Structural Decomposition Analysis of CO_2 Emission Reduction due to Energy Tax in Power Sector Planning

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***Abstract*—This study analyses the CO_2 emission implications of considering energy tax in power sector planning for the case of Indonesia. There are four energy tax rates considered in this study i.e. US$0.5/MBtu, US$1.0/MBtu, US$2.0/MBtu and US$5/MBtu. Furthermore, this study also analyses the decomposition of the economy-wide CO_2 emission changes due to the carbon tax rates by using an input-output model. The implications of energy tax on utility planning would bring the sytem more efficient because more energy efficient technology power plants, such as CCGT, would be selected, while in the case of environmental implications, CO_2 emissions would be reduced. The results show that there is a significant change in the annual CO_2 emissions if energy tax rate of US$5/MBtu is introduced. There are three major components that affect the total economy-wide change in CO_2 emissions, i.e., fuel mix-, structural-, and final demand- effects. The results show that the fuel mix effect is found to be most influential in reducing the CO_2 emission during the planning horizon under all of the energy tax rates considered and is followed by the final demand- and structural-effects.**

***Index Terms*—** power sector planning, energy tax, decomposition analysis.

I. Introduction

Recently, environmentally sound sustainable development has become a main concern both in industrialized and developing countries. In Indonesia, Law No. 23 which is primarily aimed at environmental management, was enacted in year 1997. There are several technology options towards low carbon green growth in Indonesia. However, the adoption of these technologies to mitigate CO_2 emission would not take place without policy interventions from the government. Major direct policy instruments to mitigate CO_2 emissions include carbon tax, carbon emission permits, while indirect instruments include energy tax. This study analyzes the effects of introducing selected energy tax rates in the power sector of Indonesia.

Levy of energy tax does not only affect the electricity generation on supply-side but also reduces the demand for electricity through the increase of electricity price due to the tax. Furthermore, energy tax could affect CO_2 emission changes. The total economy-wide change in CO_2 emission due to the adoption of energy efficient and less carbon intensive technologies with the energy tax in the power sector is a combined effect of a number of factors. There are three major factors that affect the total change in emissions due to the energy tax in the power sector, i.e., fuel mix effect (i.e., the change in emissions due to variation in fuel mix), structural effect (i.e., the change in emissions due to changes in technological coefficients), and final demand effect (i.e., the change in emissions associated with changes in final demand).

There are some studies using input-output decomposition analysis to analyze factors behind changes in energy use (see e.g. [1] – [4]), however, the input-output decomposition models in these studies are not complete input-output decomposition models, or in other words, error terms or residual are still included in the model. Reference [5] employs a complete input-output decomposition model, however, the study is not in the context of power sector development. Reference [6] uses a complete input-output decomposition model in the study of power development planning, however, energy tax is not considered in the study.

The present study develops an input-output (I-O) decomposition method or a structural decomposition analysis to analyze the roles of different factors contributing to the economy-wide change in CO_2 emission due to energy tax in the power sector. The decomposition framework is applied to analyze the contributions of the various factors to the change in CO_2 emissions due to the energy tax in the power sector of Indonesia from a long term power generation planning perspective during 2011-2030. The paper is organized as follows. A description of the energy tax and the I-O decomposition model is presented in the next section followed by the input data and assumptions used in the study. The economy-wide environmental implications of the energy tax in power sector planning are examined in the subsequent sections. Finally, the major findings of the study are summarized.

II. Energy Tax

Primary energy sources have long been subject to fiscal levies such as taxes on mineral oils and value added tax. These taxes are generally applied during energy production and/or transformation. An energy tax is based on quantity of energy consumed and is specified in some common units like in barrels of oil equivalent or in British thermal units (Btu) ([7]). Similarly, other authors, [8], [9], and [10] define energy tax as tax based on the Btu (energy) content of the energy sources.

