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Abstract

Corporate motives and strategies of both investing and hosting country affect the outcomes of a CDM project—*who* introduces *what* technology to *whom*—and result in large differences in economic viability and the CO_2 emission reductions. This is particularly true for steel industry in which steel making consists of many detailed and complex processes, a given strategy could produce cumulative effects of the individual technologies used, leading to large energy savings overall. The objective of this study is to demonstrate some analytical methods that can be used to quantitatively evaluate the impacts of technology selection on the profit performance of CDM projects. Specifically, in this study we analyze a CDM project to introduce energy saving technology from Japan to a small steel manufacturer in China's Shandong Province, and conduct a simulation of the quantitative relationships between various technology options and profitability. Based on these results, we examine the environmental and economic significance of technology selection for CDM projects. To take this further, we then reconsider the profitability of a project as typical FDI activity (i.e., without the CDM), and by comparing this outcome with the CDM case, we clarify the significance and potential of the CDM.

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1. Introduction

The use of flexibility mechanisms known as the so-called Kyoto Mechanisms, including the Clean Development Mechanism (CDM), was approved internationally to help Annex I countries meet their greenhouse gas (GHG) emission reduction targets, at the third session of the Conference of the Parties (COP-3) to the UN Framework Convention on Climate Change (UNFCCC) in 1997. The CDM entered its implementation phase after four years of negotiations that culminated in comprehensive agreement in 2001 (the Marrakesh Accords) relating to its operational rules. At COP-8 in November 2002, the CDM executive board approved trial accreditation and verification of Operational Entities (OE) that are responsible for the administrative functions of registration and certification of CDM projects, moving the preparations for institutional arrangements into the final stage. Because many of the implementation rules had been undecided up to that point, much CDM-related research focused on discussions about the CDM system itself and methods to estimate baselines. But with implementation rules decided, the focus of research will now shift to issues such as estimating the CO_2 reduction potential of CDM projects, the selection of priority sectors, and building the implementation capacities. In the Asian region, developing countries are beginning such work, in cooperation with international organizations such as the World Bank (National Strategic Studies for Indonesia, Thailand, China, etc. at http://www.worldbank.org/nss), and the United Nations Environment Programme (UNEP, CDP Capacity Building Program for Vietnam, Cambodia, and Philippines at http://cd4cdm.org/).

Energy costs account for a large portion of production costs in energy intensive industries such as steel making, creating a strong incentive to save energy. Energy saving strategies for the steel industry can be broadly classified into simplification of processes and improvements in work operations, continuous casting, recovery and utilization of waste energy, and thermal recycle of sludge and wastes—and each of these involves a range of technologies. Generally speaking, because steel making consists of many detailed and complex processes, a given strategy could produce cumulative effects of the individual technologies used, leading to large energy savings overall. This phenomenon has been witnessed in Japan's steel industry, in which improvements in operational efficiency implemented carefully in all processes have helped to realize a large improvement in productivity (Japan Iron and Steel Federation, 1991; Kotani and Kondoh, 2002). Three major factors that affect the potential of CO_2 emission reductions in a CDM project are: (1) differences in the technology levels between the technology provider and technology recipient, (2) costs, and (3) incentives for the participating entities. Each of these is closely related to the technology selection, i.e., what kinds of technologies are introduced to which country. In other words, for the steel industry the selection of technology is one of very important factors for a CDM project.

A common method used to ascertain the CO_2 reduction potential of a CDM project is to calculate the relationship between the average unit emissions reduction (i.e., average cost per unit of CO_2 reduction) in a particular industry and the predicted price of certified emission reductions (CERs) (e.g., Kainuma *et al.*, 1999, 2000; Jiang, 1998; Baron *et al.*; 2000; Woerdman *et al.*, 2001; Jotzo et al., 2002; Chen, 2003). This is the mainstream approach because the focus is on considering differences between industries, from a macro perspective, by estimating the CO_2 emission reductions that could be achieved from CDM projects for industry overall, or for one particular industry. But the case of the steel industry makes it clear that estimates resulting from this approach can only have limited meaning, if one considers the importance of technology selection or differences in the significance of a given technology in a given industry. In addition, if one considers that CDM projects are ultimately conducted on a project-by-project basis, and that the investors are likely to be mainly from private sectors, the situations for specific projects can differ widely. Such individual project specific variations including technology selection can largely affect average unit emissions reduction, and accordingly obscure the overall picture of sectoral CO_2 reduction of the steel industry.

Meanwhile, in the context of economic globalization, corporations from developed countries are constantly scouring the world for investment opportunities, and technology is transferred from developed to developing countries as a part of global strategies of corporations. This dynamic foreign direct investment (FDI) activity presents developing countries with many options for the introduction of energy saving technologies. It is important to understand whether or not the new mechanism offered by the CDM changes the business decisions of corporations. Such motives and strategies affect the outcomes of a CDM project—*who* introduces *what* technology *to whom*—and result in large differences in economic viability and the CO_2 emission reductions. This is why we are emphasizing the need to specify concretely who are the technology providers and recipients, when evaluating a CDM project, and to conduct analysis only after being as specific as possible about the technology. This is also why individual case studies are so important.

The objective of this study is to demonstrate some analytical methods that can be used to quantitatively evaluate the impacts of technology selection on the profit performance of CDM projects. Specifically, in this study we analyze a CDM project to introduce energy saving technology from Japan to a small steel manufacturer in China's Shandong Province, and conduct a simulation of the quantitative relationships between various technology options and profitability. Based on these results, we examine the environmental and economic significance of technology selection for CDM projects. To take this further, we then reconsider the profitability of a project as typical FDI activity (i.e., without the CDM), and by comparing this outcome with the CDM case, we clarify the significance and potential of the CDM.

2. Review of relevant studies

2.1. Estimating abatement costs

Much research has been conducted on the costs of reducing CO_2 emissions connected with energy consumption. This work has been conducted from the economic perspective in the context of measures to address global warming, based on the view that it is advantageous to make the reductions in countries, regions or sectors where the costs of reduction are the cheapest. The platform for the methodology comes from the economic analysis of the costs of energy conservation that is done with the aim of efficient use of finite energy resources, and this approach has been used since many years ago (*e.g.*, Nordhaus, 1979). After the Earth Summit in 1992, the issue of climate change became one of key topics on the agenda of international negotiations, animating debate about how to calculate the costs and evaluate the economics of climate policies, and boosting the need for research into the costs of reducing CO_2 emissions (IPCC, 1995).

