was used to estimate the shadow price of tradeable goods.

[4] The estimated costs of premature mortality are calculated by multiplying the estimated mortality reduction effect of single pollutant emissions reductions by the net present value of lost wages per person and divided by total emission reductions. Reference emission levels were derived from EDGAR 4.3 and the Fast Scenario Screening Tool was used to evaluate the impact of pollutant dispersion on human health (effect of single pollutant emission reductions). The age of premature mortality was derived from the Global Health Data Exchange tool. The resulting pollution values are used for all six subprojects: NO_x = CNY1,294; SO_2 = CNY1,188; PM = CNY1,292; CO = CNY 0.

Table 1: Energy Savings and Pollutant Mitigation

	Category	CO	THC/VOC	NOx	PM	SO_2[a]	CO_2[b]
Taxi	Baseline emission factor[c] (g/km)	2.45	0.277	0.135	0.003	50 ppm	--
	Correct factor[d]	1.47	1.43	1.58	1.12	--	
	Emission factor[e] (g/liter)	33.32	3.66	1.98	0.031	0.074	2,361
	Emissions from gasoline[f](ton)	163.2	17.9	9.7	0.15	0.36	11,569
Total reference case emissions (ton)		**163.2**	**17.9**	**9.7**	**0.15**	**17.9**	**11,569**
Project emissions (ton)		**49.0**	**11.8**	**1.9**	**0.03**	**0**	**0**
Net emission reduction (ton)		**114.2**	**6.1**	**7.8**	**0.12**	**17.9**	**11,569**
Energy savings (TCE)[g]							**5,318**

CO = carbon monoxide, CO_2 = carbon dioxide, g/km = grams per kilometer, g/liter = grams per liter, kg/ton = kilograms per ton, NO_x = nitrogen oxide, PM = particulate matter, SO_2 = sulfur dioxide, THC = total hydrocarbon, VOC = volatile organic compound.

[a] GB 17930-2016 Gasoline for motor vehicles Stage IV.

[b] China carbon trade network: CO_2 emission factor of gasoline 2.361 kg/liter (www.tanpalfang.com).

[c] Emission under the scenario of speed 30 km/h, temperature 15°C, moisture 50% and 50 ppm sulfur content.

[d] Consider the impacts from temperature, moisture, sulfur content of gasoline, average speed of taxi (assuming 30–40 km/h) and the deterioration of catalytic converter.

[e] Fuel consumption is 10.8 liter/100 km which meets the GB 20997-2007 Limits of fuel consumption for light duty commercial vehicles.

[f] Gasoline consumption of 3,618,807 liters.

8. **Economic costs.** 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. The residual value of the project is assumed to be zero. Operating costs are assumed to be constant in real terms. All prices and costs are expressed in 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. An SERF of 1.01371 was used to estimate the shadow price of tradable goods.[5] 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). Eighty percent of labor inputs were assumed to come from skilled labor and 20 percent from unskilled labor.

9. **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

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[5] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

11. Table 2. The EIRR of the subproject with the global environmental benefits included is 24% and the EIRR without the global environmental benefits is 19.8%. This is higher than the social cost of capital, which is 6%. The ENPV is CNY 101.7 million including global environmental benefits and CNY 72.5 million without it.

Table 2: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Avoided Costs of Petrol and Nitrogenous Fertilizer Use	Avoided Pollution	Net Economic Benefits
2017	(131.24)	-	-	-	(131.24)
2018	-	(39.74)	76.94	3.04	40.24
2019	-	(39.74)	79.72	2.91	42.89
2020	-	(39.74)	75.06	2.79	38.11
2021	-	(39.74)	70.67	2.67	33.61
2022	-	(39.74)	66.55	2.56	29.38
2023	-	(39.74)	62.68	2.46	25.40
2024	-	(39.74)	59.03	2.36	21.65
2025	-	(39.74)	55.61	2.26	18.13
2026	-	(39.74)	52.39	2.17	14.82
2027	-	(39.74)	49.37	2.08	11.71
2028	-	(39.74)	46.53	1.99	8.78
2029	-	(39.74)	43.85	1.91	6.02
2030	-	(39.74)	41.34	1.83	3.43
2031	-	(39.74)	38.98	1.75	0.99
2032	-	(39.74)	36.76	1.68	(1.30)
ENPV (CNY millions) with global environmental benefit					88.28
ENPV (CNY millions) without global environmental benefit					66.49
EIRR (%) – with global environmental benefit					22.1
EIRR (%) – without global environmental benefit					18.9

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

12. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in capital and operating expenses, and to decreases in the marginal cost of climate change of CO_2. The sensitivity analysis in Table 3 indicates that the EIRR remains above the 6% social cost of capital when capital and operating costs are substantially increased. When global environment benefits are not included, the EIRR remains above the cost of capital even when capital costs are increased. However, it falls below the 6% threshold when operating costs are increased.

Table 3: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 20%	Price of CO_2 -20%
EIRR (%) – with global environmental benefit	22.07	15.88	10.23	22.0
EIRR (%) – without global environment benefit	18.86	12.92	3.60	-

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.

B. Industrial By-product Gas Utilization

13. **Project objective.** The subproject will use coke oven gas, an industrial by-product, to produce LNG for use in the transportation sector. It will install LNG producing infrastructure at an iron and steel facility in Linfen City to produce 180,000 metric tons of LNG a year. The subproject employs innovative technology to convert an industrial by-product into a useful application. The LNG produced will replace diesel consumption in heavy-duty vehicles. The subproject will thus avoid coke oven gas that would otherwise be released into the atmosphere, and air pollution from diesel combustion in heavy-duty vehicles. The subproject will result in 239.4 million liters of avoided diesel combustion and avoid reduce approximately 581,000 tons of CO_2, 691 tons of SO_2, 1,942 of NO_X, 49 tons of PM, 30 tons of CO, and 16 tons of THC/VOC.

