Economy-wide CO_2 Emission Reduction Due to Carbon Tax in the Power Sector: A Structural Decomposition Analysis

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***Abstract*—In this paper, a structural decomposition analysis based on an input-output framework has been developed to examine the factors, which affect the economy-wide CO_2 emission changes due to the introduction of carbon tax in the Indonesian power sector during 2011-2030. 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 CO_2 mitigation under the carbon tax of US$200/tC would be 20.5 times higher than that with the carbon tax rate of US$5/tC. The fuel mix effect is found to be most influential in reducing the CO_2 emission during the planning horizon under all of the carbon tax rates considered and is followed by the final demand- and structural-effects.**

***Index Terms*—Carbon tax, CO_2 emission reduction. input-output, sstructural decomposition analysis.**

I. Introduction

IN the face of the international concern for climate change, analyses of alternative policies and strategies to reduce greenhouse gases have received an increasing attention of climate policy planners and researchers. Accordingly, an analysis of the economy-wide effects of policy options like carbon tax and tradable carbon emission permits, the two major economic instruments is a matter of growing interest in the climate change economics and policy literature.

As is well known, an introduction of a carbon tax is expected to make less carbon intensive energy resources and technologies relatively more attractive. The total economy-wide change in CO_2 emission due to the adoption of energy efficient and less carbon intensive technologies with the carbon 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 carbon 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).

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There are few studies that analyze the factors behind the changes in CO_2 emissions from the power sector, e.g., [1]-[3]. However, these studies are focused on the historical emissions based on Divisia decomposition approaches and do not analyze the economy-wide effects of using carbon tax in the power sector. A limited number of studies have used the input-output decomposition method to analyze the changes in energy use and pollutant emissions from the power sector (see e.g., [4]-[10]). Reference [6] examined the changes in CO_2, SO_2 and NO_x emissions in the power sector due to the replacement of old coal-fired power plants with eight types of electricity generation stations, while [11] analyzed the impacts of increasing electricity tariff to the long run marginal cost on prices of other products by using an input-output approach. Reference [8] examined the impacts of end-use energy efficiency improvements on CO_2 emissions from the economy, while [9] carried out similar analysis on SO_2 emissions. However, none of these four studies deals with pollutant emissions from a long term generation expansion planning perspective nor did they consider the effects of carbon tax. Reference [4] examined the sectoral impacts in the economy due to the electricity supply investment, electricity supply shortage, as well as the increase in electricity rates of hydro-electric, fossil fuels, nuclear, and non-utility electric power. Reference [7] analyzed the economy-wide changes in CO_2, SO_2 and NO_x emissions due to the introduction of demand side management programs in framework of the long term generation expansion planning. However, the studies by both [4] and [7] did not involve the analysis of the effects of carbon tax. Although [10] analyzed the effect of the carbon tax on the demand for the PV system and on the CO_2 emission, the study was not based on the long term generation expansion planning. Furthermore it did not examine the factors affecting the CO_2 emission reduction.

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 carbon 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 carbon 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 I-O decomposition model is presented in the next section followed by the brief overview of the power sector in Indonesia, and the input data and assumptions used in the study. The economy-wide environmental implications of the carbon tax in power sector development are examined in the subsequent sections. Finally, the major findings of the study are summarized.

II. Methodology

There are three major factors that affect the total change in CO_2 emission following the introduction of the carbon tax in the power sector , i.e., (i) the change in emissions due to variation in fuel mix (here after the "fuel mix effect" (*FME*)), (ii) the change in emissions due to changes in technological coefficients (hereafter the "structural effect" (*STE*)), and (iii) the change in emissions associated with changes in final demand (here after the "final demand effect" (*FDE*)).

