IMPLICATIONS OF CONSIDERING RENEWABLE PORTFOLIO STANDARD (RPS) IN POWER SECTOR DEVELOPMENT: AN INPUT-OUTPUT ANALYSIS

Charles O. P. MARPAUNG
Christian University of Indonesia
Indonesia
elektuki@centrin.net.id

Atmonobudi SOEBAGIO
Christian University of Indonesia
Indonesia
atmono@cbn.net.id

Ram M. SHRESTHA
Asian Institute of Technology
Thailand
ram@ait.ac.th

ABSTRACT

This paper analyses the environmental implications of considering renewable portfolio standard (RPS) in power sector development in Indonesia during 2006-2025. An input-output analysis was carried out to examine the CO_2 emission changes in the whole economy. There are four main factors that affect the CO_2 emission changes, i.e., fuel mix effect, structural effect, final demand effect and joint effect. The results show that the CO_2 emission sin the whole economy would be mitigated by about 6.1%, 12.6% and 17.8% if RPS levels of 5%, 10% and 15% are considered respectively during 2006-2025. Of the total CO_2 emission mitigation, the share of fuel mix effect would be the highest to the total reduction of CO_2 emission and then followed by the structural effect. Unlike the fuel mix- and structural-effects, the final demand effect would reduce the CO_2 emission at all RPS levels considered (i.e., 5%, 10% and 15%). The share of joint effect is negligible.

INTRODUCTION

Electricity generation in Asian developing countries as a whole is expected to increase at a higher rate than the demand for non electric energy. In most of these countries, power generation is predominantly based on fossil fuels. The combustion of fossil fuels is the primary source of GHG and other harmful emissions. These emissions are expected to increase these emissions considerably in future. Among the fossil fuels, coal is the dominant fuel used for power generation in India, China, and Indonesia (see [1, 2, 3]). Including CO_2 emissions, coal is also considered to be the largest source of SO_2 and other harmful pollutants. If the present structure of power generation is to continue, GHG and other harmful emissions in these countries will be much higher in the future. Thus, the subject of reduction of GHG emissions and other harmful emissions in power sector has gained immense importance. In some countries like China, the environmental policy priorities are at the local and regional level; thus, GHG reduction is only attractive if it includes direct or indirect reduction of local pollutants. Renewable and cleaner technologies for power generation are becoming ever more important options in many Asian developing countries due to government preference to enhance national energy security and the desire to improve the local environmental quality.

The Renewable Portfolio Standard (RPS) is a policy instrument to increase the production of electricity from higher-cost energy sources with desirable social and environmental benefits. The RPS is rapidly emerging as a popular mechanism among policy makers to increase the penetration of renewable energy in the electricity market. In Asian developing countries, RPS is attracting the attention of policy makers due to the growing interest in using cleaner energy and reducing the dependency on imported energy. Few studies have so far focused on RPS design (see [4, 5, 6, 7]). However, most existing studies deal with the effect of RPS in the context of developed countries. [8] and [9] have conducted studies related to RPS in the case of China; however, they did not examine the effect of RPS on CO_2 emission changes in the whole economy. The Governments of Indonesia and Thailand have also incorporated RPS into their energy policy (see [10, 11]). Similarly, more Asian countries could adopt RPS as a national policy over time. However, there is no in depth study so far focused on economy-wide environmental implications of RPS for the Asian developing countries.

The present study will analyze the economy-wide environmental implications of considering RPS from a long term capacity expansion planning in Indonesia-a developing country- during 2006-2025. This study will also examine the factors that affect the change in CO_2 emissions in the whole economy due to considering RPS by using an input-output approach. This paper is organized as follows. The brief explanation of the power sector in Indonesia is presented in the next section followed by the methodology, and the input data and assumptions used in the study. The results and discussions of considering RPS in power sector planning are examined in the subsequent sections. Finally, major findings are presented.