14. **Project rationale.** The PRC has enjoyed rapid economic growth in the past few decades, especially in the BTH region. Industrialization has meant that more heavy-duty vehicles, such as trucks and vans are required to transport goods. Heavy-duty vehicles in the PRC are a major source of air pollution. They represent 3.5% of all vehicles in the Beijing region yet contribute to 90% of PM and 60% of NO_x vehicle emissions. These pollutants contribute to respiratory diseases such as asthma and bronchitis, and smog, which leads to an increased likelihood of premature mortality.

15. The subproject will use industrial by-product coke oven gas to produce LNG. LNG is a low-emission alternative to diesel fuel. It is also cost-competitive and allows vehicles to travel a further distance between fuel stops. The LNG market is growing in the PRC. By the end of 2015 there were 230,000 LNG vehicles, which could increase to between 400,000 and 500,000 by 2020. The number of LNG filling stations has also been growing, from 241 stations in 2011 to 2,650 stations in 2015. The subproject will increase the availability for LNG fuel and encourage individuals and firms to purchase LNG trucks or retrofit existing diesel trucks to be LNG compatible.

16. Alternative productive uses of coke oven gas were evaluated including: electricity, steam, industrial chemicals such as methanol, ammonia, and hydrogen production. LNG production is a recent technological innovation for utilizing waste coke gas and may present a better alternative than other products. LNG production represents an energy efficient utilization of coke oven gas: The energy efficiency of coke oven gas to LNG is 69% comparted to 40% for electricity generation.[6, 7] There is also an over-supply of methanol in the PRC, limiting the viability for further production. Furthermore, LNG production from coke oven gas is cheaper and more energy efficient than extracting natural gas from wells. The price of coke oven gas is cheaper than natural gas, and production centers are closer to the market.

17. **Economic benefits.** The economic analysis of the project was conducted in accordance with the ADB's Guidelines for the Economic Analysis of Projects. The economic benefits for the subproject include (i) diesel savings, which is derived from the substitution of diesel use for LNG in heavy-duty trucks; and (ii) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario). The price of diesel is calculated as the retail pump price, which is currently CNY5.80/liter. Because coke gas is typically used to generate electricity for a plant’s own use, the opportunity cost of forgone electricity production (1,156 gigawatt-hours) is subtracted from the project’s total energy

[6] Government of the PRC. 2012. *Twelfth Five-Year Plan for Natural Gas Development.* Beijing.
[7] Wang Xiulin et al. Technology and economic analysis for coke oven gas to LNG, China Petroleum and Chemical Industry Standard and Quality, No. 2, Page 37

savings (diesel savings).[8] In addition, the cost to retrofit 2,784 diesel trucks (CNY70,000 each) to use LNG fuel is also subtracted as a one-time cost from the value of diesel savings.[9]

18. Global environmental benefits from CO_2 abatement is valued at the 2016 global social cost of carbon of USD 36.30 per ton of CO_2, adjusted to 2017 price levels, 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 is valued by estimating the cost of premature mortality (labor loss) associated with SO_2, VOC, $PM_{2.5}$, NOx, and CO emissions.[10] A 6% fuel efficiency improvement was applied to the analysis to represent the reduction in diesel use in the reference case. Therefore, diesel consumption and pollution mitigation follow a 6% year-on-year decrease from the first year of operation. Table 4 shows the estimated energy savings and pollutant mitigation for the first year of operation when compared to the reference cases.

Table 4: Estimated Energy Savings and Pollutant Mitigation

Energy Savings (liters of diesel)	239,400,000					
	CO_2[a]	**SO_2**[b]	**NO_x**	**PM**	**CO**	**THC/VOCs**
Diesel emissions (ton)[c]	629,622	20.6	2,597.4	48.6	922.1	56.7
Coke oven gas for power generation emissions (ton)[d]	455,040	691.2	123.8	0	0	0
Total reference case emissions (ton)	1,084,662	711.8	2,721.2	48.6	922.1	56.7
Project emissions (ton)	503,688	20.6	779.2	0	692.4	40.9
Net emission reduction (ton)	580,964	691.2	1,942.0	48.6	29.7	15.8

CO = carbon monoxide, CO_2 = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, SO_2 = sulfur dioxide, THC = total hydrocarbon, VOC = volatile organic compound.
[a] China carbon trade network: CO_2 emission factor of diesel 2.630kg/liter (www.tanpalfang.com).
[b] GB 17930-2016 Gasoline for motor vehicles Stage IV.
[c] Fuel consumption is 43 liter/100 km which meets the GB 30510-2014 Fuel Consumption Limits for heavy-duty commercial vehicles Stage II. Consumption considers the impacts from temperature, moisture, sulfur content of diesel, average speed of trucks (assuming 40–80 km/h) and the load factor (100%).
[d] Annual coke oven gas consumption is 576 million cubic meters.
Source: Ministry of Environmental Protection: Technical Guidelines of Air Pollutant Inventory for Automobiles

19. **Economic costs.** 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. The residual value of the project is assumed to be zero. Operating costs are assumed to be constant in real terms. All prices and costs are expressed in 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. The SERF of 1.01371 was used to estimate the shadow price of tradeable goods.[11] 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). Eighty percent of labor inputs were assumed to come from skilled labor

[8] The avoided cost of coal generation is CNY 517,142 per gigawatt-hour (adjusted to 2017 prices). OECD. ECD. "Project Costs of Generating Electricity".2015.
[9] The number of trucks required to be retrofitted is estimated by dividing the amount of diesel avoided in liters by the amount of fuel required for a truck that has 200,000km in mileage, with a fuel efficiency of 43 liters/100 km.
[10] The following pollution values are used: NO_x = CNY1,294; SO_2 = CNY1,188; PM = CNY1,292; CO = CNY0.
[11] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

and 20%from unskilled labor.

20. **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 ENPV when global environmental benefits (CO_2 reduction) are included is CNY1.58 billion, and the EIRR is 43.2%. When global environmental benefits are ignored, the ENPV falls to CNY498 million and the EIRR falls to 28.6%.

