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Environmental co-benefits of the promotion of renewable power generation in China and India through clean development mechanisms

A. Murata [a, *], J. Liang [a], R. Eto [b], K. Tokimatsu [c], K. Okajima [d], Y. Uchiyama [d]

[a] *National Institute of Advanced Science and Technology, AIST East 1-2-1 Namiki, Tsukuba, Ibaraki, Japan*
[b] *Institute of Energy Economics, Inui Bldg. Kachidoki, 13-1 Kachidoki 1-chome, Chuo-ku, Tokyo, Japan*
[c] *Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa, Japan*
[d] *University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan*

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ABSTRACT

The purpose of this study is to evaluate the effectiveness of the co-benefits of reducing air pollutant emissions for renewable power generation Clean Development Mechanisms (CDMs). We also quantitatively discuss how co-benefit values depend on the emission standard policies. For this purpose, long-term baselines are developed considering the emission reduction policies and renewable energy promotion measures in China and India. And a new assessment of marginal damage cost of air pollutant emissions is performed based on a social survey conducted in several Asian cities. Due to the emission standard promulgated in 2011, the baseline emissions of air pollutants on a long-term are significantly decreased in China. The co-benefits of reducing air pollutant emissions per avoided carbon dioxide (CO_2) emission is shown to be much lower than the values reported in previous studies, and the positive effect of the co-benefits of CDMs is rather limited. For the Indian baseline, where an air pollutant emission standard is assumed only for particulate matters, the co-benefit values of reduced air pollutant emissions are found to be close to those reported in previous studies, and the inclusion of co-benefits for CDM evaluation is found effective in improving the viability of renewable power generation CDMs.

1. Introduction

Many activities that reduce greenhouse gas (GHG) emissions can simultaneously contribute to the reduction of air pollutants and, hence, their damage to human health. Based on integrated assessment studies, Nemet et al. [1] reported that air quality co-benefits range from $27 to 196/ton of carbon dioxide (CO_2) in developing countries and the full inclusion of air quality co-benefits in climate policy design would almost certainly enhance social outcomes. Shrestha and Pradhan [2] estimated, using the MARKAL modeling framework, that Thailand would achieve a 43% sulfur dioxide (SO_2) emission reduction from the base level as a result of a targeted CO_2 emission reduction of 30%. Therefore, the co-benefits approach to climate change is regarded as an important policy issue for Japan in the light of the Kyoto mechanism reforms [3,4]. On the other hand, Sun et al. [5] argued the policy implications of co-benefits for Clean Development Mechanism (CDM) based on a co-benefit assessment of Chinese CDM projects. They suggested that co-benefits should not be incorporated into current international climate change mitigation negotiation, but decision-making would benefit from co-benefit assessment, which can indicate optimized trade-offs between climate change mitigation and protection of the local environment.

China and India are supposed to be the host countries in many CDM project proposals. The study of co-benefits is becoming popular in China. For example, Rive and Aunan [6] estimated the air quality co-benefits from eleven CDM projects in seven regions of China. Using the data for 2010 from GAINS-Asia baseline scenario09 as emission factors, they concluded that CDMs could be making a nontrivial contribution to China's SO_2 reductions under the 11th

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Abbreviations: CDM, clean development mechanism; CER, certified emission reduction; CHP, combined heat and power; PDD, project design document; GDP, gross domestic product; GHG, greenhouse gas; LCA, life-cycle assessment; MWTP, marginal willingness to pay; NO_x, nitrogen dioxides; PM, particulate matter; SO_x, sulfur dioxides.

* Corresponding author.
E-mail address: aki.murata@aist.go.jp (A. Murata).