POWER SECTOR IN INDONESIA

Power demand in Indonesia recorded an annual average growth rate of over 13% during 1993-2002 (see [12]). The Java-Madura-Bali Islands account for approximately 80% of the total electricity generation and 70% of the total generation capacity in the country. The total installed capacity in the Java-Madura-Bali Islands (include IPPs) in 2002 was 18,608 MW which comprised of 86.4% thermal power plants and 13.6% hydropower plants. Of the total thermal generation capacity, coal based power plants had the largest share (41.4%), followed by gas-, oil- and geothermal-based power plants with shares of 27.5%, 26.4% and 4.7% respectively. Candidate power plants of the existing utility for the Java-Madura-Bali Islands are mainly those based on gas and coal. Oil-based power plants would not be considered as a matter of national policy while renewable plants such as geothermal- and hydro- power plant potential are limited. Nuclear power is likely to be fiercely opposed by environmentalists and is not yet considered as an option.

METHODOLOGY

Generation Expansion Planning Model

The objective function of the generation expansion planning model used is total supply side cost. The supply-side cost consists of capacity costs of candidate power plants, as well as fuel-cost and operation and maintenance-costs of existing and candidate power plants.
The model includes the following constraints:

a. Power demand constraints: Total power generation from all existing and candidate power plants plus power import and power generation avoided by energy efficient end-use appliances/equipments cannot be less than the sum of total power demand and transmission and distribution losses in all periods ("blocks"), seasons and years of the planning horizon considered.
b. Plant availability constraints: Power generation from each power plant at any daily period, season and year cannot exceed its available capacity.
c. Reliability constraints: The sum of installed power generation capacity of all plants, power import and generation capacity avoided by energy efficient end-use options in any year can not be less than peak power demand plus a reserve margin in that year.
d. Hydro energy constraints: Total energy generation from a hydropower plant cannot exceed the level of hydro energy available to the plant in each season and year of the planning horizon.
e. Annual thermal energy generation constraints: Electrical energy generation from each thermal plant cannot exceed an upper limit that corresponds to the installed capacity and availability of the plant.
f. Maximum capacity constraints: Total number of generating units of each type in the planning horizon cannot exceed the maximum permissible (i.e., feasible) number of units. That is, total installed capacity of a type of power plant cannot exceed the maximum allowable capacity of that type of plant.

The flow chart for assessing the CO_2 mitigation in generation expansion planning is as shown in Figure 1.

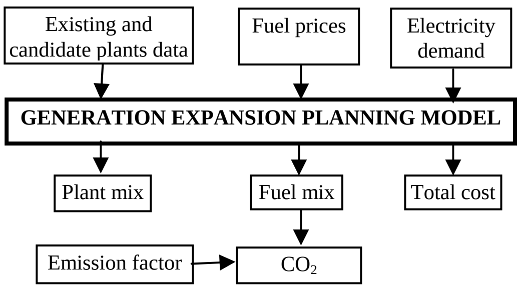

Figure 1:
Flow chart for assessing the implications of considering RPS in generation expansion planning

Decomposing Total Economy-wide Emission Changes Due to Considering RPS

There are four major components which affect the change in the total emission of a pollutant in the whole economy with the RPS, i.e., (i) fuel mix effect (i.e., the change in emissions due to variation in fuel mix), (ii) structural effect (i.e., the change in emissions due to changes in technological coefficients due to the adoption of DSM options), (iii) final demand effect (i.e., the change in emissions associated with changes in final demand for goods and services for power plant construction) and joint effect (i.e., the interactive effect between or among the fuel mix-, structural- and final demand-effects). The final demand effect can be decomposed further into direct effect (i.e., the change in the pollutant emissions due to the use of fossil fuels directly in the production of goods and services which are used for final demand) and indirect effect (i.e. the change in the pollutant emissions associated with the use of fossil fuels which are expended to produce goods and services used as inputs to produce goods and services for final demand).

