# Integrated Assessment for CDM Activities in Asian Countries using Interlinkages of Energy System Models and Life-cycle Assessment Models

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**Abstract**

The middle-term targets for energy-related carbon dioxide ($CO_2$) emission reduction by 2020 in Japan are ranged from +4% to -25% from the level in 1990. Kyoto mechanisms, such as CDM, might be indispensable, if we have to achieve large amount of $CO_2$ emission reduction. This study aims at developing a method for evaluating CDM activities in the next decades, focusing on investment in supply-side energy technologies in Asian countries. By combining energy system models of Japan and Asia and life-cycle assessment models, potential amount of CDM credits anticipated from those activities will be discussed with their costs and benefits including co-benefits, in the light of the contribution of technology development to Japanese global environment policies.

By using MARKAL model, possible energy-related $CO_2$ emission reduction by carbon price is analyzed for estimating marginal reduction cost curve in Japan. By developing a method to assess potential of CDM activities, potential amount of CDM credits in China has been evaluated by applying GOAL model. A new power generation planning model of Chinese 6 major power grids is developed for precise evaluation of baseline grid emission factors. Life-cycle cost and $CO_2$, SOx and NOx emissions have been evaluated by using Energy Chain Multi-layered Evaluation System to 4 types of power generation technologies in 3 places in China. Literature survey has been conducted focusing on data concerning environmental science and environmental economics for adjusting LIME to Asian countries. A survey in Shanghai and a preliminary test in Delhi have been made to estimate willingness to pay for avoiding health risks. Based on the present results in this study, preliminary cost-benefit analysis for CDM activity in China replacing by advanced power generation plants has been done.

## 1. Introduction

The Japanese government set a long-term target of cutting global green house gas (GHG) emissions by half from the current level by 2050 as a common goal for the entire world in the "Cool Earth 50". Large amount of energy-related carbon dioxide ($CO_2$) emission reduction, such as 60 to

80% and -4 to 25% will be required as the long-term and the middle-term reduction targets for Japan, respectively. National Institute for Environmental Studies (NIES) has reported "Japan Scenarios towards Low-Carbon Society (LCS)"[4] and shown 70% $CO_2$ emission reduction by 2050 is feasible in Japan in their report. It not only requires energy demand reduction by changing life-style and social system and innovative energy technologies development, but also may have uncertainty and cost too much. On the other hand, it is recognized that cost-effective methods based on the Kyoto mechanisms, such as clean development mechanism (CDM), will be indispensable to achieve the Cool Earth 50. However, LCS basically does not depend on the Kyoto mechanisms or evaluate CDM activities in Asian countries by supply-side energy technologies. Fig.1. shows outline of the relationship among different type models and their rolls.

Based on the background mentioned above, the objective of this research is to develop a method for evaluating CDM activities by supply-side energy technologies in Asian countries in the next decades and to evaluate CDM activities from potential of CDM credits and cost-benefit considering co-benefits points of view. The method will be developed by integrating different two types of models, such as energy system models of Japan and Asia and life-cycle assessment models with economic evaluation.