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References [11], [12], and [13] state that the President Clinton's original Btu tax proposal had proposed to apply tax to all fuels at a rate proportion to their energy content (Btu), the tax rate being 25.7 US cents per million Btus. For example, coal, natural gas, petroleum products and nuclear are taxed at 26 cents per million Btu (MBtu) though petroleum products were to have additional surtax at 34 cents/MBtu. Similarly, hydro would be taxed like nuclear but renewable energy sources, like solar, wind and geothermal would be tax-free ([14]). Reference [9] states that "although nuclear and hydro power plants do not emit greenhouse gases they do cause major environmental damages and risks" as well as national security risk in the case of nuclear power and "thus, it is appropriate that they be included in the tax base". Hence, in the case of electricity produced by nuclear fission and hydro power, the average heat rate (Btu) per kilowatt-hour (kWh) of fossil fuel production was applied to calculate the tax rate ([9]). However, exported fuels, feedstock uses and selected renewable energy sources, such as solar power, wind, geothermal and biomass were exempt from the original proposal. The exemptions were justified because of their relatively low environmental impacts. Reference [10] states that energy taxes can be applied in the form of specified production taxes on hydro and nuclear power. Refence [7] reports that energy tax also covers nuclear and renewable energy. Reference [15] states that "energy taxes often apply at different rates to different forms of energy and may have specific exemptions and other special provisions".

According to [16], unlike most regulations, energy taxes give ongoing incentive to innovation; improve energy efficiency and economic signals to reduce energy use. It further sends educational messages about the seriousness of the government's intention to tackle climate change and other pollution problems. In addition to increasing the efficiency, taxation of energy also provides revenues to the state. Reference [10] states that introducing new taxes on energy use have been usually for environmental benefits and fiscal reasons.

Generally two possibilities can be considered for energy tax in the power sector, where the tax can be imposed on the electricity delivered or on the primary energy carriers used for electricity generation [17]. Taxation of final energy delivery only influences the choices made by the final energy consumers. However, in the case of imposition of taxes on primary energy resources used for electricity generation, the fuel cost and electricity generation cost would automatically increase translating into electricity price increase. The energy tax causes shift in activation order of different power plants favoring relatively efficient power plants. Furthermore, tax on primary energy carriers enclose the effects of final energy delivery (and even amplified for electricity) and force generators to optimize their production [17].

III. METHODOLOGY

This section presents the development of structural decomposition analysis based on an input-output decomposition model which is used to determine the factors that affect the total change in economy-wide CO_2 emissions due to the energy tax in the power sector. The model in this study is different from [6] in terms energy tax is considered in the present study. The model used in this study extends the work by [18], which provided the methodology for examining the components of change in the UK economy-wide life cycle implications of various types of electricity generation. Unlike in [18] and also in [1]-[4], in this study we develop a complete input-output decomposition model (without residual) to analyze the total change in CO_2 emissions in the whole economy due to the carbon tax in the power sector. In the model that we develop, we consider not only the changes in the technological coefficients of the electricity sector as is the case in [18], but also the changes in technological coefficients of other sectors, which were not considered by them. Furthermore, the change in the technological coefficients of the electricity and other sectors in this study are based on the output of the generation expansion planning model. It should be noted that the demand for goods and services for the construction of power plants and the demand for electricity would both change with an energy tax. This study captures the change in final demand in due to both the change in demand for goods and services for power plant construction, and the change in demand for electricity with the energy tax. Furthermore, the I-O decomposition analysis in this study is based on long term power generation planning model, which is not the case in [18].

The symbols used in the decomposition model in this study are defined as follows:

p	=	types of fuels used by producing sectors,
q	=	number of producing sectors,
EFD	=	electricity final demand,
CPP	=	construction of power plants,
$\boldsymbol{A_T}(t)$, $\boldsymbol{A_0}(t)$	=	matrix (q x q) of input-output (i.e., technological coefficients) with and without energy tax in year t respectively,
$\boldsymbol{C_T}(t)$, $\boldsymbol{C_0}(t)$	=	matrix (q x p) of direct fuel requirement coefficients (defined as fuel use per unit of total output of a sector) with and without energy tax in year t respectively,
$\boldsymbol{E}$	=	column vector (p x 1) of a CO_2 emissions coefficients (defined as CO_2 emissions per unit of fuel used),
$\boldsymbol{I}$	=	identity matrix (q x q),
$\boldsymbol{L_T}(t)$, $\boldsymbol{L_0}(t)$	=	Leontief matrix (q x q) of input-output with and without energy tax in year t respectively,
$\boldsymbol{X_T}(t)$, $\boldsymbol{X_0}(t)$	=	column vector (q x 1) of total output with and without energy tax in year t respectively,
$\boldsymbol{Y_T}(t)$, $\boldsymbol{Y_0}(t)$	=	column vector (q x 1) of final demand with and without energy tax in year t respectively.