The development of an I-O decomposition model to determine the factors that affect the total change in economy-wide emission of a pollutant due to considering RPS is presented in this section. The present study extends past work by [13] which provided the methodology for examining the components of change in CO_2, SO_2 and NO_x emissions due to replacing old coal power generation with various types of electricity generation in the UK economy. Some extensions to the work of [13] have been carried out in the present study, i.e., it is not only changes in the technological coefficients of the electricity sector, but the technological coefficients of other sectors would also most likely to change. Another distinction from [13] is the electricity final demand changes from year to year during the planning horizon. In the present study, the first order component related to structural change is defined as the structural effect, while the second or the third order components are defined as joint-effects (see [14]).

The symbols which are used for the decomposition methodology are:
m = types of fuels used by producing sectors,
n = number of producing sectors,
$\boldsymbol{A}_{RPS}(t)$, $\boldsymbol{A}_0(t)$ = matrix (n x n) of input-output (i.e., technological coefficients) with and without considering RPS in the electricity sector in year t respectively,
$\boldsymbol{C}_{RPS}(t)$, $\boldsymbol{C}_0(t)$ = matrix (n x m) of direct fuel requirement coefficients (defined as fuel use per unit of total output of a sector) with and without considering RPS in the electricity sector in year t respectively,
$\boldsymbol{E}$ = column vector (m x 1) of a pollutant emissions coefficients (defined as pollutant emissions per unit of fuel used),
$\boldsymbol{F}_{RPS}(t)$, $\boldsymbol{F}_0(t)$ = row vector (1 x m) of total fuel use by producing sector with and without considering RPS in the electricity sector in year t respectively,
$\boldsymbol{I}$ = identity matrix (n x n),
$\boldsymbol{L}_{RPS}(t)$, $\boldsymbol{L}_0(t)$ = Leontief inverse matrix (n x n) with and without considering RPS in the electricity sector in year t respectively,

$X_{RPS}(t)$, $X_0(t)$ = column vector (n x 1) of total output with and without considering RPS in the electricity sector in year t respectively,
$Y_{RPS}(t)$, $Y_0(t)$ = column vector (n x 1) of final demand with and without considering RPS in year t respectively.

Hereafter, we suppress the time argument in order not to clutter the notations. The derivation of the decomposition model is as follows. First, the difference in total output due to considering RPS in the electricity sector (ΔX) is calculated as follows:

$$\Delta X = X_{RPS} - X_0 \quad (1)$$

Noting that the total output vectors with and without RPS (i.e., X_{RPS} and X_0 respectively) can be expressed as $X_{RPS}=[I-A_{RPS}]^{-1}Y_{RPS}$ and $X_0=[I-A_0]^{-1}Y_0$ respectively, Equation (1) can be expressed as:

$$\Delta X = [I - A_{RPS}]^{-1} Y_{RPS} - [I - A_0]^{-1} Y_0 \quad (2)$$

Denoting $L_{RPS} \equiv [I-A_{RPS}]^{-1}$ and $L_0 \equiv [I-A_0]^{-1}$, Equation (2) can be written as:

$$\Delta X = L_{RPS} Y_{RPS} - L_0 Y_0 \quad (3)$$

Equation (3) can be extended to analyze the change in total pollutant emission with RPS as compared to that without RPS (ΔP_{Total}) by considering the fuel-use coefficients matrices in RPS and without RPS cases (i.e., C_{RPS} and C_0 respectively) and a matrix of pollutant emissions coefficients (E):

$$\Delta P_{Total} = E' C_{RPS}' L_{RPS} Y_{RPS} - E' C_0' L_0 Y_0 \quad (4)$$

where C_{RPS}' and C_0' represent the transpose of C_{RPS} and C_0 respectively and E' is the transpose of E. The change in total pollutant emission due to RPS as stated in Equation (4) is partly due to the final demand effect (ΔP_{Final_demand}) and partly due to operating phase effect ($\Delta P_{Operating}$). Defining ΔY as (Y_{RPS}-Y_0), and substituting Y_{TUP} in Equation (4) with (Y_{RPS}-ΔY) gives:

$$\Delta P_{Total} = E' C_0' L_0 \Delta Y + E' [C_{RPS}' L_{RPS} - C_0' L_0] Y_{RPS} \quad (5)$$