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

Year	Capital Costs	Operating Costs	Avoided Costs of Diesel	Forgone electricity and cost of retrofits	Avoided Pollution	Net Economic Benefits
2017	(452.74)	-	-	-	-	(452.74)
2018	(194.03)	-	-	-	-	(194.03)
2019	-	(107.22)	1,305.21	(1,292.70)	147.86	53.15
2020	-	(107.22)	1,221.90	(597.82)	141.71	658.57
2021	-	(107.22)	1,148.58	(597.82)	135.82	579.36
2022	-	(107.22)	1,079.67	(597.82)	130.17	504.80
2023	-	(107.22)	1,014.89	(597.82)	124.76	434.60
2024	-	(107.22)	954.00	(597.82)	119.57	368.52
2025	-	(107.22)	896.76	(597.82)	114.60	306.31
2026	-	(107.22)	842.95	(597.82)	109.84	247.75
2027	-	(107.22)	792.37	(597.82)	105.27	192.61
2028	-	(107.22)	744.83	(597.82)	100.90	140.69
2029	-	(107.22)	700.14	(597.82)	96.71	91.81
2030	-	(107.22)	658.13	(597.82)	92.69	45.78
2031	-	(107.22)	618.64	(597.82)	88.84	2.45
2032	-	(107.22)	581.53	(597.82)	85.15	(38.36)
2033	-	(107.22)	546.63	(597.82)	81.62	(76.79)
2034	-	(107.22)	513.84	(597.82)	78.23	(112.97)
2035	-	(107.22)	483.01	(597.82)	74.98	(147.05)
2036	-	(107.22)	454.03	(597.82)	71.87	(179.14)
2037	-	(107.22)	426.78	(597.82)	68.89	(209.37)
ENPV (CNY millions) – with global environment benefit						1,581.62
ENPV (CNY million) – without global environment benefit						498.38
EIRR (%) – with global environment benefit						43.16
EIRR (%) – without global environment benefit						28.58

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

21. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity to economic projections. Table 6 indicates that the EIRR remains well above the 6% social discount rate during sensitivity analysis. The EIRR is robust even when global environmental benefits are ignored.

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

	Base Case	CAPEX + 20%	OPEX + 20%	Price of CO_2 -20%
EIRR – with global environment benefit	43.16	36.94	41.04	40.55
EIRR – without global environment benefit	28.58	22.97	25.38	N/A

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.

C. Smart Industrial Zone Development

22. **Project objective.** The project will construct a smart microgrid that integrates various renewable energies, energy storage, and energy management system technologies in an industrial zone. The smart microgrid will replace coal-dominated grid electricity and coal-fired boilers for heat. It will also demonstrate the potential for greater uptake and use of multiple intermittent renewable energy (RE) technologies by introducing energy management system technologies that optimize energy production and consumption within the microgrid, and eventual integration with the main grid. The proposed microgrid comprises the following technologies: solar photovoltaic panels; gas-based tri-generation for heating, power, and cooling; battery storage systems; chilled water thermal storage systems; a linear Fresnel solar thermal heating system; and an air source heat pump. An energy management center will synchronize these technologies. The smart microgrid will result in approximately 30,660 tons of coal equivalent (tce) of energy savings, and avoid 76,846 tons of CO_2, 366 tons of SO_2, 199 tons of NO_X, and 386 tons of PM.

23. **Project rationale.** The greater BTH region, one of the most important economic regions in the PRC, generates more than a third of the country's Gross Domestic Product (GDP). However, the region's impressive economic growth has been based on energy intensive and highly polluting industries that has led to widespread air pollution. The PRC has increased coal-based power and heat generation to keep with demand from these industries made large investments in wind and solar generation, with capacity now reaching 15% of the generation mix. However, the existing grid's inability to absorb intermittent generation has resulted in RE curtailment.

24. Energy management centers in micro-grids are an innovate technology solution to the problem of RE generation curtailment. This subproject showcases an energy management center with solar and wind technology. These energy management centers could be deployed to build smart energy grids within new cities new towns in eastern China, to greatly improve energy efficiency (EE) and broadly utilize clean and low-carbon energy supply.

25. **Economic benefits.** The economic analysis of the project was conducted in accordance with the ADB's Guidelines for the Economic Analysis of Projects. The economic benefits for the subproject include (i) coal-fired generation savings, which is estimated as the net amount of energy saved from the deployment of various RE technologies, energy storage and an energy management system compared to using conventional coal-fired boilers and power from the grid; and (ii) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

26. The subproject will result in energy savings of about 30,659.8 tce per year. The energy saved results in the avoidance of highly polluting coal-fired boilers and coal-dominated power generation from the grid. The energy saved per year was valued at the current market price of coal (CNY860/ton). Since EE improvements can be expected during the life time of the subproject, the historic annual rate of EE improvements in industry, agriculture, and service sectors in the PRC (1.27%) is applied to constrain expected energy savings and emissions avoided for the economic life of the subproject.[12]

27. 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 2017 price levels, and increased annually by 2% to reflect the potential increase in marginal social costs of global warming over time. Local

[12] IEA. 2016. *Energy Efficiency Market Report,* IEA.

environmental benefits from local pollutant emissions abatement is valued by estimating the cost of premature mortality (labor loss) associated with SO_2, $PM_{2.5}$, and NOx.[13] Table 7 shows the expected energy savings and pollution mitigated from the proposed retrofits.

Table 7: Estimated Energy Savings and Pollutant Mitigation

		Emission reduced			
Energy category	**Standard coal replaced (t)**	**CO_2 (t)**	**SO_2 (t)**	**NO_X (t)**	**PM (t)**
PV	10,209.9	21,853.0	13.6	12.4	2.6
Gas-based tri-generation	3,736.3	9,792.6	43.2	26.4	79.5
Linear Fresnel system	431.3	1,130.5	7.5	3	9.2
Air source heat pump	6,424.3	18,245.5	218.1	83.9	278.4
Energy storage system	9,858.0	25,824.8	83.8	73.0	15.8
Total	**30,659.8**	**76,846.4**	**366.2**	**198.7**	**385.5**

CO_2 = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, PV = photovoltaic, SO_2 = sodium dioxide, t = ton, tri-generation = combined cooling, heating, and power system.

