Effect of Carbon Tax on Energy Security in the Long Term Energy Sector Development of Indonesia

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***Abstract*—This paper develops an AIM/Enduse model for Indonesia to analyze the implications of considering carbon tax on energy security in energy sector development of Indonesia during 2005-2035. This paper also analyzes the environmental implications of introducing carbon tax and the diversification of energy use in the power sector due to carbon tax. The result show that the energy security in Indonesia would increase with the introduction of carbon tax. The energy security index (i.e., Shannon-Weiner Index) at carbon tax rate of US$200/tC in year 2035 would be 1.473 which is higher than those at carbon tax rates lower than US$200/tC and the base case. In the power sector, the diversification of energy use in the power sector would fluctuate at selected carbon tax rates.**

Keywords-energy security, Shannon-Weiner Index, carbon tax

I. Introduction

Although there is no obligation for developing countries to reduce their emissions, but there are several studies on GHG emission reduction have been done for developing countries. Indonesia – a developing country - had declared to reduce its GHG emission during the COP15 last year. From many literatures, there are several possible policies to meet their emissions commitments, for example carbon tax and command and control regulation. Many viewed that carbon tax is more effective than command control regulation in reducing CO_2 emissions. During 1992-2007, the CO_2 emissions from the energy sector in Indonesia increased from 157.4 million tons in 1992 to 377.2 million tons in year 2007 or with an average annual growth rate of 6.0% [1].

There is a substantial body of literature on considering carbon tax in energy sector development for GHG mitigation (see e.g., [2-3]); however, their focus was on industrialized countries only. [4] analyzed the implications of considering carbon tax, but they did not discuss the effect of carbon tax on energy security.

Some questions might be raised if the carbon tax is introduced Indonesia, i.e., (i) what would be the effect on the energy security, (ii) what would be the effect on the CO_2 intensity, and (iii) what would be the effect on CO_2, SO_2 and NO_x emissions.

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This study analyses the implications of considering carbon tax in Indonesia during 2005 – 2035. This paper is organized as follows. The brief explanation of the model used in this study is presented in the next section, followed by the overview of the energy use in Indonesia, and data and data sources and the scenarios description used in the study. The implications of considering carbon tax are examined in the subsequent sections. Finally, major findings are presented.

II. Model Framework

The AIM/Enduse model of Indonesia is broadly classified into two main components: energy supply and conversion, and service demand. Energy supply and conversion represents energy extraction, imports and conversion of primary energy to secondary energy. In this component, coal mining, natural gas extraction, refining of crude oil and power generation is considered. For power generation, altogether twenty-two existing and new technologies option are considered. Out of the new technology options considered, three technologies are coal and natural gas based carbon capture and storage (CCS) technologies. A study by BPS Statistics Indonesia is used as the basis for classification of sectors and sub-sectors of the service demand. The Indonesian economy is divided into five main sectors; namely, agriculture, commercial, industry, residential and transport. The industry sector has been subdivided into cement, steel, sugar, paper, chemicals, food, equipment, textile and others. The transport sector is sub divided as passenger and freight. Altogether fifty six end-use service demand types are considered in each of these sub-sectors. The activity parameters that drive these service demands, exogenous inputs to the model, are used to estimate the future service demand. These activity parameters include sectoral value added, number of households, appliance ownership per household, per capita GDP, average distance traveled by each vehicle type and vehicle occupancy factor. A number of 215 existing and candidate technology options are considered in meeting these end-use service demands. Fig. 1 shows the general structure of the AIM/Enduse modeling framework for Indonesia [5].

The linear programming framework of the model comprises an objective function to minimize total energy system cost year by year subjected to a number of constraints including those on service demand, energy resource availability, existing device stock, maximum allowable quantity of devices and emissions. The total cost comprises of annualized fixed cost of recruited devices during that year, variable operating cost (operation and maintenance cost of devices, and fuel cost), cost of installing removal devices (flue gas desulfurizers for pulverized coal fired power plants etc.) and cost of emissions taxes (carbon tax, energy tax etc.). The formulation also provides functions to consider the existing device quantities in the starting year of the planning horizon and to calculate the retirement of the devices at the end of its life time.