The first component in the right-hand side of Equation (5) is the change in total economy-wide pollutant emission due to RPS as compared to that without RPS due to final demand effect (ΔP_{Final_demand}), while the second component is due to operating phase effect ($\Delta P_{Operating}$) (this term is also used by [13]). Thus,

$$\Delta P_{Total} = \Delta P_{FD} + \Delta P_{Operating} \quad (5.a.)$$

After algebraic manipulation, the final demand effect component in Equation (5) can also be written as:

$$\Delta P_{Final\_demand} = E' C_0' \Delta Y + E' C_0' [L_0 - I] \Delta Y \quad (6)$$

where the first and the second components in the right hand side of Equation (6) represent direct- and indirect-effects respectively associated with the change in final demand due to RPS. It should be noted that the change in final demand (ΔY) is due to the change in demand for goods and services for construction of power plant. The operating phase effect in Equation (5) can be decomposed further into three components, i.e., (i) fuel mix effect, (ii) structural effect and (iii) joint effect. To obtain these components, first define ΔL and ΔC as (L_{RPS}-L_0) and (C_{RPS}-C_0) respectively, and substitute Y_{RPS} in the operating phase effect component in Equation (5) with (Y_0+ΔY), results:

$$\Delta P_{Operating} = E' \Delta C' L_0 Y_0 + E' C_0' \Delta L Y_0 + E' \Delta C' \Delta L Y_0 + E' \Delta C' L_0 \Delta Y + E' C_0' \Delta L \Delta Y + \Delta C' \Delta L \Delta Y \quad (7)$$

Equation (7) shows the difference in total pollutant emission between RPS and without RPS due to operating phase. The first and the second components of the right hand side of Equation (7) are called as fuel mix effect and structural effect respectively, while the last four components are called joint effects. Hence, the total change in pollutant emission in the whole economy due to RPS in power sector planning could be disaggregated into eight types of effects: The eight types of effects and the corresponding expressions to estimate them are presented in Table 1.

Table 1:
Expressions to estimate components of the total change in a pollutant emission in the whole economy due to considering RPS

No.	Component	Estimating expression
	Final demand (FD) related to:	
1	Direct effect	$\mathbf{E}'\ \mathbf{C}_0(t)'\ \Delta\mathbf{Y}(t)$
2	Indirect effect	$\mathbf{E}'\ \mathbf{C}_0(t)'\ [\mathbf{L}_0(t) - \mathbf{I}]\ \Delta\mathbf{Y}(t)$
3	Fuel mix (FM) effect	$\mathbf{E}'\ \Delta\mathbf{C}(t)'\ \mathbf{L}_0(t)\ \mathbf{Y}_0(t)$
4	Structural (ST) effect	$\mathbf{E}'\ \mathbf{C}_0(t)'\ \Delta\mathbf{L}(t)\ \mathbf{Y}_0(t)$
	Joint effect related between:	
5	FM and ST changes	$\mathbf{E}'\ \Delta\mathbf{C}(t)'\ \Delta\mathbf{L}(t)\ \mathbf{Y}_0(t)$
6	FM and FD changes	$\mathbf{E}'\ \Delta\mathbf{C}(t)'\ \mathbf{L}_0(t)\ \Delta\mathbf{Y}(t)$
7	ST and FD changes	$\mathbf{E}'\ \mathbf{C}_0(t)'\ \Delta\mathbf{L}(t)\ \Delta\mathbf{Y}(t)$
8	FM, ST and FD changes	$\mathbf{E}'\ \Delta\mathbf{C}(t)'\ \Delta\mathbf{L}(t)\ \Delta\mathbf{Y}(t)$

INPUT DATA AND ASSUMPTIONS

Most of data used for generation expansion planning (e.g., existing-, committed- and candidate-power plant data) in this study are based on [12]. The electricity demand forecasts are based on [12]. In the base case (i.e., without RPS), peak demand is assumed to grow 6.28% per year. The planning horizon of the study is 20 years (i.e. from 2006 to 2025). Discount rate of 10% is considered. All prices used in the present analysis are economic prices in 2000 US dollars. The emission factors of each producing sector are based on [15].