A series of studies have estimated the costs of CO_2 emissions reduction by using macro economic models for measuring energy. The Energy Modeling Forum (EMF) compares the CO_2 emissions reduction costs in various countries from a number of modeling studies (IPCC, 2001). With top-down models, it is possible to compare the reduction costs of CO_2 in various countries and sectors, as well as the investment required to implement such projects. But because these studies are based on assumed average reduction costs for certain technology options in each sector, it is not possible to consider differences between technologies. Thus, that approach is not easily applicable to the micro-level evaluation of individual projects.

Shukla (1995) estimates reduction costs by sector, while explicitly considering technology options. That study estimates CO_2 reduction costs, targeting typical technology options, using case studies from Brazil, Egypt, India, Senegal, Thailand, Venezuela and Zimbabwe. With a total of 46 options in 7 countries, this represents an average of 6.6 options evaluated per country. But in contrast to the detailed focus on individual technologies in the present study, Shukla covers only the more conventional types of technologies.[5]

Kainuma *et al.* (1999, 2000) and Jiang *et al.* (1998) estimate the costs of CO_2 reduction

[5] For example, electricity conservation, solar energy, fuel wood and charcoal, ethanol, bagasse conversion, fuel switching by households, efficient industrial equipment, efficient transportation technology options, etc.

by considering specific technologies in a series of studies that used the AIM/End-Use Model. They calculate the average cost function for CO_2 emission reductions, based on profile data for a number of individual new and advanced technologies, for 29 industries in 5 sectors (agricultural, industrial, residential, service and transport). For example, in the steel industry they consider 17 types of advanced technologies. Jiang *et al.* applied these methodologies to China and ranked the sectors in terms of average cost for CO_2 emission reductions (lowest to highest cost) as residential (urban), residential (rural), service, industrial, agricultural, and finally, transport. These studies made it possible to discuss the most economically efficient technology packages, taking into account the different unit reduction costs of various technologies.

2.2. Assessment of AIJ

The CDM allows for the acquisition of credits counting back to the year 2000,[6] but there are still few examples of implementation, and comparative analysis is insufficient to date. In this context, the economic aspects of the CDM and JI (Joint Implementation) have been analyzed through the results of Activities Implemented Jointly (AIJ), which acted as pilot projects for the CDM and JI, and have covered technical issues for implementation of the CDM (such as the design of baselines and inventories, additionality, etc.) and economics based on those results (e.g., Ellis, 1999; Bosi, 2001). Woerdman *et al.* (2001) conducted a comprehensive and exemplary study that analyzes reduction costs. It separates AIJ analysis into implementation in non-Annex I countries (envisioning future

[6] Stipulated in Article 12.10 of the Kyoto Protocol.

CDM projects), and implementation in Annex I countries (envisioning future JI projects), analyzes costs per ton of CO_2 emission reductions for each project type, and attempts to clarify the conditions necessary for projects to achieve a high cost-benefit ratio. Compared to the average \$46/t-CO_2 for AIJ projects overall,[7] the unit reduction cost for energy efficiency improvement projects implemented in non-Annex I countries was only \$16/t-CO_2. By project type, forest preservation was the cheapest, at an average \$1/t-CO_2, and more expensive projects were ranked (from low to high cost) as agriculture, energy efficiency, reforestation, and renewable energy. However we point out that there are a number of limitations in the above studies to consider the amounts of CO_2 emission reductions of future CDM projects. First of all, a common problem of this kind of analysis is the large difference in costs between AIJ projects conducted as trials, and CDM projects that involve real investment activities. (Michaelowa *et al.*, 1999; Michaelowa, 2002; Schwarze, 2000).[8] Another point, similar to the problem of differences in average reduction costs between project types, is that cost differences exist even between projects in a given sector. Figure 1 is a comparison, by sector, of the disparity between projects in the same sector in terms of the unit cost of CO_2 emission reductions. The comparison was done using the maximum, minimum and average cost, for (1) results of estimates calculated from investment costs and reductions reported to the UNFCCC for all AIJ projects (110 in total); (2) estimated results for AIJ projects (17 in

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7 In order to be closer to the CDM/JI, this analysis assumes that prices take the banking of credits into account.

8 Schwarze (2000) showed that AIJ projects had regional imbalances similar to patterns evident in trade and official development assistance, but that this was the result of lower transaction costs. It was shown that Europe had a tendency to invest in Eastern European economies in transition (EITs), Japan in East Asia, and the United States in South America.

total) implemented in non-Annex I countries covered in research by Woerdman *et al.* (2001); and (3) results of estimates of CDM project feasibility studies (64 in total) conducted by the New Energy and Industrial Technology Development Organization (NEDO). In addition, we also show the costs of CO_2 emission reductions (maximum, average, minimum) of individual energy efficiency technologies being promoted by NEDO, specifically for the steel industry. This figure shows clearly that the differences in the costs of CO_2 emissions reductions are too great to be ignored—differences between sectors, between individual projects in the same sector, and between technologies.