28. **Economic costs.** The project lifespan is expected to last 25 years with a construction period of 3 years. The residual value of the project is assumed to be zero. 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 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. The SERF of 1.01371 was used to estimate the shadow price of tradable goods.[14] 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). Eighty percent of labor inputs were assumed to come from skilled labor and 20% from unskilled labor.

29. **Economic internal rate of return calculation.** The EIRR and the ENPV for the project are shown in Table 8. The subproject has an ENPV at a 6% social discount rate of CNY64.91 million when global environmental benefits (CO_2 reduction) are included. The EIRR is above the 6% threshold at 7.49%. When global environmental benefits are excluded, the EIRR is below the 6% threshold and the ENPV is negative.

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[13] The following pollution values are used: NO_x = CNY1,294; SO_2 = CNY1,188; $PM_{2.5}$ = CNY1,292.
[14] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

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

Year	Capital Costs	Operating Costs	Avoided Costs of Coal Use	Avoided Pollution	Net Economic Benefits
2017	(217.03)	-	-	-	(217.03)
2018	(130.22)	-	-	-	(130.22)
2019	(86.81)	-	-	-	(86.81)
2020	-	(3.50)	25.31	21.68	44.21
2021	-	(3.50)	24.30	21.81	44.01
2022	-	(3.50)	23.33	21.94	43.82
2023	-	(3.50)	22.40	22.07	43.63
2024	-	(3.50)	21.50	22.21	43.45
2025	-	(3.50)	20.64	22.34	43.27
2026	-	(3.50)	19.81	22.48	43.10
2027	-	(3.50)	19.02	22.61	42.93
2028	-	(3.50)	18.26	22.75	42.76
2029	-	(3.50)	17.53	22.89	42.61
2030	-	(3.50)	16.83	23.03	42.45
2031	-	(3.50)	16.16	23.18	42.31
2032	-	(3.50)	15.51	23.32	42.16
2033	-	(3.50)	14.89	23.47	42.03
2034	-	(3.50)	14.29	23.61	41.89
2035	-	(3.50)	13.72	23.76	41.77
2036	-	(3.50)	13.17	23.91	41.64
2037	-	(3.50)	12.65	24.06	41.52
2038	-	(3.50)	12.14	24.21	41.41
2039	-	(3.50)	11.65	24.36	41.30
2040	-	(3.50)	11.19	24.52	41.20
2041	-	(3.50)	10.74	24.67	41.10
2042	-	(3.50)	10.31	24.83	41.00
2043	-	(3.50)	9.90	24.99	40.91
2044	-	(3.50)	9.50	25.15	40.82
ENPV (CNY millions) – with global environment benefits					64.91
ENPV (CNY millions) – without global environment benefits					(169.96)
EIRR (%) – with global environment benefits					7.49
EIRR (%) – without global environment benefits					1.05

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

30. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in capital and operating costs, and to decreases in the marginal cost of climate change of CO_2. Table 9 indicates that the EIRR remains above the 6% social discount rate when operating costs are increased or the price of CO_2 decreases. The EIRR falls slightly below the 6% threshold when capital costs are increased. The EIRR is negative in all scenarios when global environmental benefits are excluded.

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

	Base Case	CAPEX + 20%	OPEX + 20%	Price of CO_2 -20%
EIRR – with global environment benefit	7.49	5.72	7.32	7.03
EIRR – without global environment benefit	1.05	(0.32)	0.78	N/A

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.

D. Deep-well Geothermal District Heating System

31. **Project objective.** The subproject will construct geothermal district heating system using deep-well geothermal energy technology. The district heating system will serve a newly-built residential areas in Lingcheng District, Dezhou City, Shandong Province. The project will be completed in five phases, with each phase involving the drilling of four production and four disposal wells, and the construction of four heat exchange stations. The district heating system will eventually serve a heating area of 800,000 square meter (m^2).

32. **Project rationale.** Winter heating in northern areas of the PRC is largely through coal-based centralized heating infrastructure, a legacy of the PRC's Huai River Policy.[15] Winter heating in Dezhou City lasts for 24 hours a day, 122 days a year between November and March. Coal fired boilers emit pollutants including PM, SO_2, and NO_x. These pollutants tend to be trapped in small areas from fog and lower wind speeds that are occur during the winter. High levels of air pollution contribute to respiratory diseases such as asthma and bronchitis, smog, and an increased likelihood of premature mortality. In 2016, Dezhou City was ranked the lowest in Shandong Province for the comprehensive air quality index.

33. Deep-well geothermal heating is an innovative approach to district heating. It involves drilling 1–2 km deep to extract water at temperatures over 50°C. Dezhou city has rich geothermal resources at depths of 1.1 to 1.5 km underground, with temperatures ranging from 50–85°C. These temperatures are high enough to be pumped without additional heating. The subproject will adopt technology that uses variable frequency drives, further reducing electricity consumption by nearly a quarter compared to standard technology. To minimize the potential impact of production on groundwater resources and sustainability of the geothermal resource, this subproject will filter and recharge the underground sources through injection wells.

34. Several alternatives to deep well geothermal development were considered for the project such as shallow ground source heating and solar PV heaters. Shallow ground source heating requires less capital costs and has minimal impact on groundwater resources. However, more shallow wells are needed to serve the same area that a deep-well system serves. A shallow well system also requires most electricity to heat water than a deep-well system. Other alternatives to geothermal heating include solar water heaters. Dezhou City receives a good amount of sunshine a year and is well known for solar photovoltaic (PV) development. However, solar heating may be more unreliable than geothermal heating during the winter, when solar irradiance is lower. Geothermal deep-wells also offer the advantage of a longer life span.