There are two components of the final demand effect (*FDE)*, i.e., (i) the change in final demand due to the change in final demand for goods and services for power plant construction (hereafter "*FDE_CPP"*), and (ii) the change in final demand due to the change in electricity final demand (hereafter "*FDE_EFD"*). Each individual component under final demand effect (i.e., *FDE_CPP* and *FDE_EFD*) can be decomposed further into (i) the change in the CO_2 emissions due to the use of fossil fuels directly in the production of goods and services which are used for final demand and (ii) the change in the CO_2 emissions due to the fossil fuels which are expended to produce goods and services which are useful as inputs to produce goods and services for final demand. Thus, *FDE_CPP* can be expressed in terms of its direct and indirect effects; these effects are hereafter denoted as "*FDE_CPP_D"* and "*FDE_CPP_ID"* respectively. Similarly *FDE_EFD* can be expressed in terms of its direct- and indirect-effects; these effects are hereafter denoted as "*FDE_EFD_D"* and "*FDE_EFD_ID"* respectively.

Hence the total change (*TC*) in a CO_2 emission is now can be written as:

$$TC = FME + STE + FDE\_CPP\_D + FDE\_CPP\_ID + FDE\_EFD\_D + FDE\_EFD\_ID \quad (1)$$

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 carbon tax in the power sector. The present study extends the work by [6], 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 [6] and also in [7], 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 [6], 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 a carbon 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 carbon 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 [6].

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

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

$$\boldsymbol{\Delta X} = \boldsymbol{X_T} - \boldsymbol{X_0} \quad (2)$$

Noting that the total output vectors with and without carbon tax (i.e., $\boldsymbol{X_T}$ and $\boldsymbol{X_0}$ respectively) can be expressed as $\boldsymbol{X_T}=[\boldsymbol{I}-\boldsymbol{A_T}]^{-1}\boldsymbol{Y_T}$ and $\boldsymbol{X_0}=[\boldsymbol{I}-\boldsymbol{A_0}]^{-1}\boldsymbol{Y_0}$ respectively, Equation (2) can be expressed as:

$$\boldsymbol{\Delta X} = [\boldsymbol{I} - \boldsymbol{A_T}]^{-1}\,\boldsymbol{Y_T} - [\boldsymbol{I} - \boldsymbol{A_0}]^{-1}\,\boldsymbol{Y_0} \quad (3)$$

Denoting $\boldsymbol{L_T} \equiv [\boldsymbol{I} - \boldsymbol{A_T}]^{-1}$ and $\boldsymbol{L_0} \equiv [\boldsymbol{I} - \boldsymbol{A_0}]^{-1}$, Equation (3) can be written as:

$$\boldsymbol{\Delta X} = \boldsymbol{L_T}\,\boldsymbol{Y_T} - \boldsymbol{L_0}\,\boldsymbol{Y_0} \quad (4)$$

Equation (4) can be extended to analyze the change in total CO_2 emission *(TC)* with the carbon tax as compared to that without the tax by considering the fuel-use coefficients matrices in the cases with and without the carbon tax (i.e., $\boldsymbol{C_T}$ and $\boldsymbol{C_0}$ respectively) and a matrix of CO_2 emissions coefficients ($\boldsymbol{E}$):

$$TC = \boldsymbol{E}'\,\boldsymbol{C_T}'\,\boldsymbol{L_T}\,\boldsymbol{Y_T} - \boldsymbol{E}'\,\boldsymbol{C_0}'\,\boldsymbol{L_0}\,\boldsymbol{Y_0} \quad (5)$$

where $\boldsymbol{C_T}'$ and $\boldsymbol{C_0}'$ represent the transpose of $\boldsymbol{C_T}$ and $\boldsymbol{C_0}$ respectively and $\boldsymbol{E}'$ is the transpose of $\boldsymbol{E}$. The change in total CO_2 emission due to considering carbon tax in the power sector as stated in Equation (5) is partly due to the final demand effect

(*FDE*) and partly due to operating phase effect (*OPE*). The *FDE* and the *OPE* that contribute to the total change in CO_2 emissions can be derived from equation (5) by using polar decompositions or the average of all possible first order decompositions [12]-[14] as follows:

$$TC = \boldsymbol{E}'\,\Delta\boldsymbol{C}'\,\boldsymbol{L}_T\,\boldsymbol{Y}_T + \boldsymbol{E}'\,\boldsymbol{C}_0'\,\Delta\boldsymbol{L}\,\boldsymbol{Y}_T + \boldsymbol{E}'\,\boldsymbol{C}_0'\,\boldsymbol{L}_0\,\Delta\boldsymbol{Y} \quad (6)$$