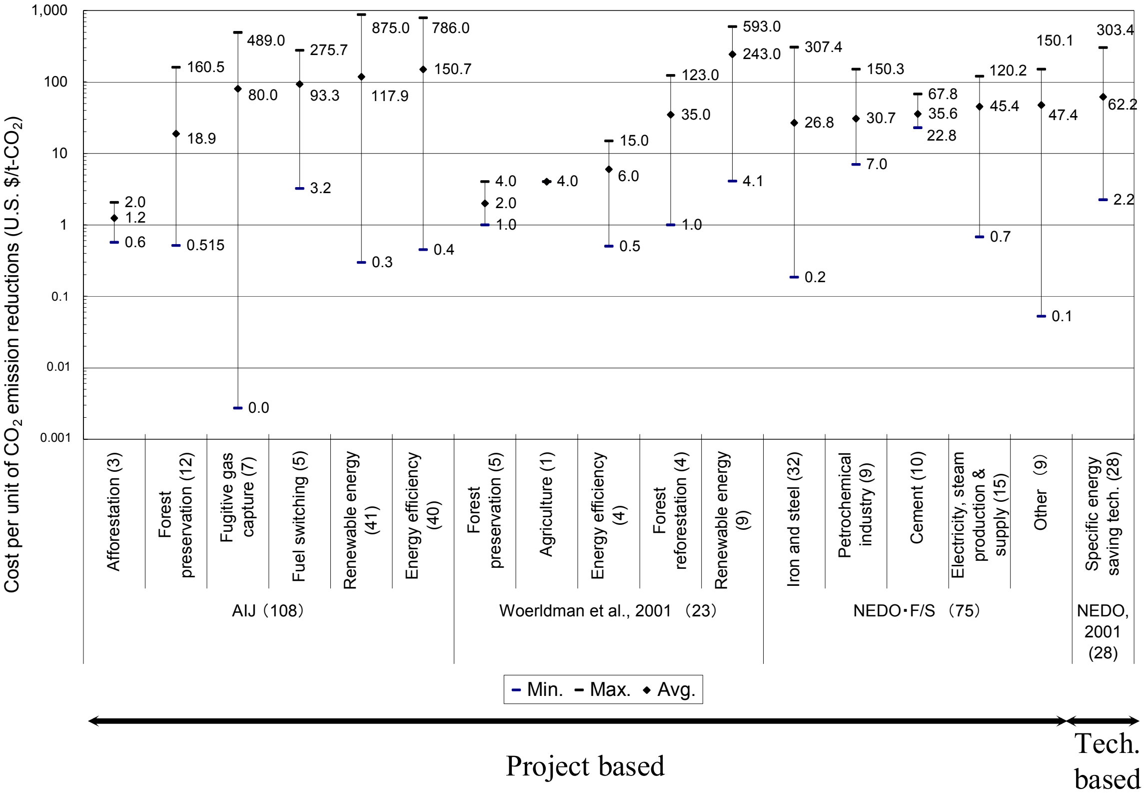

Figure 1. Cost Per unit of CO_2 emission reduction, by project type, sector and technology (U.S.$/ t-$CO_2$).

1. The values of AIJ are calculated by dividing the the total investment amount reported under uniform reporting format (URF), by the product of CO2 emission reduction per year and the product period in years. In other words, total cost (US$) ÷ [US$ per avoided ton of CO2 equivalent (t-CO2/yr) × project duration (years)]
2. AIJ and the NEDO F/S Japan energy conservation technology case studies all are calculated using 10 years as the project duration or credit creation period.
3. The values used in Woerldman *et al.* (2001) are for projects implemented in developing countries as part of AIJ, and the

2.3. Analysis of profitability of CDM projects

In recent years more and more detailed studies have paid attention to project economics, with consideration of various prices that affect profitability, including the prices of technology, raw materials, and CERs, etc. For example, regarding the potential of the CDM for the power generation sector in the Asia-Pacific region, APERC (2001) considers the profitability of project implementation from the perspective of revenues and costs. In terms of revenues, the analysis makes assumptions based on wholesale electricity prices and CER sales. The expenditures of project implementation include capital investment, operation and maintenance, and fuel prices. The study includes a sensitivity analysis of CER prices, as well as other factors, such as various tax rates on the income. The analysis resulted in an internal rate of return (IRR) of between 1.2% and 6.0% for a coal fired power generation unit displacement project in China with a combined cycle gas turbine (CCGT). Meanwhile, for a construction project in Indonesia of a CCGT power generation unit using natural gas, the IRR was between 2.7% and 19.9%. For a fuel switching project in Thailand, from biomass generation to co-firing power generation using coal, the IRR was between 12.0% and 20.8%.

Meanwhile, a series of studies by Ujikawa (2003) involved cost-benefit analyses based on detailed information obtained from field research on construction costs and energy conserving benefits of specific technologies, targeting blast furnaces in steel plants of Shandong Province with a capacity of 50 cubic meters or less. The technologies included blast furnace upgrades with sintering plants as supplementary equipment, ore size selectors and coke plant equipment. The studies concluded that for the province overall, the benefits exceeded the costs starting in the third year.

Kosugi *et al.* (2002) conducted a cost-benefit analysis of the hypothetical introduction into China of natural gas cogeneration systems (for electricity and heat) using the CDM. The study found that even where a project was profitable overall, the cost-benefit relationship for the investor could worsen and the incentive to invest be eroded, depending on the investment contribution ratio between the investing and host countries, the credits from CO_2 reductions, and the contractual arrangements for allocating indirect profits.

The above studies on individual projects discuss issues based on just one energy saving technology or on a predetermined package of related technologies. But where multiple technologies are involved, that is, where a number of separate technologies and equipment are combined—as is the case in the steel making industry—the energy saving effects in the production processes are the cumulative result of energy saving effects of specific individual technologies. It is clear that because there are a many possible combinations of technologies, the meaning of the word "technology" changes, and this means that different approaches are needed to evaluate technologies.

3. Research framework

3.1. Methodology

For a given plant, there are *a* separate energy-saving technology options that could be introduced, and when evaluating the technology package to be introduced as a combination of *m* types of energy-saving technology options, the total possible number of evaluation cases *N* is expressed by the following formula.

$$N = \sum_{m=1}^{a} {}_{a}C_{m} \quad (1)$$

For each evaluated case N (=1, 2, … …), the total cost $COST_N$, amount of energy saving dE_N and amount of CO_2 reduction $dCO2_N$ are expressed by the following formulas.

$$COST_N = \sum_{i=1}^{m} (\varpi_i CEQ_i + \theta_i CLB_i) + RF_N \quad (2)$$

$$dE_N = \sum_{i=1}^{m} de_i \quad (3)$$

$$dCO2_N = \sum_{i=1}^{m} dco2_i \quad (4)$$

Here, CEQ_i is the equipment price for energy technology option i in the technology-providing country, and CLB_i is the construction costs for technology option i in the technology-providing country. In addition, ω_i is the equipment price difference rate or cost change rate between provider and host country, and θ_i is the construction cost difference rate or cost change rate. These parameters were adopted to explicitly express the differences in costs of technology transfer depending on differences in form of investment. RF_N is the CDM registration fee[9] that is deducted from CER revenues, for introduced technology package N. Meanwhile, de_i is the energy-saving effect (tons of oil equivalent per year, or TOE/yr) and dCO_{2i} reduction effect (t-CO_2/yr) for the case of introduction of specific technology option i.

The energy price $Pe(t)$ during time period t is expressed as shown below, where δe is the annual rate of energy price increase.

$$Pe(t) = Pe(0)(1+\delta e)^t \quad (7)$$

The expenditures $Exp_N(t)$ for the technology introduction project after time period t are expressed as shown below, as well as revenue $Rev_N(t)$, the price of energy $Pe(t)$ and the price of CERs $Pc(t)$ after time period t. Meanwhile, f_i is the share of CDM proceeds going to the Adaptation Fund, in connection with CDM revenues from introduced technology option i.