The input-output decomposition model is derived as follows: First, the difference in total output due to considering energy tax in the electricity sector ($\boldsymbol{\Delta X}(t)$) is calculated as follows:

$$\boldsymbol{\Delta X}(t) = \boldsymbol{X_T}(t) - \boldsymbol{X_0}(t) \quad (1)$$

Noting that the total output vectors with and without energy tax (i.e., $\boldsymbol{X_T}(t)$ and $\boldsymbol{X_0}(t)$ respectively) can be expressed as

$\boldsymbol{X_T}(t)=[\boldsymbol{I}-\boldsymbol{A_T}(t)]^{-1}\boldsymbol{Y_T}(t)$ and $\boldsymbol{X_0}(t)=[\boldsymbol{I}-\boldsymbol{A_0}(t)]^{-1}\boldsymbol{Y_0}(t)$ respectively, Equation (1) can be expressed as:

$$\boldsymbol{\Delta X}(t) = [\boldsymbol{I} - \boldsymbol{A_T}(t)]^{-1}\, \boldsymbol{Y_T}(t) - [\boldsymbol{I} - \boldsymbol{A_0}(t)]^{-1}\, \boldsymbol{Y_0}(t) \quad (2)$$

If we define $\boldsymbol{L_T}(t) \equiv [\boldsymbol{I} - \boldsymbol{A_T}(t)]^{-1}$ and $\boldsymbol{L_0}(\mathrm{t}) \equiv [\boldsymbol{I} - \boldsymbol{A_0}(t)]^{-1}$, and substitute $[\boldsymbol{I} - \boldsymbol{A_T}(t)]^{-1}$ and $\boldsymbol{L_0}(t) \equiv [\boldsymbol{I} - \boldsymbol{A_0}(t)]^{-1}$ in Equation (2) with $L_T(t)$ and $L_0(t)$ respectively, Equation (2) now can be written as follows:

$$\Delta X(t) = L_T(t)\, Y_T(t) - L_0(t)\, Y_0(t) \quad (3)$$

For the purpose of analysing the total economy-wide change in CO_2 emission (TC) due to introducing energy tax as compared to that without energy tax, we multiply the first- and the second-components of the right hand side of Equation (3) with C_T and C_0 respectively and also with the E matrix. The results is now given in the following equation:

$$TC = E'\, C_T(t)'\, L_T(t)\, Y_T(t) - E'\, C_0(t)'\, L_0(t)\, Y_0(t) \quad (4)$$

where $C_T(t)'$ and $C_0(t)'$ represent the transpose of $C_T(t)$ and $C_0(t)$ respectively while E' is the transpose of E. By using polar decomposition or the average of all possible first order decomposition ([15]-[17]), Equation (4) can be written as follows:

$$TC = E'\, \Delta C(t)'\, L_T(t)\, Y_T(t) + E'\, C_0(t)'\, \Delta L(t)\, Y_T(t) + E'\, C_0(t)'\, L_0(t)\, \Delta Y(t) \quad (5)$$

The first component of the right hand side of Equation (5) is called fuel mix effect (FME), i.e., the change in total economy-wide CO_2 emission as a result of changing the fuel mix used by power plants due to introducing the energy tax. The second component of the right hand side of Equation (5) is called structural effect (STE), i.e., the change in total economy-wide CO_2 emission as a result of changing the efficiency of power plants. The FME and the STE are also called as operating pahase effect (OPE) ([18]). The last component of the right hand side of Equation (5) is called final demand effect (FDE), i.e. the change in total economy-wide CO_2 emission due to the change in demand for the eletricity and the demand for goods and services for construction of power plants. The FDE component can also be written as:

$$FDE = E'C_0(t)'\Delta Y(t) + E'C_0(t)'[L_0(t) - I]\Delta Y(t) \quad (6)$$

The right hand side of Equation (6) shows the direct- (first component) and the indirect- (second component) effects of the FDE. Since $\Delta Y(t) = \Delta Y_{CPP}(t) + \Delta Y_{EFD}(t)$, *where* $\Delta Y_{CPP}(t)$ is changes in demand for goods and services for construction of power plant, and $\Delta Y_{EFD}(t)$ is changes in electricity final demand, and if $\Delta Y(t)$ in Equation (6) is substituted with ($\Delta Y_{CPP}(t) + \Delta Y_{EFD}(t)$), Equation (6) can now be written as follows:

$$FDE = E'C_0(t)'\Delta Y_{CPP}(t) + E'C_0(t)'[L_0(t) - I]\, \Delta Y_{CPP}(t) + E'C_0(t)'\Delta Y_{EFD}(t) + E'C_0(t)'[L_0(t) - I]\, \Delta Y_{EFD}(t) \quad (7)$$

where the first two components of the right hand side of Equation (7) are called the direct effect due to the change of final demand for power plant construction (FDE_CPP_D), and the indirect effect due to the change of final demand for power plant construction (FDE_CPP_ID) respectively. While the last two components represent the direct effect due to the change of demand for electricity (FDE_EFD_D), and the indirect effect due to the change of demand for electricity (FDE_EFD_ID) respectively. Hence, the total components which affect the total economy-wide CO_2 emission changes due to the introduction of energy tax in the power sector could be calculated by using the following equations (Equations 8-13):

$$\text{(a) } FME = E'\, \Delta C(t)'\, L_T(t)\, Y_T(t) \quad (8)$$

$$\text{(b) } STE = E'\, C_0(t)'\, \Delta L(t)\, Y_T(t) \quad (9)$$

$$\text{(c) } FDE\_CPP\_D = E'\, C_0(t)'\, \Delta Y(t) \quad (10)$$

$$\text{(d) } FDE\_CPP\_ID = E'\, C_0(t)'\, [L_0(t) - I]\, \Delta Y(t)_{CPP} \quad (11)$$

$$\text{(e) } FDE\_EFD\_D = E'\, C_0(t)'\, \Delta Y(t)_{EFD} \quad (12)$$

$$\text{(f) } FDE\_EFD\_ID = E'\, C_0(t)'\, [L_0(t) - I]\, \Delta Y(t)_{EFD} \quad (13)$$

The generation expansion planning (GEP) used in this study is similar to that used in [4]. The GEP is used to obtain the least cost fuel mix and power development plan corresponding to given demand forecast under different energy tax rates.

Introducing energy tax would result an increase in price of electricity, and hence a reduction in demand for electricity. With the new level of electricity demand, the GEP model is rerun to obtain the new least cost power development plan. The new least cost development plan would give new level of electricity price, and accordingly, the value of demand for electricity is revised. With the new value of demand for electricity, the GEP model is rerun and the new least cost power generation expansion plan is obtained. This procedure is repeated until the equilibrium combination of electricity price and output is obtained. After the equilibrium point is obtained, the CO_2 emissions are calculated based on the information obtained from the optimal fuel requirements and relevant emission factors.

In this study, to update the existing I-O table, the outputs of generation expansion planning are used. For example, the level and type of fuel used by each type of power plants are obtained from the GEP model. This information would be used to modify the transaction matrix of the I-O table particularly the elements related to the fuel use by the electricity sector. The change in demand for electricity with the introduction of energy tax is estimated based on the change in electricity price (that is measured in terms of change in the average incremental cost of electricity generation). The change in electricity demand is used to modify the final demand part of the I-O table. The demand for goods and services for constructing power plants, the size (i.e., capacity), of which is determined by the generation expansion planning model, would be used to update the final demands in the I-O Table.

IV. Input Data and Assumptions

Energy tax is another emission tax that can be used to help control the global climate change. Unlike carbon tax, energy tax depends on the quantity of energy consumed and is specified in some common unit (like in barrels of oil equivalent, or in British thermal units (BTU)). There are four energy tax rates considered in this study i.e. US$0.5/MBtu, US$1.0/MBtu, US$2.0/MBtu and US$5/MBtu.