Candidate plants used for the analysis in the electricity generation expansion planning consisted of gas turbine (GT)-, gas-based combined cycle (CC)-, conventional coal-fired power plant-, Integrated Gasification Combined Cycle (IGCC)-, Pressurized Fluidized Bed Combustion (PFBC)-, supercritical coal-, large hydro-, pumped storage-, biomass fired integrated gasification combined cycle (BIGCC)-, solar-, wind turbine-, and geothermal-power plants. This study considers three RPS levels, i.e., 5%, 10% and 15%.

This study uses the Input-Output Table of Indonesia for 2000 (see [16]). For the purpose of this study, we aggregate and disaggregate some of the sectors as a result of which the total number of sectors in the I-O table is reduced from original 175 to 35. The methodology of sector aggregation is available in [17] while the methodology of sector disaggregation can be seen in [13, 18]. Based on the modified I-O table, the technological coefficients for the year of 2006 up to 2025 are updated (see [13, 19] for updating the technological coefficients). Although it is not an ideal approach, this is along the lines of some research on Input-Output applications (see e.g., [19, 20, 21, 22, 23]). The values of fuel use per unit output of producing sectors (except thermal power generation sector) are assumed to remain constant at their 2000 levels during the planning horizon. This assumption is made due to the unavailability of technological coefficients for the future. Furthermore, the analyses are focused on the comparison of the economy-wide pollutant emissions between with and without RPS. The levels of fuel use per unit output of thermal power generation sector in the RPS and without RPS cases correspond to the respective least cost generation expansion plans.

In the present study, exports are treated as a part of final demand and imports are ignored. This was also the approach followed by [13] and [18] in the case of UK. If the true picture of Indonesian responsibility for pollution emissions is to be obtained, then the pollution emissions by the Indonesian attributable to exports should be subtracted, while the emissions taking place overseas to satisfy Indonesian import demand should be added on.

RESULTS AND DISCUSSIONS

Without setting the RPS at a certain level, the total installed capacity in year 2025 would be 86,606 MW. Of the total installed capacity in year 2025, the share of hydro-, geothermal-, biomass- and wind-based power plants would be about 2.9%, 1.51%, 0.95% and 0.95% respectively. The shares of fossil fuel based power plants, i.e., coal-, gas-, and oil-based power plants would be about 56.49%, 31.48% and 5.72% respectively. The total electricity generation during 2006-2025 without considering RPS would be about 5,235 TWh. The shares of electricity generation from hydro-, geothermal-, biomass-, and wind-based power plants to the total electricity generation during 2006-2025 would be about 2.52%, 1.92%, 2.31% and 0.13% respectively. In this study, the RPS is increased to 5%, 10% and 15%. Due to hydro resources are limited, so only the share of electricity generation from geothermal-, biomass- and wind-based power plants were considered to be set to 5%, 10% and 15%.

The results show that the CO_2 emission can be reduced by 6.1%, 12.6% and 17.8% if RPS levels of 5%, 10% and 15% are considered. Table 2 shows the total CO_2 mitigation in the whole economy during 2006-2025 due to the introduction of RPS in the Indonesian power sector. Table 2 also shows the shares of each factor to the total CO_2 mitigation.