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[9] The CDM registration fees were announced at the sixth CDM executive board meeting. These fees are subtracted from CER revenues during the first year that CERs are generated, and depend on the average annual GHG reductions (CO_2 equivalent) over the life of the project. The fees are U.S.$5,000 for average annual reduction of 15,000 t-CO_2eq/yr or less, U.S.$10,000 for over 15,000 to 50,000 t-CO_2eq/yr or less, U.S.$15,000 for 50,000 to 100,000 t-CO_2eq/yr or less, $20,000 for over 100,000 to 200,000 t-CO_2eq/yr or less, and $30,000 for over 200,000 t-CO_2eq/yr.

$$Exp_N(t) = \begin{cases} COST_N & (t = 0) \\ 0 & (t \neq 0) \end{cases} \quad (8)$$

$$Rev_N(t) = dE_N(t) \cdot Pe(t) + dCO2_N(t) \cdot Pc(t) - f_i \cdot dCO2_N(t) \cdot Pc(t) \quad (9)$$

Profit performance can be evaluated based on the balance between revenues and expenses for a project, but when considering a long period of time, a discount rate reflecting the actual change of net present value is important. For projects in this study, it is assumed that the initial investment to introduce an energy saving technology package is recovered by the annual energy cost saving from conserving energy and the revenue from CERs obtained under the CDM. Thus, for each technology package *N*, the discount rate *j* is set at a fixed amount for each period, and from the present until *t* time periods later, the sum of present values of capital expenditures I_N and the sum of present values of cash flows V_N are as shown below.

$$I_N(t) = Inv_N(0) + \frac{Inv_N(1)}{1+j} + \frac{Inv_N(2)}{(1+j)^2} + \cdots + \frac{Inv_N(t)}{(1+j)^t} = \sum_{n=0}^{t} \frac{Inv_N(n)}{(1+j)^n} \quad (10)$$

$$V_N(t) = \frac{Rev_N(1)}{1+j} + \frac{Rev_N(2)}{(1+j)^2} + \cdots + \frac{Rev_N(t)}{(1+j)^t} = \sum_{n=0}^{t} \frac{Rev_N(n)_n}{(1+j)^n} \quad (11)$$

The internal rate of return (*IRR*) is defined as the discount rate *j* required to make the sum of present values of future cash flows equal to the required investment amount. In other words, it is the discount rate that results in a net present value of zero.

$$NPV_N = V_N(t) - I_N(t) = \sum_{n=0}^{t} \frac{Rev_N(n) - Inv_N(n)}{(1+IRR_N)^n} = 0 \quad (12)$$

If *IRR* is higher than a suitable discount rate (called the cut-off rate), corporate value will increase by implementing the project. In practice, if *IRR* and interest rate *j* are compared and *IRR* is greater than *j*, this project would be worth adopting, and if *IRR* is less than *j* the reverse is true.

As for implementation of small-scale CDM projects[10] led by private corporations, research on feasibility and obstacles for the CDM has pointed out that an IRR of 15% or higher is a necessary precondition for a project to attract investment (Sutter 2001). Following that example, the present study uses a standard of 15% to evaluate profitability of investment for IRR_N calculated for each technology package *N*.

3.2. Simulation assumptions

3.2.1. Cost saving scenarios (CSS) for technology transfers

Cost is a major obstacle when considering transferring an energy saving technology from Japan to a local plant in China. To increase the profitability of a project, we establish scenarios for reducing costs associated with technology transfer, which can be divided into equipment cost and construction cost. We define cost saving scenario I (CSS-I) as the implementation of a project using 100% of Japan's price levels. In this case, all of the equipment and construction materials are imported from Japan to China, and it is assumed that technicians from Japan do the construction work. Next, we define cost saving scenario II (CSS-II) as a case in which the equipment comes from Japan, but only the construction and installation of equipment is contracted out to corporations in the host country. In this case, because personnel costs account for the majority of construction costs, we calculate the cost reduction ratio from the income disparity between China and

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10 A small-scale CDM project is either (a) renewable energy project equivalent to maximum electrical generation of 15 MW (or equivalent), (b) energy efficiency improvement project activity that reduces energy consumption by up to a maximum of 15 GWh per year, (c) a project that reduces anthropogenic emissions from sources and the direct emissions are under 15 kilotons in CO2 equivalent per year.

Japan using per capita GDP (using PPP data, from WB 2002). Specifically, we use the value ω=0.16 for 2001. In short, this means reducing construction costs by 84%. Finally, we define cost saving scenario III (CSS-III) as a case in which, besides contracting the construction out locally, further cost reduction is achieved through local procurement of some of the parts for the equipment. The resulting cost reductions are interrelated in a complex way and determined by not only the different technology levels and costs between Japan and China, but also the ratio of local equipment procurement. In this study, due to the availability of data, we use one approach for all technologies, drawing on the experience of a technology transfer involving coke dry quenching (CDQ), implemented in the past for the Shougang steel plant in Beijing. Based on the above case, we assume the equipment cost reduction parameter θ is 0.8.[11]

3.2.2. Energy price scenarios

Future changes in energy prices will have major impacts on project profitability. The primary energy sources for steel production include coal-related energy such as raw coal and coke. China depends on coal to a great extent for its energy overall, but in recent years the proportion of total energy consumption accounted for by coal has been declining. In addition, with the exception of coal for electricity generation, since 1993 measures have been taken for complete price liberalization. Coal prices continued

[11] The following were found from interviews with Capital Steel and Nippon Steel Corporation, and from AIJ reports. Capital Steel introduced CDQ technology under the NEDO Green Aid Project, using both construction costs and equipment costs at 100% of Japanese price levels (Unit 1). This energy saving technology transfer project was later recognized as an AIJ project. Later, Unit 2 was introduced between Capital Steel and Nippon Steel Corporation, and at that time, a portion of technology was procured locally. As a result, it was possible to reduce equipment costs by 20% compared to Unit 1.

dropping from then until 2001, but in 2002 the trend changed to a slight increase. China liberalized its coal market, but because it still has lower prices than the international market prices,[12] it is not possible to rule out a large increase in the future. According to recent forecasts by the IEA (2003), the international market price of coal for the period 2002 through 2010 will be steady at $39/t-steam coal, and after that there will be a small but steady price increase to $44/t-steam coal in 2030. In that context, for this simulation, we use the two scenarios shown below for changes in energy prices in China's non-transparent energy market. It must be mentioned, however, that we take coal for use in boilers as the indicator for determining future energy price scenarios, and assume that coke and other energy prices will change in the same way. For the first scenario ("low energy price scenario"), it is assumed that coal prices in China will move in a stable way during the project period, and that they will match changes in international prices. In other words, it is assumed that the difference between prices in China and the international market will remain constant. The rate of price increase used for the 10-year period from 2001 to 2011 is 0.3% per year. The second scenario ("high energy price scenario") assumes that over the course of the project period (i.e., by 2011) China's energy will rise to international market prices. The producer's price of boiler coal in China in 2000 (from IEA 2002) was U.S.$27.3 t-steam coal (in 2000 prices). Thus, for the second scenario, if we assume that the price of boiler coal in China will rise to the international market price by 2010, this means an annual price increase of 3%.