The first and the second components of the right hand side of Equation (6) is the change in total economy-wide CO_2 emission due to carbon tax as compared to that without the tax due to fuel mix effect (*FME*) and structural effect (*STE*) respectively while the third component is due to final demand effect (*FDE*). The fuel mix effect and the structural effect are also called as operating phase effect (*OPE*) ([6]). After an algebraic manipulation, the *FDE* component in Equation (6) can also be written as:

$$FDE = \boldsymbol{E}'\boldsymbol{C}_0'\Delta\boldsymbol{Y} + \boldsymbol{E}'\boldsymbol{C}_0'[\boldsymbol{L}_0\text{-}\boldsymbol{I}]\,\Delta\boldsymbol{Y} \quad (7)$$

where, the first and the second components of the right hand side of Equation (7) represent direct- and indirect-effects respectively associated with the change in final demand due to the carbon tax in the power sector. Changes in the final demand ($\Delta\boldsymbol{Y}$) comprise of two major categories, i.e., changes in (i) demand for goods and services for construction of power plant ($\Delta\boldsymbol{Y}_{CPP}$) and (ii) electricity final demand ($\Delta\boldsymbol{Y}_{EFD}$) or in other words $\Delta\boldsymbol{Y} = \Delta\boldsymbol{Y}_{CPP} + \Delta\boldsymbol{Y}_{EFD}$. The total change in CO_2 emission due to final demand effect can be decomposed into two parts, i.e., the change associated with the construction of power plants (*FDE_CPP*) and that related to electricity final demand (*FDE_EFD*); these components can be obtained by substituting $\Delta\boldsymbol{Y}$ in Equation (7) with ($\Delta\boldsymbol{Y}_{CPP} + \Delta\boldsymbol{Y}_{EFD}$). Hence, there are four components under the *FDE* that affect the total change in emissions, i.e. (i) the direct effect due to the change of final demand for construction (*FDE_CPP_D*), (ii) the indirect effect due to the change of final demand for construction (*FDE_CPP_ID*), (iii) the direct effect due to the change of demand for electricity (*FDE_EFD_D*), and (iv) the indirect effect due to the change of demand for electricity (*FDE_EFD_ID*). Hence, the total change in CO_2 emission in the whole economy due to the carbon tax in the power sector could be disaggregated into six types of effects and each component could be calculated by using the following equations (Eqs.8–13):

$$(a)\ FME = \boldsymbol{E}'\,\Delta\boldsymbol{C}(t)'\,\boldsymbol{L}_T(t)\,\boldsymbol{Y}_T(t) \quad (8)$$

$$(b)\ STE = \boldsymbol{E}'\,\boldsymbol{C}_0(t)'\,\Delta\boldsymbol{L}(t)\,\boldsymbol{Y}_T(t) \quad (9)$$

$$(c)\ FDE\_CPP\_D = \boldsymbol{E}'\,\boldsymbol{C}_0(t)'\,\Delta\boldsymbol{Y}(t)_{CPP} \quad (10)$$

$$(d)\ FDE\_CPP\_ID = \boldsymbol{E}'\,\boldsymbol{C}_0(t)'\,[\boldsymbol{L}_0(t) - \boldsymbol{I}]\,\Delta\boldsymbol{Y}(t)_{CPP} \quad (11)$$

$$(e)\ FDE\_EFD\_D = \boldsymbol{E}'\,\boldsymbol{C}_0(t)'\,\Delta\boldsymbol{Y}(t)_{EFD} \quad (12)$$

$$(f)\ FDE\_EFD\_ID = \boldsymbol{E}'\,\boldsymbol{C}_0(t)'\,[\boldsymbol{L}_0(t) - \boldsymbol{I}]\,\Delta\boldsymbol{Y}(t)_{EFD} \quad (13)$$

The generation expansion planning (GEP) model as shown in [7] is used to obtain the least cost fuel mix and power development plan under different tax rates corresponding to given demand forecasts. For a given power demand, a carbon tax would result in an increase in electricity price and hence a reduction in electricity demand. With the lower level electricity demand, the GEP model is rerun to obtain the new least cost power development plan. After the new least cost plan is obtained, the corresponding price of electricity is estimated and the value of electricity demand is revised accordingly. The GEP model is rerun to revise the power generation expansion plan. This procedure is repeated until the equilibrium combination of electricity price and output is obtained. CO_2 emissions are calculated using the information on optimal fuel requirements and relevant emission factors.