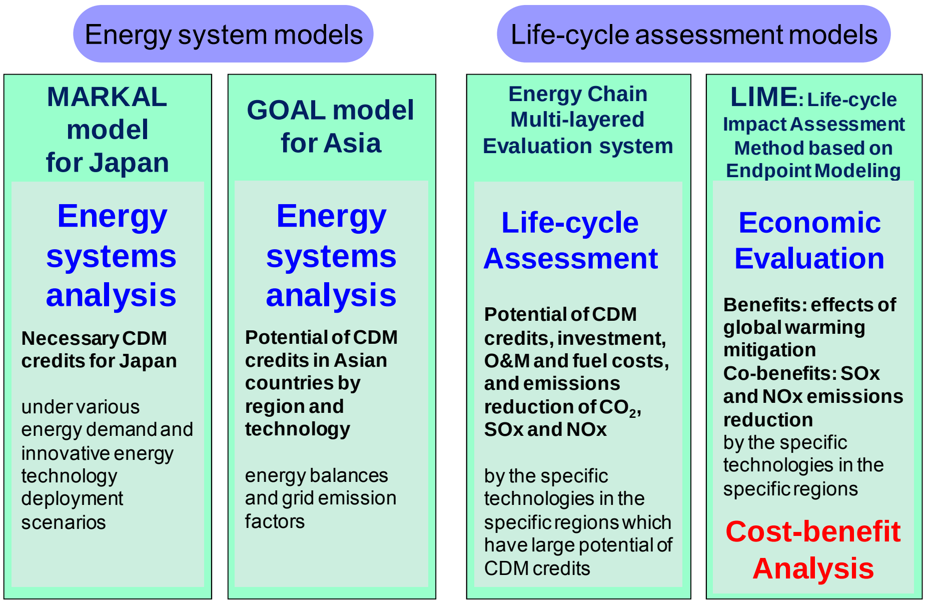


**Figure 1:** The rolls of energy system models and life-cycle assessment models for evaluating CDM activities in Asian countries from potential of CDM credits and cost-benefit points of view.

## 2. Energy system models

### 2.1 MARKAL model for Japan

To estimate how much CDM credit is needed by Japan in order to reduce its GHG emissions substantially, the MARKAL[5] model for Japan is used. It covers energy system from primary energy supply to final energy consumption during 65 years (1988 to 2052; 13 periods, each period is 5 years) with about 260 energy technologies and 40 energy carriers. The outline of the MARKAL model for Japan is shown in Fig.2. Energy demand scenario and fossil fuel prices scenarios in the model are assumed based on the "Long-term Energy Supply and Demand Outlook"[6] of Japan and the "World Energy Outlook"[7]. Sensitivity analysis concerning the trade-off coefficient between two objective functions, total system cost and total $CO_2$ emissions, is done.

Based on the sensitivity analysis, relationship between carbon price and energy-related $CO_2$ emissions in Japan is estimated as shown in Fig.3. Marginal reduction cost curve for energy-related $CO_2$ emissions is also given based on the analysis (See Fig.4). These results are somewhat different from the studies by others research institutes for discussing the middle-term $CO_2$ emission reduction target for Japan[8] except energy-related $CO_2$ emissions until 2030. The difference may be caused by the difference in modeling of energy conservation and technology options. Presently the MARKAL model for Japan needs further improvement, especially on energy technology options, such as innovative energy technologies and energy conservation technologies.