For the purpose of input-output decomposition analysis, we update the technological coefficients of the latest Indonesia input-output (I-O) table, i.e., I-O table 2005 for each year in the planning period of 2011-2030. Indonesia I-O table 2005 has 175 sectors.

For the purpose of this study, the 175-sector Indonesia I-O table is aggregated into 37 sectors. In aggregating the sectors, all energy sectors (e.g., coal, oil, gas, geothermal, electricity) are maintained as independent sectors. Industrials sectors with high energy intensity and high CO_2 production (e.g., iron and steel, pulp and paper, cement, textile, transport, etc) are also maintained as separate sectors. All sectors related to agriculture are aggregated into one sector. All service industries are also aggregated into one sector. Although using input-output approach is not an ideal method for analysis of effects of a policy over the long term, this is along the lines of some research on input-output applications (see e.g., [22]). The values of fuel use per unit output of producing sectors (except thermal power generation sector) are assumed to remain constant at their 2005 levels during the planning horizon. This assumption is made due to the non-availablity of data on the fuel use by the producing sectors (except thermal power generation sector) in the future due to the model that we use in this study is a non-integrated assessment model. Furthermore, the analyses are focused on the comparative study of the economy-wide CO_2emissions with and without the energy tax in the power sector. The fuel use per unit of thermal power generation is obtained from the least cost generation expansion plan using the GEP model. The emission factors of the production sectors are based on [23].

In the present study, the exports are treated as a part of the final demand and the imports are ignored. This is also the approach followed by [18] in the case of UK. If the true picture of Indonesian responsibility for CO_2 emissions is to be obtained, then the emissions attributable to the Indonesian exports should be subtracted and conversely, while the CO_2 emissions taking place overseas to satisfy the Indonesian demand through imports should be added on.

V. RESULTS AND DISCUSSIONS

Introducing energy tax would affect the selection of power plant technologies. Table I shows that CCTs (such as IGCC, PFBC and SC) would never be selected during 2011-2030 although these plants are considered as efficient power plants. This is because the capacity costs of these plants are relatively high compared to other plants. Coal-based power plant would be less cost effective with the increase of energy tax rates. Even at energy tax of US$5/MBtu, this plant type is not cost effective anymore. This is reasonable, because energy tax disfavor power plants which have relatively low efficiency such as conventional coal power plants. At low energy tax rates (such as energy tax of US$0.5, US$1.0 and US$2 per MBtu), EETs (such as CCGT) are less cost effective. At these tax rates, the number of CCGT selected during 2011-2030 would be lower than that at the base case. However, at high energy tax rate (i.e. US$5/MBtu energy tax rate), the CCGT would become much more cost effective. At this tax rate, about 42,600 MW of CCGT would be selected during 2011-2030. This indicates that energy tax would be less effective if it is applied to power plants which use relatively costly fuel, such as natural gas, although the power plants are relatively efficient. Undispatchable RETs such as wind power plant becomes more cost effective with the increase of energy tax rates, however solar-based power plant is still too expensive to be selected. Other RETs such as BIGCC would be less cost effective with the increase of energy tax rates. Even at high energy tax rates, such as US$5/MBtu, BIGCC would not be attractive anymore. Aside from the relatively high capacity cost, the fuel cost would also become relatively high with the increase of energy tax rates. Although energy tax is not levied to geothermal power plant, this plant has relatively high capacity and steam costs, so this plant would not be selected during 2011-2030. The selection of other plant types and the total power plant selected during 2011-2030 at all cases are seen in Table I.