35. **Economic benefits.** The economic analysis of the project was conducted in accordance with the ADB's Guidelines for the Economic Analysis of Projects. The economic benefits for the subproject include (i) coal fired generation savings, which is estimated as the net amount of energy saved to heat 800,000 square meters using conventional coal-fired boilers, assuming a boiler efficiency of 75%; and (ii) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

36. The subproject will result in energy savings of about 13,200 tce per year. The energy saved results in the avoidance of highly polluting coal fired boilers. The energy saved per year was valued at the current market price of coal (CNY860/ton). Since EE improvements can be

[15] Ebenstein, A., Fan, M., Greenstone, M., He, G. and Zhou, M., 2017. New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy. *Proceedings of the National Academy of Sciences*, pp. 10384-10389

expected during the life time of the subproject, the historic annual rate of EE improvements in the urban heating sector in the PRC (approximately 2%) is applied to constrain expected energy savings and emissions avoided for the economic life of the Project.[16]

37. 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 2017 price levels, and increased annually by 2% to reflect the potential increase in marginal social costs of global warming over time. Local environmental benefits from local pollutant emissions abatement is valued by estimating the cost of premature mortality (labor loss) associated with SO_2, $PM_{2.5}$, and NOx.[17] Table 10 shows the expected energy savings and pollution mitigated from the proposed retrofits.

Table 10: Estimated Energy Savings and Pollutant Mitigation

Energy Savings (tce)	13199.9			
	CO_2	**SO_2**	**NO_x**	**PM**
Total reference case emissions (ton)	45,229.3	146.7	127.7	4.9
Project emissions (ton)	9,991.4	6.2	5.7	0.0
Emission reduction(ton)	35,237.9	140.5	122.0	4.9

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

38. **Economic costs.** The project lifespan is expected to last 35 years with a construction period of 3 years. The residual value of the project is assumed to be zero. 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 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. The SERF of 1.01371 was used to estimate the shadow price of tradeable goods.[18] 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). Eighty percent of labor inputs were assumed to come from skilled labor and 20% from unskilled labor.

39. **Economic internal rate of return calculation.** The EIRR and the ENPV for the project are shown in Table 11. The subproject has an ENPV at a 6% social discount rate of CNY 39.30 million when global environmental benefits (CO_2 reduction) are included. The EIRR is above the 6% threshold at 9.23%. When global environmental benefits are excluded, the ENPV and EIRR are negative. The main benefit of this subproject is the substantial reduction in CO_2 compared to the reference scenario.

[16] IEA. 2016. *Energy Efficiency Market Report,* IEA.
[17] The following pollution values are used: NO_x=CNY1,294; SO_2=CNY1,188; $PM_{2.5}$=CNY1,292.
[18] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

Table 11: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Avoided Costs of Coal Use	Avoided Pollution	Net Economic Benefits
2017	(37.70)	-	-	-	(37.70)
2018	(48.34)	(1.36)	2.82	2.33	(44.56)
2019	(37.39)	(4.08)	6.92	5.81	(28.73)
2020	-	(6.72)	10.86	9.30	13.44
2021	-	(6.59)	10.65	9.30	13.36
2022	-	(6.59)	10.44	9.30	13.16
2023	-	(6.59)	10.24	9.31	12.96
2024	-	(6.59)	10.05	9.31	12.76
2025	-	(6.59)	9.85	9.31	12.57
2026	-	(6.59)	9.66	9.31	12.38
2027	-	(6.59)	9.48	9.31	12.19
2028	-	(6.59)	9.29	9.31	12.01
2029	-	(6.59)	9.11	9.31	11.83
2030	-	(6.59)	8.94	9.31	11.66
2031	-	(6.59)	8.77	9.31	11.49
2032	-	(6.59)	8.60	9.32	11.32
2033	-	(6.59)	8.43	9.32	11.16
2034	-	(6.59)	8.27	9.32	11.00
2035	-	(6.59)	8.11	9.32	10.84
2036	-	(6.59)	7.95	9.32	10.68
2037	-	(6.59)	7.80	9.33	10.53
2038	-	(6.59)	7.65	9.33	10.39
2039	-	(6.59)	7.50	9.33	10.24
2040	-	(6.59)	7.36	9.33	10.10
2041	-	(6.59)	7.21	9.33	9.96
2042	-	(6.59)	7.08	9.34	9.82
2043	-	(6.59)	6.94	9.34	9.69
2044	-	(6.59)	6.80	9.34	9.56
2045	-	(6.59)	6.67	9.34	9.43
2046	-	(6.59)	6.54	9.35	9.30
2047	-	(6.59)	6.42	9.35	9.18
2048	-	(6.59)	6.29	9.35	9.06
2049	-	(6.59)	6.17	9.36	8.94
2050	-	(6.59)	6.05	9.36	8.82
2051	-	(6.59)	5.94	9.36	8.71
2052	-	(6.59)	5.82	9.36	8.60
ENPV (CNY millions) – with global environment benefits					39.30
ENPV (CNY millions) – without global environment benefits					-75.67
EIRR (%) – with global environment benefits					9.23
EIRR (%) – without global environment benefits					-6.88

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

40. **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 12 indicates that the EIRR remains above the 6% social discount rate when environmental benefits are included under all sensitivity scenarios. The EIRR is negative in all scenarios when global environmental benefits are excluded.

Table 12: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	**CAPEX + 20%**	**OPEX + 20%**	**Price of CO_2 -20%**
EIRR – with global environment benefit	9.23	7.22	7.07	7.40
EIRR – without global environment benefit	-6.88	-8.56	-6.14	N/A

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.

E. Hydrogen-based Low-emission Transport

39. **Project objective.** The subproject will invest in hydrogen-based low-emission transportation. The subproject will deploy 100 hydrogen fuel cell buses and construct necessary fueling infrastructure. It will use surplus wind power to split water into hydrogen (H_2) and oxygen (O_2). The subproject will be piloted in Zhangjiakou, which will be a major venue for the 2022 Winter Olympics. This subproject has substantial economic benefits by replacing diesel use in buses. It derives hydrogen from clean, renewable wind-based power and has no harmful tailpipe emissions. The subproject will save 6,336,000 of liters of diesel, and avoid 16,663.7 tons of CO_2, 0.51 tons of SO_2, 197.8 tons of NO_X, 59.4 tons of CO, 3.17 tons of THC, and 7.66 tons of PM.