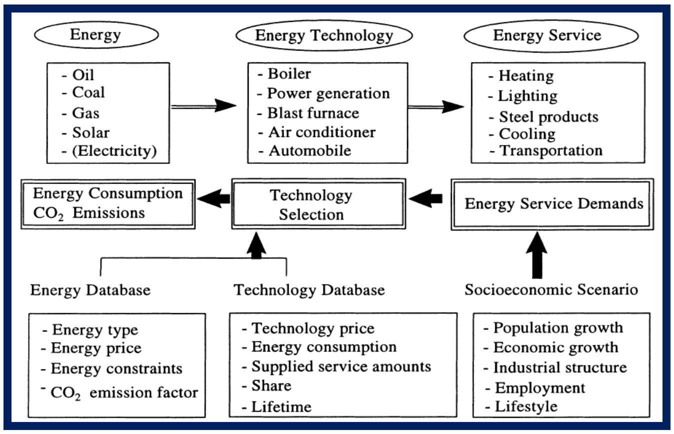

Figure 1. Structure of the AIM/Enduse model (Sources [5])

III. OVERVIEW OF ENERGY USE IN INDONESIA

The total primary energy supply (TPES) in Indonesia increased from 12.9 Mtoe in 1992 to 190.6 Mtoe in 2007 with an average annual growth rate of 3.6% [1]. The TPES in Indonesia varies from fossil energy to renewable energy. The role of fossil energy (such as coal, oil and gas) is very significant at the present time in Indonesia. Of the energy use in TPES in year 2007, the share of oil is the highest, i.e. about 36.6%, and then followed by coal and gas as much 34.4% and 25.9% respectively [1]. The fossil energy is mostly used in power-, industrial- and transport-sectors. In addition to fossil energy, renewable energy is also used in various sectors in Indonesia. Unlike the fossil energy, the renewable energy is not widely used Indonesia. The renewable energy is mostly used in the power sector, such as geothermal and hydro. The potential of fossil fuel in Indonesia is shown in Table I.

TABLE I. POTENTIAL OF FOSSIL FUEL IN INDONESIA

Energy	Potential	
Coal	64,829,260,000 ton	38,857,880 ktoe
Oil	9.75 billion barrel	1,443,779 ktoe
Gas	168.15 tera cubic feet (TCF)	4,471,974 ktoe

Source: [6]

In addition to fossil energy, renewable energy is also used in various sectors in Indonesia. Unlike the fossil energy, the renewable energy is not widely used Indonesia. The renewable energy is mostly used in the power sector, such as geothermal and hydro. The potential of renewable energy in Indonesia is shown in Table II.

TABLE II. POTENTIAL OF RENEWABLE ENERGY IN INDONESIA

Energy	Potential		Used
	(MW)	(ktoe)	(MW)
Geothermal	19,658	15,639	309.5
Hydro	75,670	74,231	2,500
Micro hydro	459	450	20,9
Biomass	49,807,000	41,996	178
Wind	9,287	9,109	0.4
Solar	1,203,750,000	$1{,}181 \times 10^6$	0.9

Source: [6]

The diversification of energy use in TPES, which is shown by Shannon-Weiner index (SWI), shows an increasing figure during 1992-2007. In year 2007, the SWI of Indonesia was 1.19, which is higher than the SWIs at the previous years. This shows that the energy security had increased during 1992-2007 (see Fig. 2).

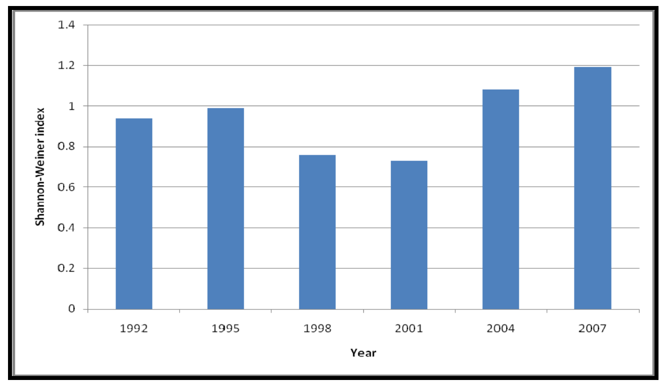

Figure 2. The Shannon-WEeiner Index (SWI) of energy use of TPES in Indonesia during 1992-2007

IV. DATA AND DATA SOURCES

The input data for the AIM/Enduse model are taken from various sources and also by using some forecasting methodology.

- Agricultural data for tilling, irrigation and milling is taken from [7]. The service demand for the future years (ASD_t) are estimated by applying linear regression analysis as shown in the following equation:

$$ASD_t = a + b\,GDP_t + c\,POP_t \qquad (1)$$

  where: ASD_t = agricultural service demand in year t; GDP_t = GDP in year t; POP_t = population in year t; a, b, c = parameters. The parameters a, b and c are obtained from the similar regression model based on the historical data of ASD_t, GDP_t and POP_t.
- Commercial data for air conditioning, refrigerator, lighting, air conditioning, elevator, thermal use was taken from some surveys. The forecast for the future is estimated by using the floor space area.
- Residential data for lighting, TV, refrigerator, fan, cooking, iron, air conditioning was taken from some surveys. The

forecast for the future was done by using the forecast of number of population in the future.