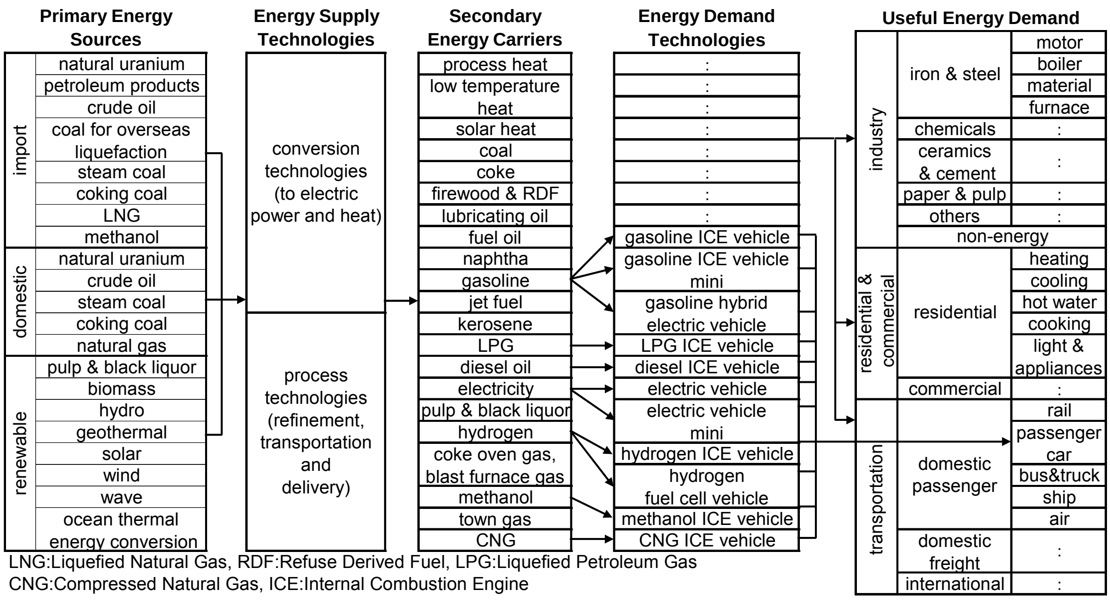


**Figure 2:** Outline of the MARKAL model for Japan.

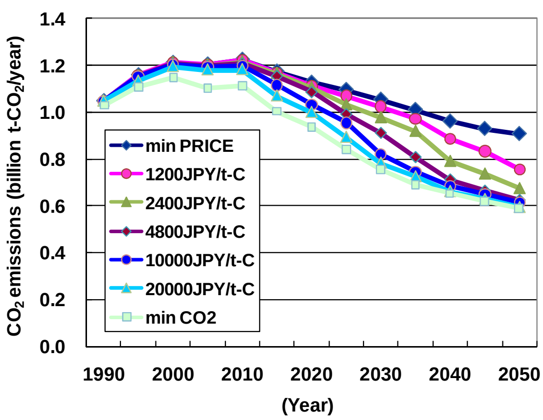


**Figure 3:** Relationship between carbon price and energy-related $CO_2$ emissions in Japan.

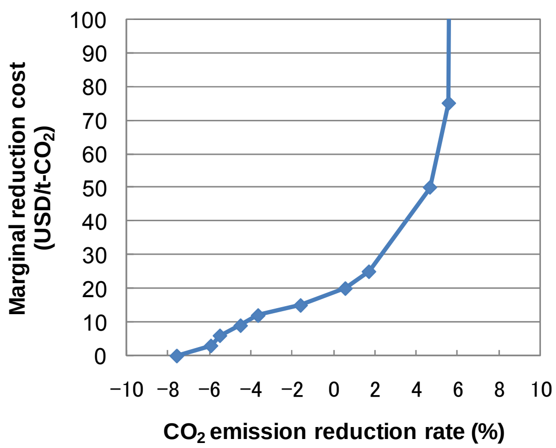


**Figure 4:** Marginal reduction cost curve for energy-related $CO_2$ emissions in Japan.

### 2.2 GOAL model for Asia

Energy system model GOAL[1,2] is a linear optimization model of energy system covering seven countries in the eastern and southeast Asia: Japan, China, Indonesia, Malaysia, Philippines, Singapore and Thailand as shown in Fig.5. China and Indonesia are divided into sub-regions to describe regional diversity in demands and resources. Currently, China is divided into three sub-regions: North-Northeast, South-Central, and Northwest-Southwest. The model's time frame is from 1998 to 2055, divided into eight time periods, 1998-2002, 2003-2007, 2008-2012, 2013-2017, 2018-2025, 2026-2035, 2036-2045, 2046-2055, unevenly. The overall energy system is composed of mutually connected regional energy system models. A regional energy system includes primary energy production, energy conversion and power generation, energy transportation and distribution (See Fig.6). The structure of a regional system is mathematically described using technological data such as conversion efficiency and availability. System cost is a principal indicator, which is the sum of expenses for mining, construction, operation and maintenance, energy trading and emission control. System cost is discounted to the present value using 6.5 percent per year in this study. The whole energy system is optimized so that discounted total system cost is minimized with constraints imposed on the emissions of $CO_2$.

The task of the GOAL model for Asia in this study is how the necessary amount of credit can be obtained from CDM activities, assuming that supply-side energy technologies are implemented in Asian countries. Energy demand scenarios by country are implemented based on the IEEJ's energy outlook[9]. A method for evaluating CDM activities from additionality and profitability points of view, same as the actual CDM projects, is developed.

CDM potential of large-scale renewable electricity generation in China is evaluated by the developed method. Supply curves of emission credits are obtained in the case of potential CDM projects of wind power generation and very large scale photovoltaic power generation (VLSPV) in China as shown in Fig.7. The lowest price of Certified Emission Reductions (CER) with which wind power generation CDM project can supply CER is found to be about 8 USD/t-$CO_2$ with 21 year long crediting period, and about 10 USD/t-$CO_2$ with 14 year long crediting period. If the price of CER is as high as 130 USD/t-$CO_2$, VLSPV CDM project starts to develop with 21 year long crediting period. But when the length of crediting period is 14 years, VLSPV CDM project is hard to be realized even with such a high price of CER.