In this study, the outputs of generation expansion planning are used to update the existing I-O table. For example, the level of fuel used by each type of power plants is obtained from the generation expansion planning 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 carbon 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 so derived 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.

III. Input Data and Assumptions

Six different carbon tax rates are considered in this study, i.e., US$5, US$10, US$25, US$50, US$100 and US$200/ton of carbon (hereafter "ton of carbon" is denoted as "tC"). These are comparable to the tax rates used in other studies. For example, carbon tax of US$80-US$320/tC were introduced in Japan to reduce CO_2 emission ([15]). Carbon taxes of US$37-US$187/tC were introduced in Norway ([16]) and NZ$25/t$CO_2$ (or about US$119/tC) in the case of New Zealand ([17]). Reference [18] considered the carbon tax rate of €10/tCO_2 (or about US$48/tC) to examine the effects of the carbon tax on European (i.e., The Netherlands, Belgium/Luxemburg, France, Germany, Spain, Portugal, Switzerland and Italy) generation mix.

The data on existing power plants, peak power demand and electricity demand profiles are based on [19]. The data on candidate power plants are based on PTP [19] and [20].

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 (see [21]) 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., [10] and [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-availability 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 carbon 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 [6] 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.

IV. Results and discussions

Before the economy-wide change in CO_2 emission due to the carbon tax is analyzed, we provide a brief discussion about how the carbon tax affects the electricity generation and the total capacity additions as well as the price of electricity.

A carbon tax would decrease the electricity demand and hence electricity generation and the total power generation capacity requirements. Furthermore, the generation mix would tend to shift towards less carbon intensive fuels and technologies at higher carbon taxes. This study finds that coal-based power generation would decrease drastically at the carbon tax of US$100/tC and would disappear at the carbon tax of US$200/tC. At this rate (US$200/tC), oil-based generation is would also be eliminated. The share of gas and geothermal based generation increases from 48.7% and 3.1% respectively in the absence of carbon tax to 80.1% and 5.9% respectively with carbon tax of US$200/tC. This is due to lack of less carbon intensive candidate thermal plants e.g., candidate plants based on gas and geothermal. Like total electricity generation, total installed capacity also decreases with carbon tax rate. No additional coal based power plants is selected at carbon tax rates above US$5/tC. The total installed capacity of oil based power plants remains unchanged because additional oil based power plant is not allowed by the government policy. As a result, the capacity mix is found to shift heavily towards the gas based power plants. The result of this study also shows that the electricity price would increase from US¢7.98/kWh in the absence of carbon tax to US¢14.87/kWh at carbon tax of US$200/tC. However, if the tax revenue from carbon tax is not considered in calculating the electricity price, the price of electricity would be US¢8.7/kWh at the carbon tax of US$200/tC. The total economy-wide changes in CO_2 emissions due to the carbon tax in the power sector during the planning horizon (2011-2030) in Indonesia (as compared to that without the carbon tax) are presented in Table I.