- Transport data was taken from [8]. From this source, we can obtain passenger-km in year 2005. The forecast in the future was done by applying linear regression analysis as shown in the following equation:

$$PASS_t = a + b\ GDP_t + c\ POP_t \quad (2)$$

where: $PASS_t$ = passenger-km in year t; GDP_t = GDP in year t; POP_t = population in year t; a, b, c = parameters. The parameters a, b and c are obtained from the similar regression model based on the historical data of $PASS_t$, GDP_t and POP_t.

- Industrial data was taken mostly from [9]. From here, production data for cement, iron and steel, etc could be obtained. The future service demand was done by considering value added in each industry.

$$SD_{i,t} = (SD_{i,o}/VA_{i,o})\ VA_{i,t} \quad (3)$$

where: $SD_{i,t}$ = service demand of sector i in year t; $SD_{i,o}$ = service demand of sector i in year 2005; $VA_{i,t}$ = value added of sector i in year t; $VA_{i,o}$ = value added of sector i in year 2005.

V. Scenario Description

There are seven scenarios are considered in this study, they are a base case scenario and six carbon tax scenarios. The base case scenario is a business as usual scenario, that is a scenario which considers the current social-economic data and there is no policy intervention from the government to reduce CO_2 emissions. The six carbon tax scenarios are scenarios with six different carbon tax rates, i.e., US$5, US$10, US$50, US$100, US$150 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 taxes of US$80-US$320/tC were introduced in Japan to reduce CO_2 emission [2]. Carbon taxes of US$37-US$187/tC were introduced in Norway [3] and NZ$25/t$CO_2$ (or about US$119/tC) in the case of New Zealand [10]. [11] considered the carbon tax rate of €10/tCO_2 (or about US$48/tC) to examine the effects of the carbon tax on European (i.e., The Netherlands, Belgium/ Luxemburg, France, Germany, Spain, Portugal, Switzerland and Italy) generation mix. Sometimes the carbon tax is also expressed in US$/t$CO_2$. The conversion of carbon tax in US$/tC to US$/tCO_2 can be seen in Table III.

TABLE III. Carbon Tax In Per Ton Of C And Per Ton Of CO_2

Carbon Tax	
US$/tC	US$/t$CO_2$
5	1.36
10	2.73
50	13.64
100	27.27
150	40.91
200	54.55

Since different fuels have different carbon content, the values of carbon tax of the fuels in per ton of oil equivalent basis would vary from fuel to fuel. These are shown in Table IV.

TABLE IV. Carbon Tax In Per Ton Of Oil Equivalent Of Fuels, US$/TOE

Fuel	Carbon Tax Rate (US$/tC)					
Type	5	10	50	100	150	200
Coal	5.3	10.6	53	106	159	212
Oil	4.3	8.6	43	86	129	172
Gas	3.2	6.4	32	64	96	128

In the base case, the GDP growth is assumed to be 5% per year during the planning horizon (2005-2035). In this study we also include nuclear power plant as a candidate option. This is following the government plan to introduce nuclear power plants into operation by the year 2016. All advanced technologies used to produce the service demand are also considered in the base case.

VI. Results and Discussions

Introducing carbon tax in Indonesia would affect the total primary energy supply (TPES). The TPES would decrease with the introduction of carbon tax. In year 2035, the TPES at carbon tax rate of US$200/tC would be 5% lower than the TPES at the base case. How would the energy use in the TPES diversify with the introduction of carbon tax? The diversification of the energy is measured with the Shannon-Weiner Index (SWI). SWI also shows how secure is the energy of a country. Fig. 3 shows the SWI in year 2010 and 2035 at selected carbon tax rates. As shown in Figure 3, the SWIs in year 2010 were constant at all tax rates. This is because the carbon tax is applied starting from year 2013. In year 2035, the SWIs would increase with the introduction of carbon tax. The SWI in the base case in year 2035 would be 1.395. If carbon tax rates of 5, 10, 50, 100, 150, and 200 US$/tC are introduced, the SWIs would be 1.395, 1.425, 1.425, 1.444, 1.451, 1.470, 1.473 respectively. This shows that introducing carbon tax in Indonesia would increase the diversity of the energy use, or the energy security in Indonesia would increase with the introduction of carbon tax.