The baseline emission in the CDM project assessment must be evaluated in reference to the power grid where the CDM project is implemented. Since the boundaries of the Chinese power grids in GOAL model for Asia are not identical to those of the actual power grids, a new power generation planning model of the Chinese six major power grids is developed for the improved evaluation of the baseline grid emission factors of $CO_2$ and air pollutants (sulfur oxides (SOx) and nitrogen oxides (NOx)). To build the model whose time frame is from the year 2006 to the year 2026, the shapes of annual load duration curves in the six major power grids are estimated in reference to the year 2006 and then a database is developed about the performance and economics of power generation technologies as well as their environmental performance and their existing and planned capacities. The impact of environmental protection on the baseline emission of $CO_2$ is evaluated. Three scenarios are prepared in the light of SOx and NOx removal. It is found that difference among the three scenarios is fairly small with respect to the average $CO_2$ emission per kWh and the average fuel consumption per kWh of all the thermal power plants, though the impact of environmental protection scenarios on thermal power plant mix is not negligible.

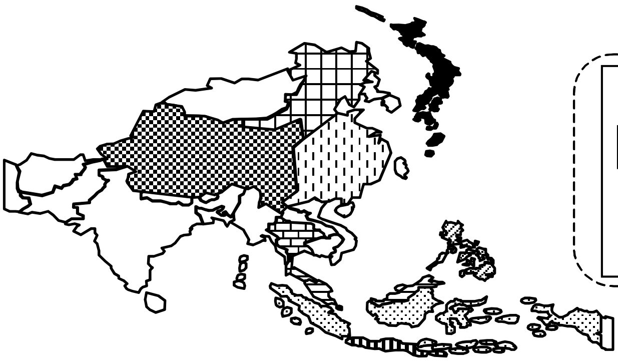

**Figure 5:** Regions of the GOAL model.

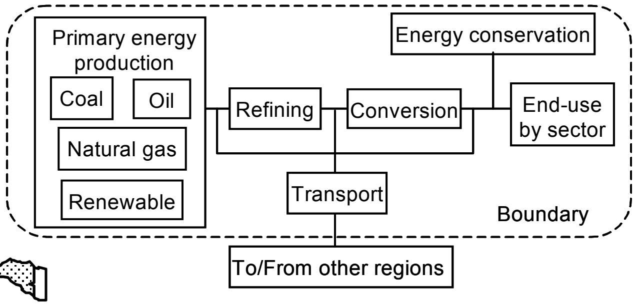


**Figure 6:** Reference regional energy system of the GOAL model.

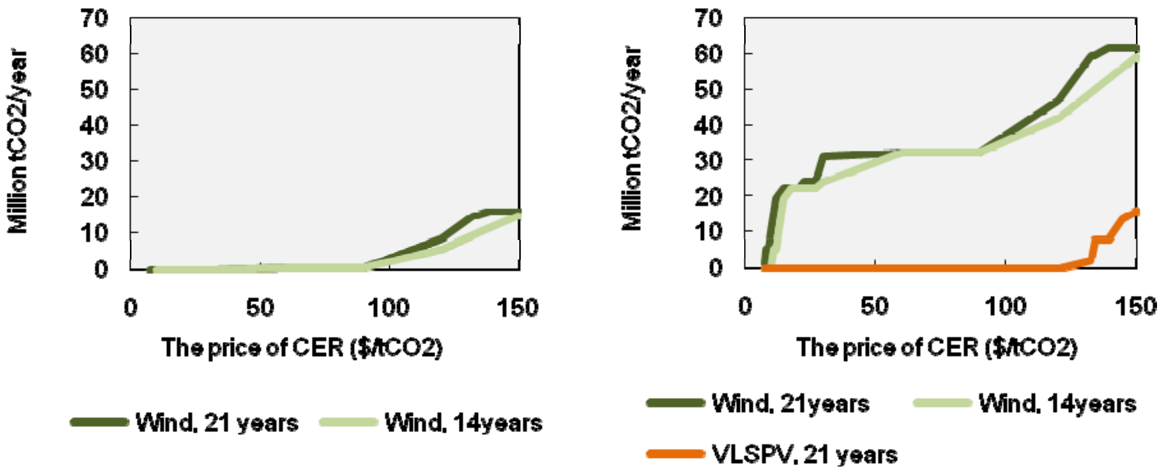


**Figure 7:** CDM credit potential of large-scale renewable electricity generation in China by the GOAL model.

## 3. Life-cycle assessment models

### 3.1 Energy Chain Multi-layered Evaluation System

It is important to assess the effect of energy technologies on energy efficiency, environmental and economical burdens in the total energy supply chain - from resource mining to end use through conversion, generation, and transportation processes. An Energy Chain Multi-layered Evaluation System has been developed so that it can assess a fully fuelled energy chain system from life-cycle efficiency, $CO_2$ emissions and cost points of view (Fig. 8).