TABLE I
TOTAL POWER PLANT TECHNOLOGY SELECTION IN THE AT DIFFERENT TAX RATES DURING 2011-2030

Power Plant Technology	Base	Energy tax rate (US$/MBtu)			
		0.5	1	2	5
Conv. coal	39,600	38,000	36,400	34,000	0
IGCC	0	0	0	0	0
PFBC	0	0	0	0	0
SC	0	0	0	0	0
CCGT	19,800	18,600	18,600	16,800	42,600
GTPP	1,400	1,000	0	0	200
Geothermal	0	0	0	0	0
BIGCC	825	525	450	225	0
Hydro	55	0	0	0	55
PS	1,000	1,000	1,000	1,000	1,000
Wind	255	1,136	1,238	1,427	1,500
Solar	0	0	0	0	0
Total	62,935	60,261	57,688	53,452	45,355

The selection of different types of power plants would affect the capacity mix and the total installed capacity during 2011-2030. At the end of the planning horizon (in year 2030), the total installed capacity at energy tax rates of US$0.5, US$1.0, US$2.0 and US$5.0 per MBtu would be 83,362 MW, 80,789 MW, 76,553 MW and 68,401 MW respectively, or the total installed capacity would be about 0.96, 0.93, 0.88 and 0.79 of the total installed capacity at the base case, respectively. The installed capacity of conventional coal power plant in year 2030 would decrease with the increase of energy tax rates. The share of conventional coal power plant to the total installed capacity in year 2030 at energy tax US$2.0/MBtu and lower would be about 57%, however, at energy tax of US$5.0/MBtu, its share would decrease dramatically to 14%. In the case of gas-based power plant, its share would decrease if energy tax is introduced until the rate of US$2.0/MBtu, i.e. would decrease from 30.8% at energy tax rate of US$0.5/MBtu to 29.9% at US$2.0/MBtu energy tax rate. At energy tax rate of US$5/MBtu, its share to the total cost would increase dramatically to 71.4%.

The share of oil-based power plan would be the same at all tax rates. This is because there is no candidate power plant for oil-based power plant following the government policy. The share of BIGCC would decrease with the increase of energy tax rates, however, its share is relatively low, i.e. less than 1% at all cases. There is no installed BIGCC at US$5/MBtu tax rate. The share of wind plant would increase with the increase of energy tax rates, i.e. from 0.95% without tax to 2.2% at US$5/MBtu tax rate. The share of geothermal power plants would be almost the same at all cases, i.e. around 2%, and the share of hydro power plants would also be almost the same at all cases, i.e. around 3%.

The total economy-wide changes in CO_2 emissions due to the energy tax in the power sector during the planning horizon (2011-2030) in Indonesia (as compared to that without the energy tax) are presented in Table II. As shown in the table, the total CO_2 emission reduction in the whole economy during the planning horizon would increase from 113 to 2,540 million tons with the increase of energy tax from 0.5 to 5 US$/MBtu, or in other words, the CO_2 mitigation at the energy tax of US$5/MBtu would be 22.5 times higner than that at the energy tax of US$0.5/MBtu.

TABLE II
DECOMPOSITION OF TOTAL CHANGES IN ECONOMY-WIDE CO_2 EMISSIONS DURING 2011-2030 UNDER SELECTED ENERGY TAX RATES, 10^6 TONS[A]

Types of effects	Energy tax rate (US$/Mbtu)			
	0.5	1	2	5
FME	**-55**	**-146**	**-244**	**-1,520**
STE	**-27**	**-53**	**-88**	**-395**
FDE	**-31**	**-88**	**-133**	**-625**
FDE_CPP	-14	-19	-24	-165
FDE_EFD	-17	-69	109	-460
TC	**-113**	**-287**	**-445**	**-2,540**

[a] Negative figure means lower emission with than without energy tax

Table II also shows that *FME*, *STE* and *FDE* would reduce the CO_2 emission under all tax rates considered in this study. Of the total CO_2 reduction, the contribution of the FME to reducce the CO_2 emission is the highest, i.e in the range of 48.7% to 59.9% and is followed by FDE and STE.

It is of interest also to analyse the role of *FME*, *STE*, and *FDE* to the total change in CO_2 emissions? The negative figure (which means a lower emission with energy tax than that without the tax) of the fuel mix effect (*FME*) under the selected energy tax rates is due to the change in fuel mix. As we know, the total electricity demand (and hence generation) would decrease with the introduction of energy tax, and accordingly, the CO_2 emission would decrease as well. It should be noted that the *FME* is the change in overall system wide emission per unit of electricity generation with energy tax as compared to that without energy tax. The reduction in total electricity generation is due to the decrease in power demand associated with the increase in electricity price due to energy tax. The negative figures of the *STE* under the selected energy tax rates indicate that the change in the structure of the economy in Indonesia due to the introduction of energy tax would decrease the CO_2 emissions.