The steel industry mostly consumes coal-related energy, but the actual type of fuel used

[12] See IEA (2003).

depends with the production process.[13] To simplify the analysis in this study, however, we use an average energy price for coal, calculated in terms of the thermal conversion (TOE) for each type of fuel actually used at the plant, calculate total energy consumption and total cost, and use the average energy cost as the coal price. It is to this price that we apply the price increase scenarios. After calculating the average price of energy consumed at the plant in question, based on interviews during field studies, we obtain the value of $43.8/TOE (=*Pe*) for 2001, the starting year for analysis.

3.2.3. CER price scenarios

At present, it is not certain at what price CERs will be traded. However, information is available on the prices of some of the purchasing that has begun on carbon credits under the CDM and JI. Examples include the Netherlands government's Emission Reduction Unit Purchase Tender (ERUPT) and Certified Emission Reduction Unit Purchase Tender (CERUPT) programmes and the World Bank's Prototype Carbon Fund (PCF), and these activities appear to be increasing.[14] The reported purchase price for credits under a CDM energy conservation project in 2001 was \$4.0/t-CO_2 (EUR4.4/t-CO_2). This study uses that amount for the CER low price scenario.

Much research has been conducted regarding prices for carbon credits. According to 13

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13 For example, in the target plant, the coal used to make coke needed to produce pig iron and the coal used in other processes is different from the coal used as fuel in other processes. Note that in this plant, about 40% of the coke used is produced in-house, while 60% is purchased elsewhere. For this study, it is assumed that the proportion of coke produced in-house and purchased from elsewhere does not change due to the implementation of the project.

14 At the beginning of 2003, Finland and Denmark governments launched a carbon credit purchasing system based on international competitive bidding similar to the ERUPT/CERUPT style. Also, in Japan, various ministries and organizations, are considering the establishment of independent or cooperative World Bank PCF-type carbon fund, as well as subsidies, etc. (Asuka, 2003).

representative studies, the global trading price for carbon credits, including from CDM projects, ranged widely, from \$1 to \$22/t-CO_2 in year 2000 dollars (Springer 2003).[15] This study sets the CER price to be U.S.\$10/t-CO_2 as the "CER price high scenario," based on the results of MS-MRT,[16] which estimated carbon credit prices using the Computable General Equilibrium (CGE) model. In addition, besides setting the CDM price scenarios as described above, we define FDI as a case with no CERs (i.e., CER = 0), which means we have a total of 3 scenarios.

3.2.4. Simulation cases

This study uses 3 scenarios each for technology transfer cost reduction types (CSS-I, CSS-II, CSS-III) and CER prices (0, low, high), and 2 scenarios (low, high) for the annual rate of increase of energy prices. The combinations of these three categories of scenarios we call "cases." Among these scenarios, the base case is defined as the most expensive scenario of technology transfer type (CSS-I), with a 0.3% annual increase in energy prices (i.e., the energy price low scenario), and no use of CERs (CER=0), which means it is in effect an FDI project. Twelve of the cases involve CERs (i.e., CER≠0) as CDM project scenarios and other 5 cases are FDI (CER=0), for a total of 18 cases, which form the basis for the simulation. The parameters and scenarios are summarized in Table 1.

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15 A lot of the research has used economic models such as AIM, EPPA, GREEN, RICE-98, etc., to estimate carbon unit prices in the international market. See also Pembreton (2002), Janssen (2001).

16 See Bernstein et al., 1999 and 1998.

Table 1. Simulation setting.

Case name	Cost saving scenario for tech. transfer	Investment cost parameters Equipment ω	Construction Θ	Energy price scenario	Annual energy price increasing ratio (%) δe	CER price scenario	CER price (US$/ t-CO2) Pc
Base case	CSS-I	1	1	Low	0.3	CER = 0	0
FDI-1	CSS-II	1	0.16	Low	0.3	CER = 0	0
FDI-2	CSS-III	0.02	0.16	Low	0.3	CER = 0	0
FDI-3	CSS-I	1	1	High	3.0	CER = 0	0
FDI-4	CSS-II	1	0.16	High	3.0	CER = 0	0
FDI-5	CSS-III	0.02	0.16	High	3.0	CER = 0	0
CDM-1	CSS-I	1	1	Low	0.3	Low	4
CDM-2	CSS-II	1	0.16	Low	0.3	Low	4
CDM-3	CSS-III	0.02	0.16	Low	0.3	Low	4
CDM-4	CSS-I	1	1	High	3.0	Low	4
CDM-5	CSS-II	1	0.16	High	3.0	Low	4
CDM-6	CSS-III	0.02	0.16	High	3.0	Low	4
CDM-7	CSS-I	1	1	Low	0.3	High	10
CDM-8	CSS-II	1	0.16	Low	0.3	High	10
CDM-9	CSS-III	0.02	0.16	Low	0.3	High	10
CDM-10	CSS-I	1	1	High	3.0	High	10
CDM-11	CSS-II	1	0.16	High	3.0	High	10
CDM-12	CSS-III	0.02	0.16	High	3.0	High	10

3.3. Baseline of the study plant

The plant targeted by this study is the Integrated Iron and Steel Making Works, a medium-sized steel maker in China's Shandong Province.[17] Basic data for the plant was obtained by a field study in November 2002. This data includes information on energy efficiency, industrial output, and pricing of fuels being used. The company profile of the plant used in the case study is summarized in Table 2. For the carbon emission factor (CEF) we use the value 0.0419 t-C/TJ recommended by the IPCC, and thermal output of coal also comes from IPCC values, at 26.8 TJ/TCE.[18]

17 The production process is divided into the ironmaking process, which makes pig iron from iron ore in a blast furnace, and steelmaking, which turns the pig iron into steel and the steel slabs that are produced are rolled into plates and bars, etc. to become steel products. Plants that conduct all the work from ironmaking to steelmaking are called integrated steel plants. The production of steel can be divided into two types, one from iron ore as the raw material to crude steel in a steel converter using pig iron made in a furnace, and the other one producing crude steel by melting pig iron and scrap iron, etc., in an electric furnace. The present case study plant is the former type.

18 The value for anthracite was used.

Table 2. Profile of the target steel plant, 2001.