The roll of the model in this study is to evaluate CDM activities by supply-side energy technologies in Asian countries, which are estimated to have large potentials of CDM credit by the GOAL model, from life-cycle costs and emissions points of view. The Energy Chain Multi-layered System is enhanced to cover CDM activities in Asian countries, especially in China.

In the analysis, integrated coal gasification combined cycle (IGCC), natural gas combined cycle (NGCC) and ultra super critical coal power plant (USC) in Xinjiang, Shanxi, and Shanghai, China are evaluated from life-cycle $CO_2$ intensities, energy profit ratios (EPRs), energy costs and $CO_2$, SOx, NOx emissions reduction points of view. Fig. 9 shows the LCA boundary. As life-cycle inventories, from fuel mining to power generation including equipment manufacturing and equipment transportation are considered. It was assumed that the equipments are manufactured in Japan and then transported to Xinjiang, Shanxi, and Shanghai. Transporter manufacturing, waste and recycling processes of equipments are not included in this study. Fig. 10 shows assumed installation sites of CDM activities and natural gas transportation in China.

$CO_2$ emission reductions are estimated based on the grid emission factors as the baseline[10)]. In Shanghai, because coal is not produced, $CO_2$ emission intensity from conventional power plants is not so high. On the other hand, advanced coal and gas-fired power plants in Xinjiang and Shanxi are supposed to provide larger reductions. Fig.11 shows the cumulative $CO_2$ emissions by unit process in the energy chain for supply-side energy technologies in Shanghai. In the fuel mining process, coal has a lower emission factor than that of natural gas. $CO_2$ emission intensities of NGCC with LNG trucks or LNG tankers are larger than that of NGCC with pipeline. This is because the liquefaction process of natural gas for LNG production has larger $CO_2$ emissions. NGCC has half of $CO_2$ emission compared with IGCC and USC. NGCC has higher energy efficiency than IGCC and USC.

The evaluation results of SOx emission intensity are shown in Fig.12. SOx emissions are evaluated with desulfurization process which has efficiency of 85% for advanced coal-fired power generations. NGCC has advantage for $SO_2$ emission. $SO_2$ emission from NGCC is negligible and effect of transportation process is very small. $SO_2$ emissions from IGCC, USC depend on sulfur content in coal. IGCC and USC become cleaner with the desulfurization process and emissions are reduced drastically. NOx emission depends on its method of fuel combustion. The evaluation result shows IGCC has low NOx emission, because of fuel gasification. USC has 1/3 NOx emission compared with conventional coal-fired power generation. NGCC has lower SOx and NOx emissions, even if without an exhaust gas denitrizer.