As shown in Table 2, fuel mix effect and structural effect would reduce the CO_2 emissions, while final demand effect and joint effect would act in the opposite direction. The shares of fuel mix effect to the total CO_2 mitigation would be the highest, i.e., in the range of 73% to 80% if RPS level is increased from 5% to 15%. The shares of structural effect would be in the range 23% to 31% at all RPS levels considered. As mentioned above, final demand effect would increase the CO_2 emissions. The shares of final demand effect are in the range 2% to 4% at all RPS levels considered. The joint effect would also increase the CO_2, emissions, however, its share is negligible (< 1%).

Table 2:
Decomposition of total changes in CO_2 emissions during 2006-2025 in the whole economy at selected RPS levels, 10^3 tons¶

Type of effects	RPS cases		
	5%	10%	15%
Fuel mix effect	-110,577	-238,504	-372,776
Structural effect	-45,443	-92,567	-111,406
Final demand effect	4,876	9,989	10,229
Joint effect	1,363	2,160	3,076
Total changes	**-149,781**	**-318,922**	**-470,877**

¶A negative figure means lower emissions with RPS than that without RPS

It is of interest also to examine the shares of the direct- and indirect-effects of the final demand component. Table 3 presents the shares of the direct- and indirect-effects of the final demand component on changes in CO_2 emissions at all RPS levels considered. As shown in Table 3, the direct- and indirect-effects are nearly equal. However, the indirect effect still dominates upon the direct effect for the CO_2 pollutants.

Table 3:
Contribution of the direct- and indirect-effects of the final demand effect on changes in CO_2 emissions during 2006-2025 at selected RPS levels

Level of RPS	Component	Final demand effect	
		10^6 tons	%
5%	Direct effect	2,970	43.2
	Indirect effect	3,906	56.8
	Total	**6,876**	**100**
10%	Direct effect	47,477	44.8
	Indirect effect	58,499	55.2
	Total	**105,976**	**100**
15%	Direct effect	57,041	47.6
	Indirect effect	62,792	52.4
	Total	**119,833**	**100**

The components under the total joint effect always act towards the increase of CO_2 emissions except the joint effect associated with changes in fuel mix, structure of production and final demand (see Table 4). Table 4 shows that the joint effect associated with changes in fuel mix and final demand has the highest share (in the range of 55 to 77% under all RPS levels considered), and is followed by the joint effect associated with changes in fuel mix and structure of production (in the range 20 to 40% under all RPS levels considered).

Table 4:
Decomposition of total changes in CO_2 emissions during 2006-2025 under the joint effect at selected RPS levels, 10^3 tons¶

Type of effects	RPS cases		
	5%	10%	15%
Fuel mix - Structural	395	448	608
Fuel mix – Final Demand	911	1623	2359
Structural – Final Demand	59	95	118
Fuel mix – Structural – Final demand	-3	-6	-8
Total Joint effect	**1,363**	**2,160**	**3,076**

CONCLUSIONS

This paper has developed an input-output decomposition approach to analyze the factors which affect the total economy-wide change in CO_2 emissions, if the power sector development considers renewable portfolio standard (RPS). There are four major components which affect the changes in CO_2 emission due to considering RPS, i.e., fuel mix effect, structural effect, final demand effect and joint effect. The final demand effect can be decomposed further into direct effect and indirect effect. The results show that the CO_2 emission would be mitigated in the whole economy by about 6.1%, 12.6% and 17.8% if RPS levels of 5%, 10% and 15% are considered respectively during 2006-2025. The fuel mix effect was found to reduce the CO_2 emissions and its share to the total CO_2 emission changes was found the highest, i.e. in the range of 73% to 80% at all RPS levels. The structural effect would also reduce the CO_2 emission and its share would be in the range of 23% to 31%. Unlike fuel mix effect and structural effect, the final demand effect would increase the CO_2 emission and its share would be in the range of 2% to 4%. The joint effect would also increase the CO_2 emission however its share is negligible at RPS levels considered. The direct- and indirect-effects of the final demand effect are nearly equal. However, the indirect effect still dominates upon the direct effect for the CO_2 pollutants.