Parameter	Value
Output	
Pig iron	560,000 tons
Crude steel	406,500 tons
Energy consumption	12.2 PJ/yr 292,300 TOE/yr
Amount of CO2 emissions	1.2 million ton-CO2/yr
Energy intensity	1,027 KgCE/ t-crude steel (=30.1 TJ/ t-crude steel)
Industrial output	815.8 million RMB (=97.9 million 2001 US$)
Total employees	1,000

Note: Production of crude iron is estimated from past pig iron and crude iron production, as well as data obtained from interviews. The carbon emission factor (CEF) is calculated from IEA (2000). The thermal conversion factor of energy consumption is calculated from IEA (2001). It was calculated as 1 TCE = 0.7 TOE, based on IEA (2001) and the China Energy Statistical Yearbook (1999).

The main fuel used at this plant is coal, and in 2001 the total energy consumption was 12.2 PJ/yr (292.3 Th. TOE/yr). The total annual CO_2 emissions from energy consumption amounted to 1.2 Mt-CO_2. Using these figures as the baseline, this study conducts a simulation of the profit performance in cases of introduction of energy-saving technology.

Table 3. Crude steel production and energy intensity in China, 2000.

Annual crude steel output	No. of enterprises	Crude steel output & share		Energy intensity (Avg.)	Gross industrial output value	
		million tons	%	GJ/t-crude steel	billion US$	(%)
output＞1Million ton	4	41.2	32.1	27.9	135.4	23.7
5Mt＞output＞1Mt	33	65.1	50.7	27.9	182.1	31.9
1Mt＞output＞0.5Mt	13	9.0	7.0	28.0	23.0	4.0
0.5Mt＞output	2,947	13.1	10.2	n.a.	231.1	40.4
Total	2,997	128.5	100.0	41.2	571.6	100.0

Source: China Steel Yearbook 2001, 2001.

Table 3 shows the relationship between production scale and energy consumption in China's steel industry. In 2000, 2,997 companies were operating in China's steel-making industry, of which 98% were small plants with 500,000 tons or less of annual crude steel output. The steel plant targeted by this case study fits into this category and is a typical state-owned corporation in China.

The overall steel industry in China has energy consumption per ton of crude steel output (i.e., energy intensity) that averages 41.2 GJ/t-crude steel, but for steel makers with crude steel output of 1 million tons or greater, the energy intensity averages 27.9 GJ/t-crude steel, indicating that energy efficiency rises in proportion to the scale of production. The energy intensity of the case study plant is 30.1 GJ/t-crude steel, which is relatively more efficient that the overall steel industry, but not as high as the level of plants with 1 million tons or more of annual output.

Meanwhile, the energy intensity of Japanese the steel industry in that year was 18.9 GJ/t-crude steel,[19] meaning that the amount of energy needed to produce one ton of crude steel was about 2.2 times higher in China's steel industry overall compared to Japan. Even in plants with annual output of 1 million tons, it was still 1.5 times Japan's energy consumption. This means that, roughly stated, if Japan's technology was introduced to China, the potential would exist to improve the energy intensity of China's steel industry overall by 45.9%. This is about the same result as found by an analysis by Price *et al.* (2002) of the potential for China's steel industry to improve energy efficiency. They calculate the energy intensity of best practice technology for each steel making process based on data on the composition of steel products (e.g., slabs, hot rolling steel, wire) and the volumes of raw materials used (e.g., iron ore, limestone and scrap iron, etc.) of the

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19 Estimate from the Committee on Iron and Steel Statistics (2002).

steel industry in countries around the world, and using these as the benchmarks, estimate the potential improvement in energy intensity in the case of introduction of best practice technologies to China's steel industry (Price *et al.*, 2002). They then indicate that it is possible to improve the energy intensity by 45%, from 36.7 GJ/t-crude steel in 1995 to 20.2 GJ/t-crude steel.

Generally speaking, for competitive reasons companies are cautious about releasing

Table 4. Technologies used in this simulation.

Process	Energy conservation technology (equipment)	Energy reduction (thousand TOE/yr)	Investment costs (million 2001US$)		
			Total	Construction	Equipment
Iron making	Efficient ignition of a sintering furnace	0.2	0.5	0.04	0.4
	Improving the segregation of sintered materials	2.0	0.9	0.2	0.7
	Coal moisture control	2.5–4.7	20.7	4.1	16.5
	Coke dry quenching (CDQ)	14.3	28.9	4.1	24.8
	Pulverized coal injection system for blast furnaces	13.3–53.3	16.5	4.1	12.4
Steel making	Regenerative burner system for ladle heating	1.0	0.3	0.04	0.3
	High efficiency gas separation	1.6	4.5	0.4	4.1
	Waste gas recovery from oxygen converter	4.0	5.0~9.1	-	-
Casting	Continuous casting machine	5.6	28.9	12.4	16.5
Rolling	Hot direct rolling	1.0	2.1	0.4	1.7
	Skid cooling water sensible heat recycling system for heating furnace	26.6	17.4	2.5	14.9

Notes:
1. From among the energy conservation technologies listed in NEDO (2001), this table excludes those with CO2 reduction cost of $1000/t-CO2 or greater.
2. The crude oil equivalent for energy reduction amount is estimated for a 1 million ton/year crude steel plant. However, for the waste gas recovery from oxygen converter, a heating capacity of 200,000 tons is assumed.
Source: Prepared based on NEDO (2001).

information such as the energy conservation effects, prices and construction costs of specific equipment. This study uses data on Japan's energy conserving technologies in key industries where greater energy efficiency is needed (NEDO, 2001). The report provides information on 29 technologies collected from major Japanese corporations regarding Japan's energy saving technologies in the steel making industry. During field studies, the authors asked the study plant's management and technical managers which of these 29 technologies they had already introduced, which they would like to introduce, and which were feasible to introduce. We found that 11 technologies had the potential to be introduced in the target plant (Table 4). If we compare they energy saving effects of each technology, there is a maximum annual energy reduction of 530,200 TOE/yr (a 355-fold improvement). Depending on the technology introduced, it is clear that there is a big difference in the energy saving effect. If these 11 technologies were combined, there would theoretically be a potential 2,047 combinations (see Equation 1). Below, we estimate project profitability using these combinations for the 10-year period from 2001, for which we have actual data, through 2011.

4. Simulation results

This study involves simulations based on 18 cases that consist of various scenarios for type of technology transfer, rate of increase of future coal prices, and CER prices. In each case, we estimate the IRR for each of the 2,047 technology packages, which are combinations of the 11 technology options. The scenarios set for the 18 cases affect economic viability (profit performance), but there is no difference between cases in the physical emissions reduction of each technology package. Therefore, for all cases, the maximum reduction of energy consumption at the target steel plant is 23.9%, equivalent to a reduction in energy consumption of 421,700 TOE/yr (crude oil equivalent). This amounts to 1.7 Mt-CO_2/yr of CO_2 emissions reduction. In addition, the simulation shows that it is technologically possible through the 11 evaluation target technologies to improve the energy intensity from the baseline 30.1 GJ/t-crude steel to 23.0 GJ/t-crude steel.