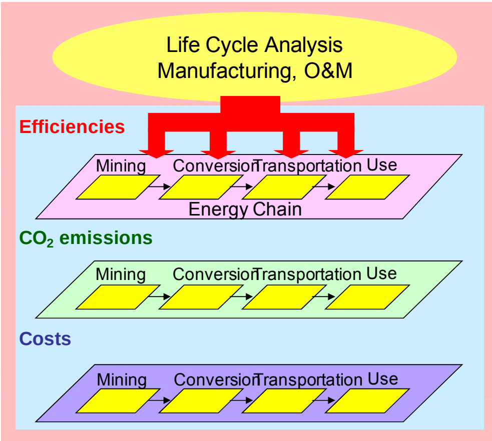


**Figure 8:** Outline of 3 layers in the Energy Chain Multi-layered Evaluation System.

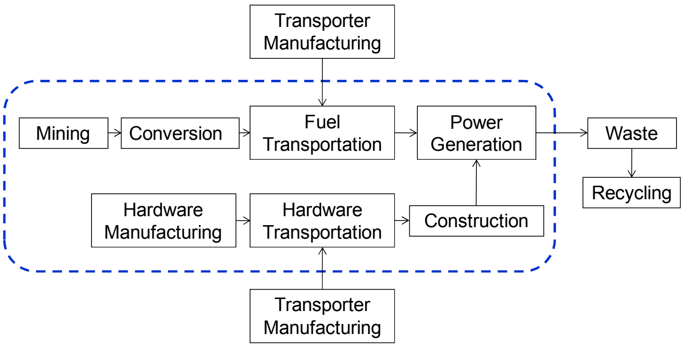


**Figure 9:** System boundary for LCA by the Energy Chain Multi-layered Evaluation System.

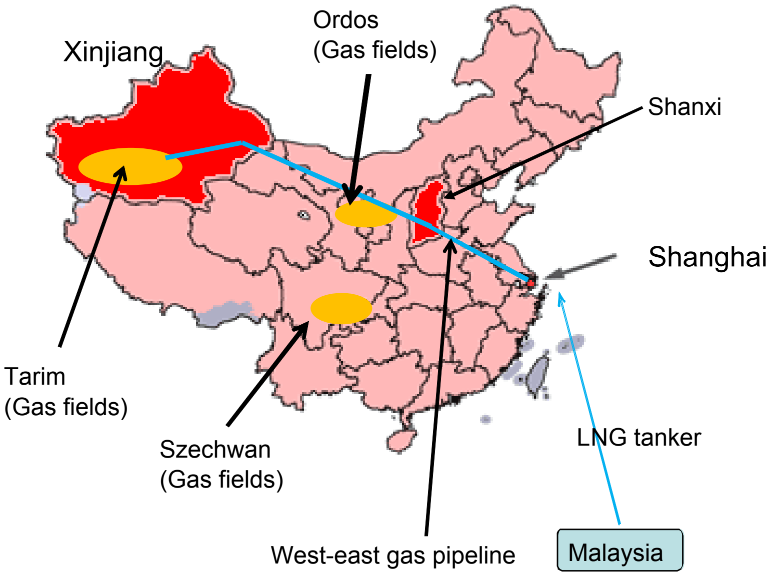


**Figure 10:** Assumed installation sites of CDM activities and natural gas transportation in China.

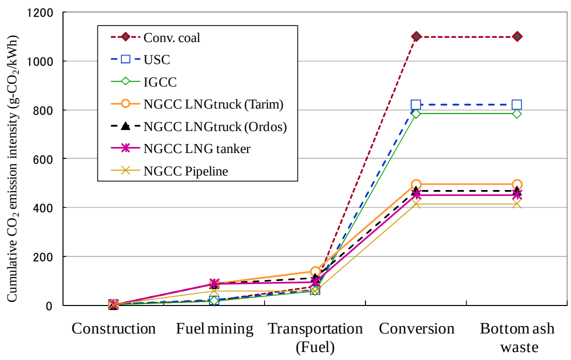


**Figure 11:** Contribution of each unit process in the energy chain to cumulative $CO_2$ emission intensity in Shanghai, China.

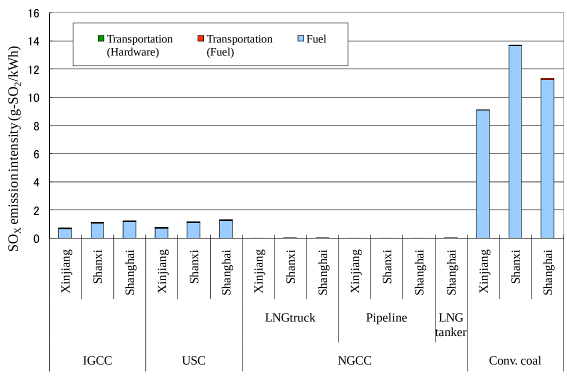


**Figure 12:** SOx emission intensity of supply-side energy technologies with desulfurization efficiency of 85% for IGCC, NGCC and USC in China.

### 3.2 LIME: Life-cycle Impact Assessment Method based on Endpoint Modeling

LIME is an endpoint type life-cycle impact assessment (LCIA) method based on Japanese current environmental background. It provides three kinds of lists, that is, characterization, damage assessment and weighting, to practitioners of LCIA in Japan. This method incorporates 4 safeguard subjects such as human health, social welfare, primary productivity and biodiversity, which damages could be integrated through the eleven impact categories from the emissions or resources extractions by the damage functions. The damages on these safeguard subjects can be aggregated into the single index in the step of weighting as shown in Fig.13.