REFERENCES

[1] Central Electricity Authority (CEA), 2000, *Sixteenth electric power survey of India*, CEA, New Delhi, India.

[2] China Power Year Book, 2001, http://www.sp.com.cn.

[3] DESDM, 2004, *Rencana umum ketenagalisrikan nasional*, Ministry of Energy and Mineral Resources, Indonesia.

[4] Lauber, V., 2004, REFIT and RPS: options for harmonized community framework, *Energy Policy*, Vol. 32, 1405-1414.

[5] Langniss, O. and Wiser, R., 2003, The renewable portfolio standard in Texas: an early assessment, *Energy Policy*, Vol. 31, 527-535.

[6] Epsey, S., 2001, Renewables portfolio standard: a means for trade with electricity from renewable success, *Energy Policy*, Vol. 29, 557-566.

[7] Berry, T. and Jaccard, M., 2001, The renewable portfolio standard: design considerations and an implementation survey, *Energy Policy*, Vol. 29, 263-277.

[8] Fan, J., Sun, W. and Ren, D. M., 2004, Renewable portfolio standard and regional energy structure optimization in China. *Energy Policy*.

[9] Wiser, R., Porter, K., and Clemmer, S., 2000, Emerging markets for renewable energy: The role of state policies during restructuring, *The Electricity Journal*, Vol.13, No.1, 13-24.

[10] Energy Policy and Planning Office (EPPO), 2004, *Thailand energy strategy and policy*, Energy Policy and Planning Office, Thailand.

[11] DESDM, 2003, *Policy on renewable energy development and energy conservation*, Ministry of Energy and Mineral Resources, Indonesia.

[12] P.T. PLN (PERSERO) (PTP), (2005), *Rencana umum ketenagalistrikan nasional*, PTP, Jakarta.

[13] Proops, J. L., Gay, P. W., Speek, S. and Schroder, T., 1996, The life time pollution implications of various types of electricity generation: an input-output analysis, *Energy Policy* , Vol. 24, No. 3, 229-237.

[14] Rose, A. and Chen, C. Y., 1991, Sources of change in energy use in the U.S. economy, 1972-1982: a structural decomposition analysis, *Resources and Energy*, 13, 1-21.

[15] Goto, T., Kato, N., Ohnishi, A., Ogawa, Y. and Sakamoto, T., 1993, *Projections of energy consumption and emissions of substances (SO_2, NO_x and CO_2) affecting the global environment in Asia: Summary*. NISTEP Report No. 27, August 1993, National Institute of Science and Technology Policy (NISTEP), Science and Technology Agency, Tokyo.

[16] BPS Statistics Indonesia (BPS), 2004, *Indonesia input-output table 2000, vol. I, II and III, BPS*, Jakarta-Indonesia.

[17] Miller, R. and Blair, P. D., 1985, *Input-output analysis: foundations and extensions*, Prentice-Hall, Englewood Cliffs, NJ.

[18] Gay, P. W. and Proops, J. L., 1993, Carbon-dioxide production by the UK economy: an input-output analysis, *Applied Energy*, 44, 113-130.

[19] Murty, N. S., Panda, M. and Parikh, J., 1997, Economic development poverty reduction and carbon emissions in India, *Energy Economics* 19, 327-354.

[20] Caloghirou, Y. D., Mourelatos, A. G. and Roboli, A., 1996, Macroeconomic impacts of natural gas introduction in Greece, *Energy*, Vol. 12, No. 10, 899-909.

[21] Lesser, J. A., 1994, Estimating the economic impacts of geothermal resource development, *Geothermic*, Vol. 23, No. 1, 43-59.

[22] Breuil, J. M., 1992, Input-output analysis and pollutants emissions in France, *The Energy Journal*, Vol. 13, No. 3, 173-185.

[23] Shrestha, R. M. and Marpaung, C. O. P., 2006, Integrated resource planning in the power sector and economy-wide changes in environmental emissions, *Energy Policy*, Vol. 34, 3801-3811.