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Nomenclature

s	Index to years
i	Index to hours
j	Index to generation plant types
k	Index to fuel types
env	Air pollutants (CO$_2$, SOx, NOx)
M(s,i)	Demand at the hour i on the load duration curve of the year s
N(s,i)	Input to pumped storage plant at the hour i in the year s
Y(s,i,j)	Output of generation plant of type j at the hour i in the year s
X(s,j)	Capacity of generation plant of type j added in the year s
Z(s,j)	Capacity of generation plant of type j existing in the year s
G(s,j)	Electricity generated by generation plant of type j in the year s
R(s,j,j')	Capacity of plant retrofitted from type j to type j' in the year s
F(s,k)	Consumption of fuel k in the year s
F(s,j,k)	Consumption of fuel k by generation plant of type j in the year s
E(s,env)	The emission of pollutant env in the year s
CER(s)	The amount of certified emission credit obtained in the year s
OBJ_{BL}	Objective function for the baseline optimization
OBJ_{CDM}	Objective function for the optimization with CDM
OBJ_{CB}	Objective function for the optimization with CDM
h(i)	The number of hours between the hour i and the hour (i + 1)
gef(j,k)	Consumption of fuel k per kWh by generation plant of type j
avl(j)	Availability of generation plant of type j
cf(j)	The annual load factor of generation plant of type j
inv(s,j)	Investment cost of generation plant of type j in the year s
vom(j)	Variable O&M (operation & maintenance) cost of generation plant of type j
afx(j)	Annual expenditure rate of generation plant of type j
dcm(s,j)	Decommissioned capacity of plant type j in the year s
pr(s,k)	Price of fuel indexed with k in the year s
tdef	Transmission and distribution loss rate
ert	Reserve rate
psef	The efficiency of pumped storage power plant
ef(k,env)	Emission factor of pollutant env per heat content of fuel k
rd(j,env)	Reduction rate of the emission of env by generation plant of type j
ebl(s,env)	The baseline emission of env in the year s
blef(s,env)	Baseline emission of pollutant env per kWh in the year s
ogpr(s,j)	On-grid power price of the plant type j in the year s
Pcer	The price of certified emission reduction
Shrp	Share of profit rate
A	The threshold value of internal rate of return for CDM project
D	Discount rate

Five-Year Plan. Apart from certified emission reductions (CERs), which are issued only during the crediting period of a CDM project, air quality improvement could be sustained all through the project life, and the amount of emission reduction depends strongly on baseline emissions of air pollutants over the longer term—a fact not fully considered in their study. They also made a preliminary economic assessment of co-benefits to health and agriculture relying on literature estimates, which do not exactly match their regional and activity aggregations. Ma et al. [7] estimated the co-benefits of wind power in Xinjiang, China. They calculated the mitigation of CO$_2$, SO$_x$, nitrogen oxides (NO$_x$), and particulate matter (PM)2.5 emissions by comparing wind power plants with coal-fired power plants with no emission control, and then made an economic assessment of air pollution co-benefits of wind power based on the estimated marginal abatement cost of air pollutants using end-pipe technologies. In contrast, few studies have examined marginal damage costs of air pollutants in India because of data limitations, while estimations for developed countries are numerous [8]. For example, the marginal SO$_x$ and NO$_x$ damage costs in Mumbai are estimated, respectively, at \$51/t and \$20/t for power plants and at \$549/t and \$450/t for non-power fuel consumption [9].

We have developed a method to evaluate the advanced thermal power generation CDM potential by using an optimal generation planning model [10–12]. This study uses this method to evaluate the effectiveness of the co-benefits of renewable power generation CDMs. The scope of this study is as follows. First, the co-benefit of reducing air pollutant emissions is evaluated by developing long-term baselines considering the emission reduction policies of host countries as well as renewable energy promotion measures such as feed-in-tariff systems. For this purpose, multi-grid optimal generation planning models developed for China and India are used. The models are outlined briefly with a detailed description of new features added for this study. Second, a new assessment of marginal damage cost of air pollutant emissions is performed and applied for the evaluation of co-benefits. For this purpose, a social survey is conducted based on the conjoint method. Finally, we present case studies assuming conceptual CDM projects of wind power generation, photovoltaic power generation, and small-scale biomass power generation in China and India, countries with sharply contrasting energy and environment policies.

2. Methods

2.1. The definition and valuation of co-benefits

In this study, the co-benefits of CDM are attributed to reduced air pollutant emissions resulting from the supply of carbon-free electricity from renewable energy power plants, which is monetized as the marginal damage cost of air pollutants. We evaluated the marginal damage cost of air pollutants by extending the results obtained under the current Japanese conditions based on life-cycle assessment (LCA) [13]. In the cited study, the marginal damage cost of air pollutants is quantified as damage factors to human health, social estates, and potential photosynthetic net primary productivity (NPP), which are then converted to monetary values by multiplying marginal willingness to pay (MWTP). To estimate the damage factors of air pollutants applicable to Asian countries in the future, by modifying the corresponding values obtained under the