40. **Project rationale.** The PRC has enjoyed rapid economic growth in the past few decades, especially in the BTH region. Towns and cities have expanded and the large availability of jobs have attracted millions of formally rural workers. Higher wages have allowed many families to own personal vehicles, in turn leading to worsening congestion. Population and economic growth has put pressure on developing systems of mass transit, especially to and within urban areas. Tourists during and following the 2022 Winter Olympics will also strain public transportation in Zhangjiakou.

41. Vehicular emissions can become concentrated in these urban areas. Diesel buses emit pollutants including PM, SO_2, NO_x, CO, and THCs/VOCs, despite reducing the number of cars on the road. These pollutants contribute to respiratory diseases such as asthma and bronchitis, smog, and an increased likelihood of premature mortality. Furthermore, traditional internal combustion engines release a considerable amount of CO_2, which contributes to global climate change. These have wider detrimental effects on society, economic productivity, and non-human ecology.

42. Hydrogen fuel cell transport represents a relatively new, low-emission technology. It has the potential to replace current diesel buses as well as alternative CNG and plug-in electric buses. Hydrolysis technology has a high potential for scale-up in the PRC, since renewable electricity output is currently underutilized. H_2 can be used as a form of energy storage, reducing the need for renewable energy technologies such as wind turbines to be curtailed. H_2 has advantages over traditional internal combustion engines and modern electric vehicles: hydrogen fuel cells do not create air pollution, since the only product is water. It also can be refueled quickly at a centralized location, meaning less interruption and greater mileage compared to charging an electric vehicle.

43. Alternatives to hydrogen-based transport include CNG buses and plug-in electric buses, which are cleaner alternatives to current diesel-based transportation. However, these alternatives have several disadvantages that make hydrogen-based transport more attractive. Plug-in buses suffer from low mileage, long charging times, and have relatively high “well-to-wheels” emissions since the PRC’s grid-based electricity is dominated by coal. CNG buses have similar mileage and emit fewer local pollutants than diesel buses, but still relies on carbon-based fuel and as such emit greenhouse gases.

44. **Economic benefits.** The economic analysis of the project was conducted in accordance with the ADB's Guidelines for the Economic Analysis of Projects. The economic benefits for the subproject include (i) diesel savings, which is estimated as the net amount of diesel saved in liters by 100 diesel buses (of equivalent capacity) that operate 20,000 km per day; (ii) investments and operations expenses in diesel buses avoided; 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). The subproject will deploy 100 hydrogen fuel cell buses by 2018. These

buses will avoid 6,336,000 liters of diesel a year by displacing trips from diesel buses. The avoided economic cost of diesel was taken as the retail pump price in the PRC, which is CNY5.80 per liter. Since improvements in fuel efficiency can be expected during the life time of the subproject, a 2.65% fuel efficiency improvement in diesel consumption was assumed, to constrain expected diesel savings and emissions avoided for the economic life of the Project.[19] Thus, the amount of diesel and associated emissions follow a 2.65% annual reduction. The fuel cell buses will also replace the capital and operating costs of the equivalent number of diesel buses with the same passenger capacity. The cost of a diesel bus is assumed to be CNY700,000 per bus. The maintenance cost of a diesel bus is assumed to be CNY50,000 per year. Because the maintenance cost of a hydrogen bus is less than that of a diesel bus at CNY19,800 per year, maintenance expenses saved is CNY31,200. Salaries, cleaning and insurance for diesel buses are assumed to be the same as hydrogen buses at CNY153,100 per diesel bus per year.

45. 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 2017 price levels, 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 is valued by estimating the cost of premature mortality (labor loss) associated with SO_2, THC, $PM_{2.5}$, NOx, and CO emissions.[20] These savings are presented in Table 13 below.

Table 4: Estimated Pollutant Mitigation

Category	CO	THC	NO_x	PM	SO_2[a]	CO_2[b]
Emission factor [c] (g/liter)	9.371	0.513	31.224	1.228	0.08	2,630
Diesel emission (ton)	59.4	3.2	197.8	7.7	0.5	16,663.7
Emissions Reduction (ton)	59.4	3.2	197.8	7.7	0.5	16,663.7

CO = carbon monoxide, CO_2 = carbon dioxide, g/km = grams per kilometer, g/liter = grams per liter, kg/m = kilograms per cubic meter, NO_x = nitrogen oxide, PM = particulate matter, ppm = parts per million, SO_2 = sulfur dioxide, THC = total hydrocarbon.
[a] GB 19147-2016 Automobile diesel fuels Stage IV.
[b] China carbon trade network: CO_2 emission factor of diesel 2.630kg/liter (www.tanpalfang.com).
[c] Emissions consider the impacts from temperature, moisture, sulfur content of diesel, average buses of trucks (assuming 40–80 km/h) and the load factor (100%).
Source: Ministry of Environmental Protection: Technical Guidelines of Air Pollutant Inventory for Automobiles

46. **Economic costs.** The economic analysis of the project was conducted in accordance with the Asian Development Bank's Guidelines for the Economic Analysis of Projects. 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. The residual value of the project is assumed to be zero. Operating costs are assumed to be constant in real terms. All prices and costs are expressed in 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. The SERF of 1.01371 was used to estimate the shadow price of tradeable goods.[21] Ninety percent of the subproject's inputs was assumed to be tradable.

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[19] Improvements in fuel efficiency was estimated by calculating the difference between the PRC's Stage III mandates in 2021 and the current Stage II mandate from 2015 for a city bus: 15.9% over 6 years. International Council on Clean Transportation. 2016. *Stage 3 China Fuel Consumption Standard for Commercial Heavy-Duty Vehicles*.
[20] The following pollution values are used (per ton): NO_x = CNY 1,294; SO_2 = CNY 1,188; PM = CNY 1,292; CO = CNY 0; THC/VOC = CNY 30.
[21] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

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). Eighty percent of labor inputs were assumed to come from skilled labor and 20% from unskilled labor.