Meanwhile, depending on type of technology transfer and external factors, there is quite a large range in the cost of CO_2 reduction[20] in the technology packages of the targeted cases, from the lowest of $2.7 to the highest of $125.7/t-$CO_2$. The average cost of CO_2 reduction was $24.6/t-$CO_2$. This is slightly lower than the average cost of $29/t-$CO_2$ for all energy conservation-related AIJ projects (Woerdman *et al.*, 2001), and is cheaper than the lowest of the range of costs ($26 to $293/t-$CO_2$) of domestic measures needed for Japan to achieve its Kyoto Protocol targets (IPCC, 2001).

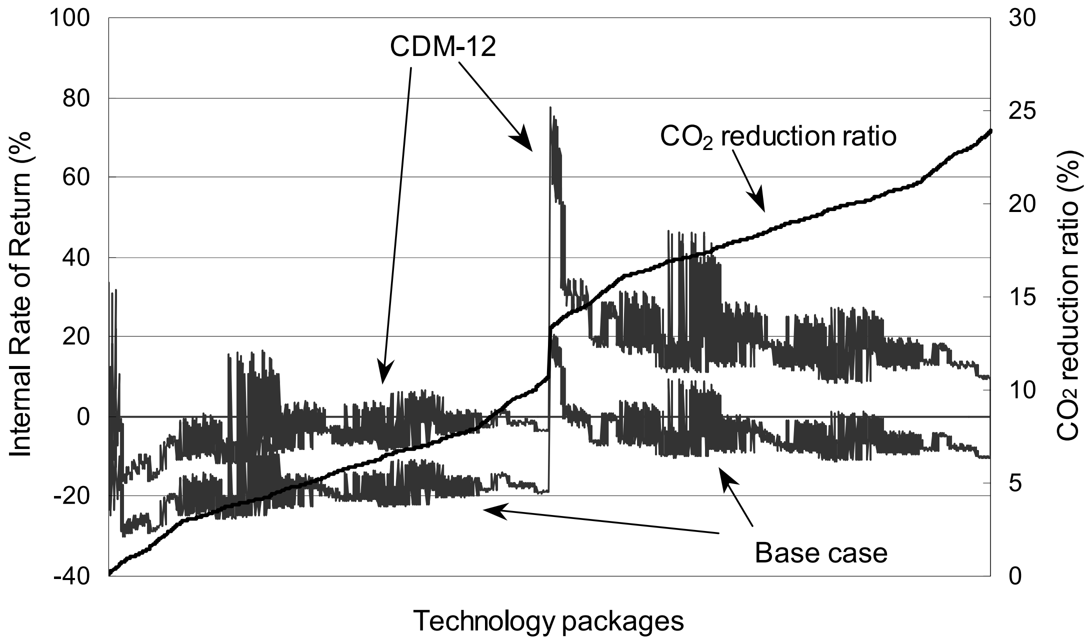

Figure 2. Estimated IRR, by technology option

From among the estimated *IRR* values for each level of technology introduction, Figure 2 shows the CO_2 reduction rates for technology packages for the cases with the largest (CDM-12) and smallest (base case) *IRR*, ranked from small to large CO_2 reduction rate.

[20] Value obtained by dividing total investment amount by the total CO2 reductions during the product implementation period.

There is a wide range in *IRR* values, from –30% to +78%, and no consistent correlation is evident between the range of CO_2 reduction and *IRR*. Comparing the largest and smallest case, it is clear that considerable differences arise in profitability, depending on the type of technology transfer and external factors. In terms of technology options, if we add "pulverized coal injection system for blast furnace" to the technology package the *IRR* improves significantly. Conversely, if we introduce "continuous casting machine" the *IRR*