To achieve cost-benefit analysis of CDM activities until around 2020 in Asian countries considering co-benefits by reduction of air pollutants, impact factors and weighting factors in the LIME have to be adjusted to Asian countries over the next decades. Regarding impact factors by global warming, a simplified climate model, MAGICC/SCENGEN is used to evaluate temperature increase and the sea level rise. On the other hand, impact factors by urban air pollution are estimated by applying exposure assessment models. For estimating weighting factors, two methods, benefit transfer and social survey are used. For benefit transfer, factors, which are used to convert the data obtained in developed countries to be applicable in developing countries based on the difference of GDP per capita, are estimated by reviewing other studies. Concerning social survey, willingness to pay for avoiding human health risk is estimated with 500 samples in Shanghai, China. Cost-benefit of CDM activities are evaluated using the adjusted LIME and the other models as shown in Fig.13.

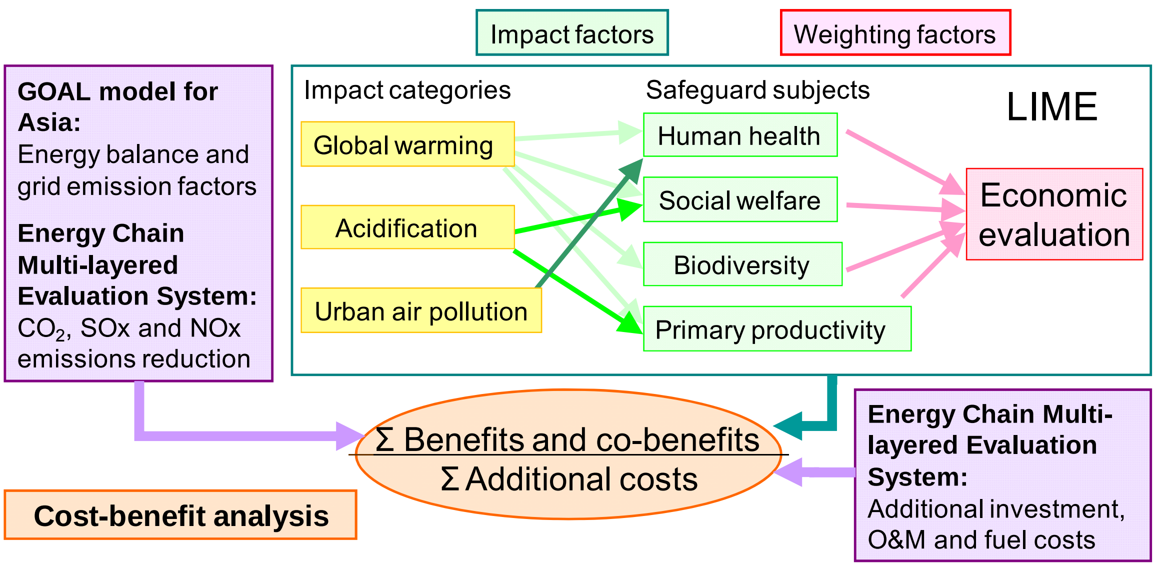


**Figure 13:** Relationship among cost-benefit analysis, the adjusted LIME and the other models.

A review work on benefit transfer studies reveals following points. One is that they calculate transfer errors and shadow price, and make identification test of compensating consumer's surplus. Another is that most of the studies are make social survey to calculate benefit in the target site, in order to apprise validity of the transferred benefit by comparing the benefit obtained by a social survey. Most of transfer errors in the studies are less than 50 %, both of transfer among intra country and inter countries. This appraisal is quite important since we may believe that transferred benefit in general contains plus minus 50% error.

A social survey to investigate monetary value of damage on human health caused by air pollution has been conducted in Shanghai. The main questionnaires are designed to ask willingness to pay (WTP) to decrease the morbidity rate for asthma. The respondents are asked willingness in the condition that the mortality rate does not change by contracting the disease, followed by a questionnaire to ask willingness to decrease mortality rate. Willingness is asked by trichotomous selection with follow up questioning. Other questionnaires are placed before and after the main questionnaires. The WTP to avoid contacting asthma is analyzed by fitting logistic distribution. The value for avoiding asthma contact is estimated to be 50,000-80,000 RMB and the value of statistical life to be 400,000-600,000 RMB. The relationship between household income and willingness is also analyzed and high income caused high value in willingness to pay, however, the dependency is weak for low income group as shown in Fig.14.