47. **Economic internal rate of return calculation.** The EIRR and the ENPV for the project are shown in Table . The ENPV at a 6% social discount rate is CNY30.82 million, while the EIRR is 14.86%.

Table 14: Economic Analysis of the subproject
(CNY million)

Year	Capital Costs	Operating Costs	Avoided Costs of Diesel Use	Avoided Cost of Diesel Bus	Avoided Pollution	Net Economic Benefits
2017	(161.90)	-	-	70.00	-	(91.90)
2018	-	(38.09)	35.77	20.31	4.67	22.67
2019	-	(38.09)	34.83	20.31	4.76	21.80
2020	-	(38.09)	33.90	20.31	4.84	20.96
2021	-	(38.09)	33.01	20.31	4.92	20.15
2022	-	(38.09)	32.13	20.31	5.01	19.36
2023	-	(38.09)	31.28	20.31	5.10	18.60
2024	-	(38.09)	30.45	20.31	5.19	17.86
2025	-	(38.09)	29.64	20.31	5.29	17.15
ENPV (CNY millions) with global environmental benefit						30.82
ENPV (CNY millions) without global environmental benefit						3.24
EIRR (%) – with global environmental benefit						14.86
EIRR (%) – without global environmental benefit						7.01

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

48. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity to economic projections. Table indicates that the EIRR remains above the 6% social discount rate even when there are considerable increases in capital costs and when there is reduction in the price of CO_2. The EIRR under the with global environmental benefit scenario falls below the 6% social discount rate when operating costs are increased. The EIRR in the scenario without global environmental benefits is above the social opportunity cost of capital in the base case but negative when CAPEX and OPEX price sensitives are applied.

Table 5: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 20%	Price of CO_2 -20%
EIRR with global environmental benefit	14.86	6.06	1.47	13.37
EIRR without global environmental benefit	7.01	-0.70	-9.89	N/A

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.

F. Super Energy Service Company (ESCO)

49. **Project objective.** The subproject will demonstrate the viability of a package of Energy Management Contracts in iron and steel industry in the PRC. The iron and steel industry is the PRC's third highest polluter of SO_2, NO_x, and PM. These pollutants contribute to respiratory diseases such as asthma and bronchitis, and smog, which leads to an increased likelihood of premature mortality. The subproject consists of seven EE retrofits in Liaoning Province in the greater BTH Region including: a waste heat recovery system to reduce energy consumption from steel production; a water-source heat pump to increase the temperature of cooling water for space heating, a dry vacuum degassing system to reduce energy consumption from steel production, a set of magnets to reduce energy consumption of steel production; an annular cooler, heat recovery ventilator, dedusting fan, and main exhauster to reduce energy consumption for pellet production; and energy efficient water pumps to reduce power consumption in steel production. The seven selected projects will result in 35,887.6 tce of energy savings, and avoid 100,135.1 tons of CO_2, 8,668.6 tons of SO_2, 272.2 tons of NO_X, and 1,464.6 tons of PM.

50. **Project rationale.** The iron and steel industry is an important driver of economic development in the PRC. This industry is also energy and pollution intensive: according to *Annual Statistic Report on Environment in China 2015*, the iron and steel industry produces 1.37 million tons of SO_2 (7.4 % of the country's total emissions), 551,000 tons of NO_x (3.0%), and 724,000 tons of and PM (4.7%).[22] In recent years, energy and emission intensity of the PRC's iron and steel industry has dropped drastically, but a substantial gap remains between Chinese and more advanced steel industries. A Super Energy Service Company (ESCO), which packages several energy efficiency projects into one investment, can make EE retrofits financially viable and help bring the iron and steel industry closer to advanced steel industry levels. Table 16 compares an advanced Chinese steel company's energy consumption and pollution levels to more advanced steel companies.

Table 16: Comparison in per ton emission of key iron and steel companies

	2001	2012	2015	International and domestic advanced level	Difference (%)
Energy (kgce/ton)	906*	601	572	470 (Ping'an Steel Company, China, 2016)	21.7
SO_2 (kg/ton)	4.64	1.53	0.85	0.44 (Nippon Steel & Sumitomo Metal, Japan 2009)	93.2
PM (kg/ton)	4.59	0.99	0.81	0.42 (Thyssenkrupp AG, Germany, 2009) 0.14 (POSCO, South Korea, 2009)	92.3 478.6

kg/ton = kilogram per ton, kgce/ton = kilogram per coal equivalent per ton, PM = particulate matter, SO_2 = sulfur dioxide.
Source: Li Xinchuang (2015), *How to Transform and Upgrade China's Steel Industry*, ISBN 978-7-5024-6795.1 (in Chinese) Page 68, 261. China Environment Newspaper, July 21, 2016.
*2000 level

51. **Economic benefits.** The economic analysis of the project was conducted in accordance with the ADB's Guidelines for the Economic Analysis of Projects. The economic benefits for the subproject include (i) coal fired generation savings, which is estimated as the net amount of energy saved in kilowatt hours after retrofits and energy efficient equipment installations compared to existing equipment; and (ii) local and global environmental benefits, which are reflected as the net amount of pollution abated compared to the reference scenario (without project scenario).

[22] ADB recognizes that there is a glut of iron and steel products in the PRC and will work closely with the planning body of the iron and steel sector–China Metallurgical Industry Planning and Research Institute–to ensure that subprojects financed are not on the Government's overcapacity list.