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

Type of effects	Carbon tax rate (US$/tC)					
	5	10	25	50	100	200
FME	**-155**	**-246**	**-444**	**-1,120**	**-2,178**	**-3,490**
STE	**-47**	**-63**	**-108**	**-195**	**-350**	**-560**
FDE	**-71**	**-108**	**-193**	**-325**	**-712**	**-1,546**
FDE_CPP	-14	-29	-44	-65	-125	-241
FDE_EFD	-57	-79	-149	-260	-587	-1305
TC	**-273**	**-417**	**-745**	**-1,640**	**-3,240**	**-5,596**

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

The table also presents the contributions of the factors that affect the CO_2 emissions as calculated using the decomposition methodology described in the previous section. Table 1 shows that the total CO_2 mitigation in the whole economy during the planning horizon would increase from 273 to 5,596 million tons if the carbon tax is increased from US$5/tC to US$200/tC. In other words, the CO_2 mitigation at the carbon tax of US$200/tC would be 20.5 times higher than that at the carbon tax of US$5/tC. As shown in Table 1, the three major components, the *FME*, *STE* and *FDE* would reduce the CO_2 emissions under all carbon tax rates. Of the total reduction in CO_2 emissions, the percentage share of the *FME* is the highest (in the range of 56 to 69% under the carbon tax rates considered) and is followed by the *FDE* (19 to 28%) and the *STE* (10 to 18%).

How big is the role of each component to the total change in CO_2 emissions? The negative figure (which means a lower emission with carbon tax than that without the tax) of the fuel mix effect (*FME*) under the selected carbon 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 carbon 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 carbon tax as compared to that without carbon tax. The reduction in CO_2 emissions is mainly due to the reduction in the use of coal resulting from the reduction of electricity generation from coal based power plants. With the introduction of the carbon tax, the share of electricity generation from coal based power plants would decrease, while the shares of electricity generation from renewable energy technology (i.e., geothermal based power plant) and less carbon intensive thermal power plants (i.e., gas based efficient power plants) would increase. The reduction in total electricity generation is due to the decrease in power demand associated with the increase in electricity price due to carbon tax. The negative figures of the *STE* under the selected carbon tax rates indicate that the change in the structure of the economy in Indonesia due to the introduction of carbon 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 carbon 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 carbon 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 carbon tax. Between the two components of the *FDE*, the *FDE_EFD* component is found to be dominant (with its share ranging from 73 to 85%).

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 carbon tax. Table 2 presents the shares of the direct- and indirect-effects for each component of the *FDE* at the selected carbon tax rates. 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 carbon 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 84% share in *FDE_EFD*, with the rest being contributed by the indirect effect (*FDE_EFD_ID*).

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

Components of final demand effect		Carbon tax rate (US$/tC)					
		5	10	25	50	100	200
Construction of power plant	*FDE_CPP_D*	42.1	47.8	45.9	44.3	43.1	47.2
	FDE_CPP_ID	57.9	52.2	54.1	55.7	56.9	52.8
Electricity final demand	*FDE_EFD_D*	84.3	86.9	87.9	84.7	85.1	89.1
	FDE_EFD_ID	15.7	13.1	12.1	15.3	14.9	11.9

V. CONCLUSION AND FIAL REMARKS

This paper has developed a structural decomposition analysis based on the input-output framework to assess the roles of factors behind the change in economy-wide CO_2 emission due to the carbon tax in the power sector. The framework allows one to estimate the contributions of three major components that affect the total change in CO_2 emissions, i.e., change in fuel mix, structural change, and change in final demand. The final demand effect itself consists of two components, i.e., effects related to changes in construction of power plant and electricity final demand. Each individual component under final demand effect is further decomposed into the direct- and indirect-effects.

The I-O decomposition framework is applied to estimate the contributions of different factors affecting economy-wide CO_2 emission in Indonesia due to carbon tax in the power sector during 2011-2030. The results show that if the carbon tax rate is increased from US$5/tC to US$200/tC, the economy-wide CO_2 emission reduction would increase from 273 to 5,596 million tons. The fuel mix-, structural- and final demand-effects would all contribute to reduce CO_2 emissions under all carbon tax rates considered. The fuel mix effect is found to play the biggest role in reducing the CO_2 emissions under the carbon tax rates considered in this study. 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 carbon tax rates considered. 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 here that this study is based on partial equilibrium analysis. The results could vary when the analysis is based on a general equilibrium framework. Furthermore, the present analysis is based on limited fuel options. In particular, it does not consider nuclear and renewable energy options except hydro and geothermal power. Further research on these issues would be interesting.

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