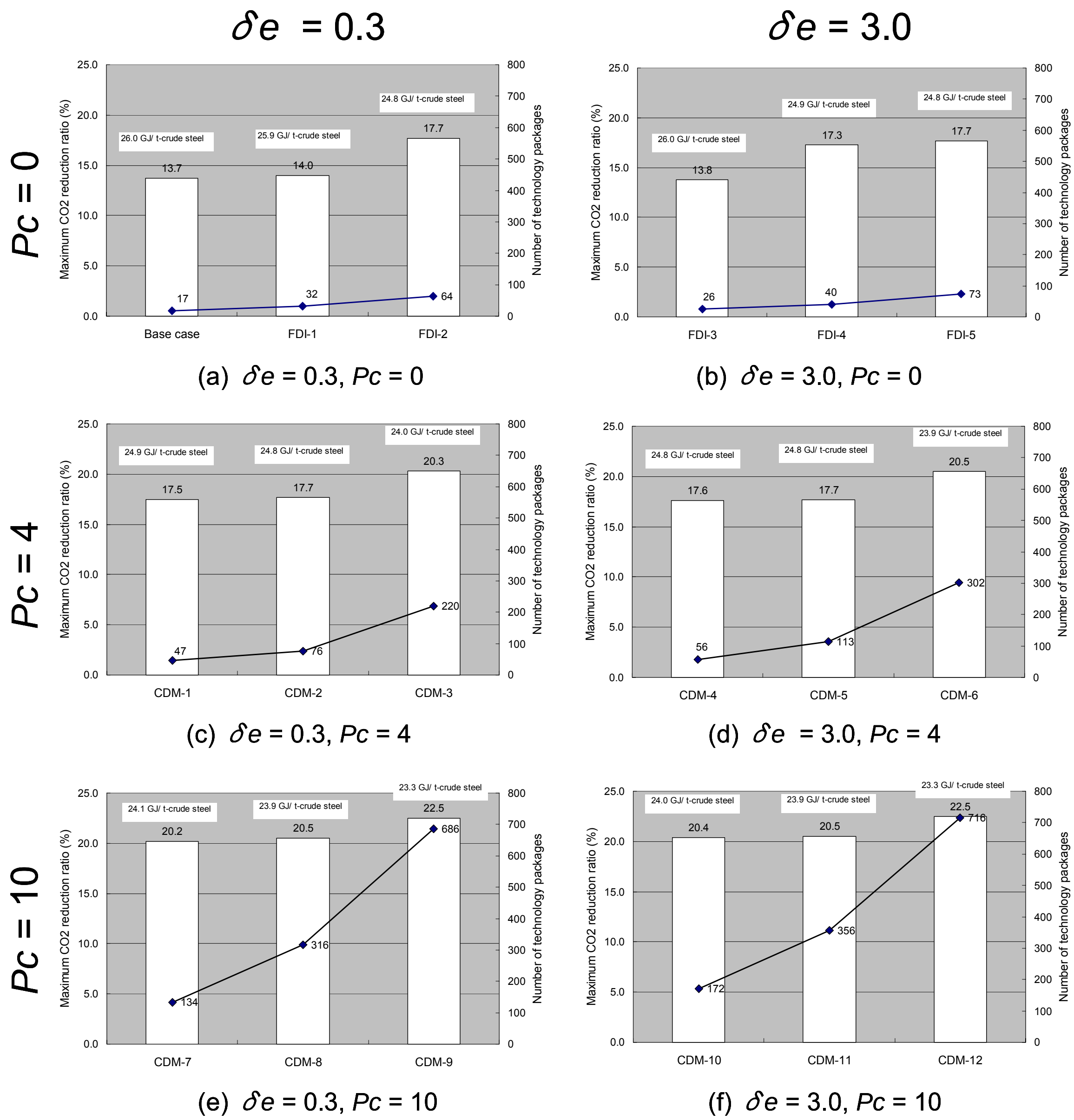

Figure 3. Simulation results (IRR > 15%).

worsens significantly.

Regarding technology packages that fulfill the cut-off rate of *IRR*>15% set in this study, Figure 3 summarizes the package number (line graph, axis on right) and its maximum CO_2 reduction rate (bar graph, axis on left). Each graph is summarized into the three cost reduction scenarios associated with technology transfers, from the left CSS-I, CSS-II, and CSS-III. The graphs also line up summaries of the same coal prices vertically, and same CER prices horizontally. In other words, seen horizontally, the first level is FDI, and other two are CDM projects.

The fact that in each graph the 3 bar graphs get larger as one moves to the right shows the impacts on CO_2 emission reductions from different types of technology transfer. The CO_2 reduction rate in the case from the baseline of CSS-I ranges between 13.7% and 20.2%, and for CSS-II between 14.0% and 20.5%, but in the case of both CSS-I and CSS-II there is almost no impact on the difference in CO_2 reduction rate. In short, it could be said that even if construction cost is reduced by procuring locally, there is no great impact on profit performance. However, in the case of CSS-III, the reduction rate rises to between 17.7% and 22.5%. In other words, if some equipment is procured locally, there is an increasing CO_2 reduction effect.

Regarding the price increase of coal, by comparing the left and right graphs, one can see the CO_2 reduction rate effect. For the target project of this study, regardless of whether the coal price maintains its current status for the next 10 years or rises by 3% per year to world prices, there is almost no impact on profit performance of the project. Comparing the scenario with a rapid rise of energy prices (FDI-3) to the base case, because only an additional 9 technology options pass the cut-off line, the maximum CO_2 reduction rate passing that line increases by only 0.1%.

If one compares 3 graphs vertically, one can see the impact of CER price on profitability. By the CER price rising from $4 to $10, the number of technology packages surpassing the profit performance line increases rapidly from 47 to 134 (CSS-I), from 76 to 316 (CSS-II) and from 220 to 686 (CSS-III). On the other hand, if it decreases from $4 to $0, and project implementation shifts from the CDM to conventional FDI, the number of technology packages surpassing the profit performance line drops dramatically from 47 to 17 (CSS-I), from 76 to 32 (CSS-II), and from 220 to 64 (CSS-III). Thus, a non-zero CER price boosts project profitability, and offers the potential for presenting a greater number of investment opportunities.

5. Discussion and concluding remarks

This study envisioned the introduction of Japanese energy saving technologies to a small scale steel plant in China, considering numerous technology combinations and the impacts of external factors such as coal price increases and CER prices. The study determined quantitatively how these factors affect the earnings structure, a key factor for corporate investment decisions. In technological terms, the first finding is that the maximum possible CO_2 emissions reduction is about 24.0% from the baseline (current situation), equivalent to 30.1 GJ/t-crude steel. This is about the same level as the results of analysis by Price *et al.* (2002) in estimating the average CO_2 reduction potential from improvements in the overall energy efficiency of China's steel industry. But when we estimate the potential CO_2 reduction of each case (18 in total) while considering profit performance, the possible CO_2 reduction from the baseline ranged between 13.7% and 22.5%, equivalent to between 24.9 and 23.3GJ/t-crude steel, respectively. The maximum reduction of 22.5% (or 94.0% of the technically feasible 24.0%) is the reduction rate at the economically viable point in cases where CER is considered (i.e., CER≠0) and external factors are optimal (i.e., δe=3.0, Pc=10, CSS-III). Meanwhile, the minimum of 13.7% is the reduction rate that allows economic viability when CER is not considered (i.e., CER=0) and implementation is under FDI with the strictest external factors (i.e., δe=0.3, Pc=0, CSS-I), and is only 57.3% of the maximum technically feasible reduction (i.e., 24.0%). This suggests that the methods used in earlier studies that consider the CO_2 emission reduction potential, of national industries overall through a macro perspective or of a specific industry overall, could result in overestimates of actual CO_2 reduction potential. This is because with that method one cannot adequately consider differences in the significance of each particular technology option or the approaches and strategies of each individual entity. This study suggests that those methods could lead to different results for CDM and FDI than reality would suggest. The result could be not only a gap between estimates and actual implementation for individual projects, but also if decision-making is biased in a certain direction, the outcomes in an overall sector could differ largely from the expected results.

Steel making consists of many detailed and complex processes, and is characterized by the fact that large energy savings can be enjoyed by the cumulative effects of many individual technologies. But one cannot make sweeping conclusions about the energy saving effects of individual technologies, as differences exist between them. Depending on the technology selection, the introduction of one specific technology could conceivably produce a large energy saving and a significant improvement in profit performance, or the reverse could also be true. The current analysis shows that a relatively large CO_2 reduction results just from introducing one technology (a pulverized coal injection system for blast furnaces) that has a large energy saving effect, and that this could dramatically improve the IRR value. If this technology is included in the mix, even in the base case with the lowest profit performance and the strictest external conditions, this study shows quantitatively that it would be possible to economically achieve a 13.7% CO_2 reduction from the baseline (about 60% of the maximum CO_2 reduction that is technically possible). This suggests that by combining such profitable technologies with other technologies, it is possible to maintain good profit performance, and to achieve greater CO_2 emission reductions. In other words, this study shows that depending on the technology selection, even without using the new mechanism of the CDM, it is to some extent possible through existing FDI to conduct a certain amount of technology transfers of energy saving technologies. This study also suggests that the CDM can complement FDI and contribute to further CO_2 reductions.

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