52. The subproject will result in energy savings of about 36,000 tce per year leading to a reduction of highly polluting coal fired power generation. The energy saved per year was valued at the current market price of coal (CNY860/ton). Since energy efficiency improvements can be expected during the life time of the subproject, the historic annual rate of EE improvements in industry, agriculture, and services sectors in the PRC (1.27%) is applied to constrain expected energy savings and emissions avoided for the economic life of the Project.[23] Global environmental benefits from CO_2 abatement is valued at the 2016 global social cost of carbon of $36.30 per ton of CO_2, adjusted to 2017 price levels, 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 (labor loss) associated with SO_2, VOC, $PM_{2.5}$, NOx, and CO emissions.[24] Table 17 shows the expected energy savings and pollution mitigated from the proposed retrofits. Supplementary Document 13 provides a detailed technical description of each project supported by the Super ESCO.[25]

Table 17: Energy Savings and Pollutant Mitigation

Project name	**Energy savings (TCE/GwH)**	**CO_2 (t)**	**SO_2 (t)**	**NO_x (t)**	**PM (t)**
Waste Heat Recovery from Flue Gas of Heating Furnace at Chaoyang Steel Plant	13,850	45,848	8635.9	242.3	1458.3
Industrial Waste Heat Recovery for Residential District Heating in Anshan	13,038 (41 GwH)	31,992	19.3	17.6	3.7
Reconstruction of 100-ton Mechanical Vacuum Degassing in Anshan	1,696 (5.39 GwH)	4,202	2.5	2.3	0.5
Energy-Saving Reconstruction on High-Pressure Quenching Water Pump at Bayuquan Heavy Plate Mill	850 (2.70 GwH)	2,105	1.3	1.2	0.2
Draft Fan Frequency Adjustment at Bayuquan Pelletizing Plant	1836 (5.83 GwH)	4,548	2.7	2.5	0.5
Water Pump Energy-saving Reconstruction at Anshan Steel Plant	2,352 (7.47 GwH)	5,827	3.5	3.2	0.7
Energy-saving reconstruction on Circulating Water Pump and Engine of Blasting Furnace at Anshan Steel Plant	2,266 (7.19 GwH)	5,614	3.4	3.1	0.7
Total	**35,887.6**	**100,135**	**8,668.6**	**272.2**	**1,464.6**

CO_2 = carbon dioxide, GwH = gigawatt per hour, NO_x = nitrogen oxide, PM = particulate matter, SO_2 = sulfur dioxide, t = ton, tce = ton of coal equivalent.

53. **Economic costs.** 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 2017 constant prices using the domestic price numeraire. Physical contingencies are included for civil works with an allowance of 10%. The SERF of 1.01371 was used to estimate the shadow price of tradable goods.[26] Ninety percent of

[23] IEA. 2016. *Energy Efficiency Market Report,* IEA.
[24] The following pollution values are used: NO_x = CNY 1,294; SO_2 = CNY 1,188; PM = CNY 1,292; CO = CNY 0.
[25] Introduction of Technologies Used for Selected Representative Subprojects (accessible from the list of linked documents in Appendix 2 of the main text of the report and recommendation of the President.)
[26] ADB. 2016. *Report and Recommendation of the President to the Board of Directors: Proposed Green Financing Platform for Accelerated Air Quality Improvement in the Greater Beijing-Tianjin-Hebei Region.* Manila.

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). Eighty percent of labor inputs were assumed to come from skilled labor and 20% from unskilled labor.

54. The estimated economic life of the project is 10 years. Because the value of the subproject's assets will not be fully worn out by the estimated technical life of the subproject (15 years), the residual value at the end of project life was calculated and included as a negative investment cost. The residual value was calculated as the proportion of technical life remaining (approximately 33%) multiplied by the investment cost of the equipment, vehicles, and furniture cost category (CNY70.67 million).

55. **Economic internal rate of return calculation.** The EIRR and the ENPV for the project with and without global environmental benefits (reduction of CO_2 emissions) are shown in Table 18. The EIRR of the subproject including global environmental benefits is 44%. Without global environmental benefits, the EIRR of the subproject is 20.52%. The EIRR of the project with and without environmental benefits are above the assumed social opportunity cost of capital (6%). The ENPV for the project including global environmental benefits is CNY298.06 million. Excluding global environmental benefits, the ENPV of the subproject is CNY98.38 million.

Table 18: Economic Analysis of the Subproject
(CNY million)

Year	Capital Costs	Operating Costs	Avoided Costs of Coal Generation	Avoided Pollution Costs	Net Economic Benefits
2017	(126.85)	-	-	-	(126.85)
2018	-	(11.84)	30.85	38.55	57.56
2019	-	(11.84)	29.62	38.57	57.20
2020	-	(11.84)	28.44	38.60	56.84
2021	-	(11.84)	27.30	38.63	56.49
2022	-	(11.84)	26.21	38.67	56.15
2023	-	(11.84)	25.16	38.71	55.81
2024	-	(11.84)	24.15	38.75	55.49
2025	-	(11.84)	23.19	38.79	55.17
2026	-	(11.84)	22.26	38.84	54.86
2027	-	(11.84)	21.37	38.89	54.56
2028	1.46	(11.84)	20.51	38.95	55.73
ENPV (CNY millions) – with global environment benefits					298.06
ENPV (CNY million) – without global environment benefits					98.38
EIRR (%) – with global environment benefits					44.00
EIRR (%) – without global environment benefits					20.52

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

56. **Sensitivity analysis.** Sensitivity analysis was conducted to assess the sensitivity of economic projections to increases in capital and operating expenditure, and to decreases in the marginal cost of climate change of CO_2. Table 19 indicates that the EIRR remains above the 6% social cost of capital when capital and operating costs are increased by 20% in the with and without global environment benefits scenarios. The EIRR in the with global environment benefits

scenario also remains robust when the real cost of CO_2 is reduced by 20%.

Table 19: Sensitivity Analysis for Economic Internal Rate of Return (%)

	Base Case	CAPEX + 20%	OPEX + 20%	Price of CO_2 -20%
EIRR (%)	44.00	36.02	42.02	39.57
EIRR (%) – without global environment benefits	20.52	15.52	18.17	-

CAPEX = capital expenditure, CO_2 = carbon dioxide, EIRR = economic internal rate of return, OPEX = operational expenditure.