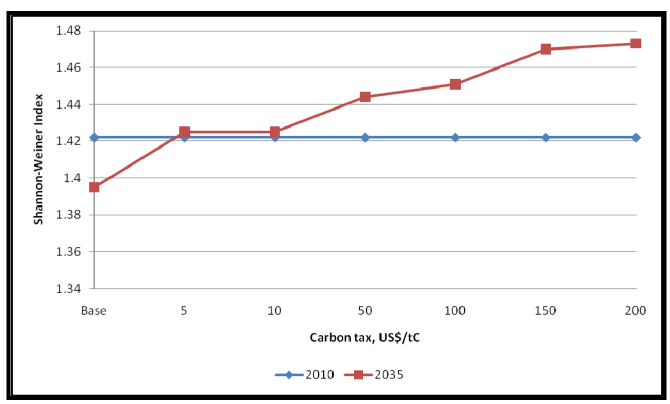

Figure 3. Shannon-Weiner index of selected carbon tax rates in year 2010 and 2035

The changes in CO_2 emissions and TPES would affect the CO_2 intensity per TPES. In year 2035 at the base case, the CO_2 intensity per TPES would be 47.66 kg/GJ. If carbon tax rates of 5, 10, 50, 100, 150, and 200 are introduced, the CO_2 intensity per TPS in year 2035 would be 44.53, 44.53, 44.15, 42.84, 42.24, and 42.22 kg /GJ.

Introducing carbon tax would also affect the CO_2 emissions. As shown in Fig. 4, the CO_2 emission reduction at carbon tax rate of US$10/tC would not change much compared to the CO_2 emission reduction at carbon tax rate of US$5/tC, i.e. in the range of 3.8 to 3.9%. However, if carbon tax rates of US$50/tC and higher are introduced, the CO_2 emission would increase significantly. It is also interesting to examine from the results that introducing carbon tax rates higher than US$150/tC in Indonesia would not affect the CO_2 emission reduction significantly, or introducing carbon tax rate higher than US$150/tC would only increase the total cost but would not affect the CO_2 emission reduction significantly.

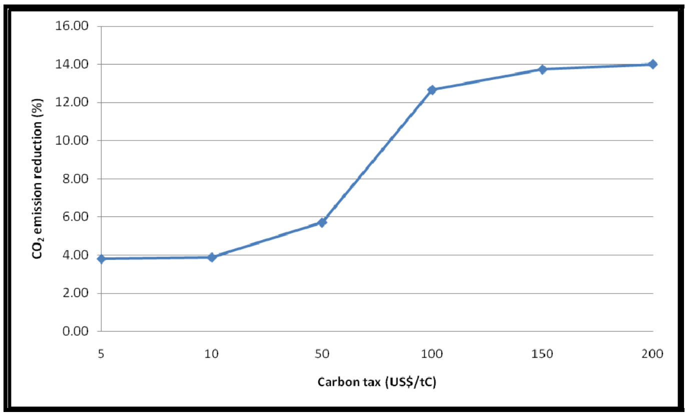

Figure 4. CO_2 emission reduction during 2005-2035 at selected carbon tax rates

Introducing carbon tax would not only the change in CO_2 emission, but also the SO_2 and NO_x emissions as well. Table 5 shows the reduction of SO_2 and NO_x emissions due to the introduction of carbon tax. During the planning horizon (2010-2035), the SO_2 emission reduction at all carbon tax rates would be in the range of 3.97% to 15.58%. Similar to SO_2, the NO_x emission would also decrease with the introduction of carbon tax. As shown in Table V, the NO_x emission reduction during 2010-2035 at the lowest carbon tax rate is 2.77% in increase to 10.75% at the highest carbon tax rate.

TABLE V. SO_2 AND NO_x EMISSION REDUSTION DURING 2005-2035 AT SELECTED CARBON TAX RATES

Carbon Tax (US$/tC)	SO_2	NO_x
5	3.97%	2.77%
10	3.97%	2.80%
50	5.03%	4.01%
100	14.34%	9.51%
150	15.53%	10.30%
200	15.58%	10.75%

In the power sector, it is also interesting to examine how the diversification of the fuel use would change with different carbon tax rates and also how it would be different between year 2020 and year 2035. To answer this, Shannon-Weiner index (SWI) of the energy use in the power sector at selected carbon tax rates in year 2020 and 2035 are calculated. The results are depicted in Fig. 5. Fig. 5 shows the SWI would fluctuate if selected carbon tax rates are introduced. The figure also shows that the SWIs in year 2020 is higher that the SWIs in year 2035.