By adapting benefit transfer to LIME, cost benefit analysis of replacement from a conventional coal power plant to advanced one in Shanghai, China has been carried out. Fig.15 shows the preliminary results of the cost-benefit analysis considering co-benefits. Based on the analysis, co-benefits by reducing air pollutants are more than benefits by reduction of green house gases. Estimated cost-benefit is at the same level compared with other studies.

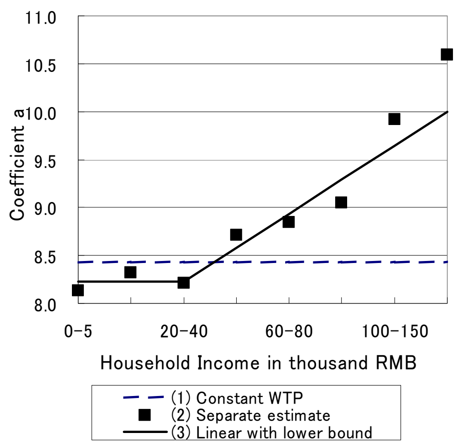


**Figure 14:** Results of the social survey in Shanghai, China. Income elasticity of willingness to pay for avoiding risks on human health.

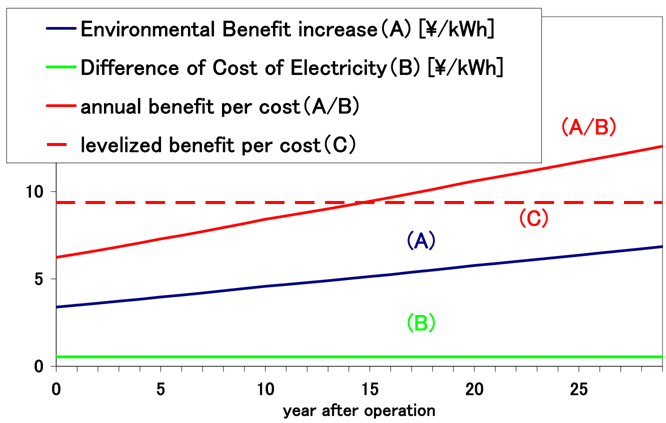


**Figure 15:** Results of the cost-benefit analysis of CDM, replacement from a conventional coal power plant to advanced one, in Shanghai, China.

## 4. Summary

In this paper, an integrated method combining energy systems analysis and life-cycle assessment is proposed for evaluating CDM activities by supply-side energy technologies in Asian countries from potential of CDM credits and cost-benefit considering co-benefits points of view. Preliminary results of the analyses by the models are introduced including cost-benefit analysis.


## Acknowledgement

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**Kewords** Clean Development Mechanism, Asia, Supply-side energy technology, Energy systems analysis, Life-cycle assessment


## References


1) Murata, Akinobu. et al., Modeling of CDM Activity to Introduce Large-Scale Renewable Power Plant in China, Renewable Energy 2008, Busan

2) Murata, Akinobu. et al., A Modeling Analysis of the Deployment of Energy Efficient Industrial Technologies in China under $CO_2$ Emission Constraints, Journal of the Japan Institute of Energy, vol.87, No.11, pp938-945 (in Japanese) (2008)

3) Okajima, Keiichi. et al. (2009), Life Cycle Evaluation of Energy Supply Technologies in China by Energy Chain Multi Layered Model, Proceedings of The International Conference on Applied Energy, Vol.1, pp.621-630, 2009, Hong Kong

4) NIES, Japan Scenarios towards Low-Carbon Society (LCS) -Feasibility study for 70% CO2 emission reduction by 2050 below 1990 level-" URL= http://2050.nies.go.jp/index.html (last access, 2008)

5) IEA/ETSAP: MARKAL home page, URL=http://www.ETSAP.org/Tools/MARKAL.htm (last access, 2009)

6) Advisory Committee for Natural Resources and Energy, Japan: Long-term Energy Supply and Demand Outlook (2008)

7) OECD/IEA: World Energy Outlook (2007, 2008)

8) The middle-term target discussing committee, The Council on the Global Warming Issue, Japan, reports by RITE and NIES (2009)

9) Ito, Kokichi, et al., Asia/World Energy Outlook 2007, The Institute of Energy Economics, Japan.

10) National Bureau of Statistics of China, China Energy Statistical Yearbook 2006, China Statistics Press, Beijing, (2006).