As mentioned before, the *FDE* would also increase the total economy-wide reduction in CO_2 emissions under all energy tax rates. Both the components of *FDE* (i.e., *FDE_CPP* and *FDE_EFD*) would reduce the total CO_2 emissions. The *FDE_CPP* component would reduce the total CO_2 emissions because of the smaller addition of power plant capacity with the energy tax, while the *FDE_EFD* component would reduce the total CO_2 emissions because of the reduced level of electricity generation that results from the increase in the electricity price due to energy tax. Between the two components of the *FDE*, the *FDE_EFD* component is found to be dominant (with its share ranging from 54.8 to 96.5%).

It is of interest also to examine the shares of the direct- and indirect-effects associated with each component of the *FDE* on CO_2 reduction with energy tax. Table III presents the shares of the direct- and indirect-effects for each component of the *FDE* at the selected energy tax rates.

TABLE III
DECOMPOSITION OF THE FINAL DEMAND EFFECT ON CO_2 EMISSION REDUCTIONS DURING 2011-2030 AT SELECTED ENERGY TAX RATES, %

Components of final demand effect		Energy tax rate (US$/Mbtu)			
		0.5	1.0	2	5
Construction od power plant	*FDE_CPP_D*	40.8	45.4	14.3	40.8
	FDE_CPP_ID	59.2	54.6	55.7	59.2
Electricity final demand	*FDE_EFD_D*	73.4	33.2	37.9	79.8
	FDE_EFD_ID	26.6	16.8	12.1	10.2

In the *FDE_CPP* component, the indirect effect (*FDE_CPP_ID*) is found to play a bigger role than the direct effect (*FDE_CPP_D*) in all energy tax rates considered. In the case of *FDE_EFD*, the direct effect (*FDE_EFD_D*) is found to play the dominant role accounting for over 73.4% share in *FDE_EFD*, with the rest being contributed by the indirect effect (*FDE_EFD_ID*).

VI. CONCLUSION AND FINAL REMARKS

This paper has developed an input-output decomposition analysis to analyse the factors which affect the change in CO_2 emission due to the introduction of energy tax in the power sector planning. From the decomposition analysis, it is found that there three major factors which affect the Coe emission mitigation due to the introduction of energy tax, they are fuel mix effect, structral effect, and final demand effect. The final demand effect itself is decomposed into the final demand effect due to the constructionof power plant and the electricity final demand. Each factors under the final demand effect is decomposed further into direct and indirect effect. The Input-Output decomposition model is applied to estaimate the change in CO_2 emission due to the introduction of energy tax in the Indoensian power system planning and also analyse the contributions of each factors to the total CO_2 emission reduction. The results show that if the energy tax rate is increased from US$0.5/Mbtu to US$5/Mbtu, the total economy wide CO_2 emission reduction during the planning horizon would increase from 113 to 2,540 million tons. All the three components: the fuel mix-, structural- and final demand-effects would all contribute to reduce CO_2 emissions under all energy tax rates considered in this study. Among the three major factors, the fuel mix effect is found to contribute the biggest role in reducing the CO_2 emissions under the energy tax rates considered. Similar to the fuel mix effect, the structural effect and the final demand effect would also reduce the CO_2 emission if the energy tax rates is introduced in the planning. In the case of the components under the final demand effect, both the construction of power plants- and electricity final demand-components of the final demand effect were found to contribute towards the reduction of CO_2 emission under all the energy tax rates considered. As mentioned above, the construction of power plants- and the electricity final demand-components are decomposed into direct- and indirect effects. The results show that the direct effect component is found to play a bigger role than the indirect effect in the electricity final demand effect, while in the case of the construction of power plant component, the indirect effect would be bigger than the direct effect.

It should be noted that the analysis used inthis study is based on partial equilibrium analysis. Different analysis by using a general equilibrium framework would give different results. It would be interseting also if nuclear power plants and renewable energy based power plants are also considered for further research.

VII. References

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