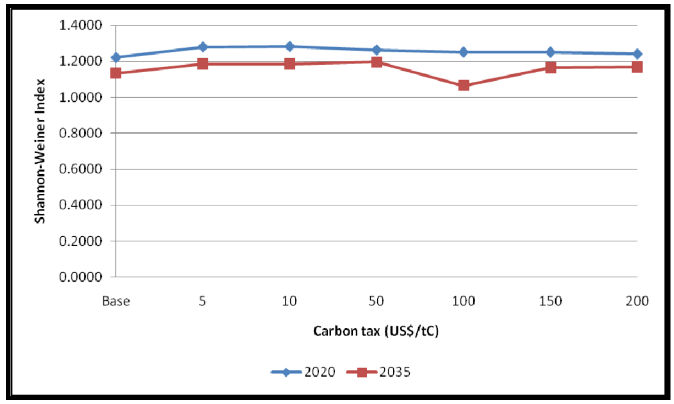

Figure 5. Shannon-Weiner index of energy use in the power sector at years 2020 and 2035 at selected carbon tax rates

VII. CONCLUSIONS

This study has developed an AIM/Enduse model to analyze the effects of considering carbon tax on energy security in the long term energy sector development of Indonesia during 2005-2035. The results show that the total primary energy supply (TPES) would decrease with the introduction of carbon tax. The TPES at carbon tax rate of US$200/tC in year 2035 would be 325 Mtoe, which is lower than that at the base case, i.e., 342 Mtoe. The CO_2 intensity per TPES would also decrease with the introduction of carbon tax. The CO_2 intensity in year 2035 at 200US$/tC carbon tax would be 42.22 kg/GJ, which is lower than that at the base case, i.e., 47.66 kg/GJ. The energy security would increase with the introduction of carbon tax. The Shannon-Weiner index would increase from 1.395 at the base case to 1.473 at carbon tax of US$200/tC in year 2035. Introducing carbon tax would affect the CO_2 emissions. In Indonesia, carbon tax rates higher than US$150/tC would not reduce the CO_2 emissions significantly. The diversification of energy use in the power sector would fluctuate with the introduction of carbon tax.

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REFERENCES

[1] International Energy Agency (IEA), Projected Costs of Generating Electricity, IEA, Paris, France, 2005.

[2] T. Nakata, and A. Lamont, “Analysis the impacts of carbon taxes on energy systems in Japan,” Energy Policy, vol. 29, pp. 159-166, 2001.

[3] A. Bruvoll, , B.M. Larsen, “Greenhouse gas emissions in Norway: do carbon taxes work?” Energy Policy, vol. 32, pp. 493–505, 2004.

[4] C. O. P. Marpaung, A. Soebagio and R. M. Shrestha, Sources of change in CO_2 emission of considering carbon tax in the Indonesian power sector: an input-output approach, The 3rd IASTED International Conference on Power and Energy Systems EuroPES 2003, 3 – 5 September 2003, Marbella, Spain.

[5] M. Kainuma, Y. Matsuoka, T. Morita (Eds.), ”Climate policy assessment: Asia-pacific integrated modeling,” Tokyo: Springer-Verlag, 2003.

[6] Departemen Energi dan Sumber Daya Mineral (DESDM), “Buku Tahunan Energi dan Sumber Daya Mineral 2001: Restrukturisasi Sektor,” Jakarta: 2002.

[7] BPS Statistics Indonesia (BPS), “Agricultural Survey: Agricultural Machinery by Province and District in Indonesia,” Jakarta: BPS, 2001.

[8] BPS Statistics Indonesia (BPS), “*Transportation and Communication Statistics 2005*,” Jakarta: BPS, 2007.

[9] BPS Statistics Indonesia, (BPS), “Large and Medium Manufacturing Statistics Indonesia 2005 Vol. 1, 2, and 3,” Jakarta: BPS, 2007.

[10] F. Scrimgeour, L. Oxley, K. Fatai, “Reducing carbon emissions? The relative effectiveness of different types of environmental tax: the case of New Zealand,” Environmental Modelling & Software, vol. 20, 1439-1448, 2005.

[11] K. R. Voorspools, W. D. D’haeseleer, “Modelling of electricity generation of large interconnected power systems: How can a CO_2 tax influence the European generation mix,” Energy Conversion and Management, vol. 47, pp. 1338-1358. 2006.