MATHEMATICAL MODELING ANALYSIS FOR INVESTIGATING THE FUTURE EXPANSION OF THE ELECTRIC POWER SYSTEM IN INDONESIA[1]

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ABSTRAK

Tulisan berikut berisikan ringkasan disertasi doktoral yang berjudul *Mathematical Modeling Analyses for Investigating the Future Expansion of the Electric Power System in Indonesia*. Studi ini memiliki lima tujuan yaitu (i) menginvestigasi sektor ketenagalistrikan sebelum dan setelah program percepatan 10.000 MW tahap I dan II; (ii) menganalisis hubungan antara pertumbuhan ekonomi dan konsumsi listrik; (iii) menyusun model ekspansi tenaga listrik dalam mencapai tujuan minimisasi biaya pembangkit dan minimisasi emisi CO_2; (iv) mengaplikasikan model optimasi sistem pembangkit untuk sistem Jawa-Bali; (v) mengusulkan kebijakan guna mencapai sistem pembangkit listrik yang rendah emisi CO_2. Studi ini mengkombinasikan dua pendekatan, yaitu ekonometrik dan program linier untuk menjawab kelima tujuan penelitian tersebut.

Kata Kunci*: Listrik, Pertumbuhan Ekonomi, Emisi CO_2, Pembangkit Tenaga Listrik.*

1 This article is the summary of the author's Ph.D. dissertation.

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ABSTRACT

The following article contains a summary of a doctoral dissertation entitled "Mathematical Modeling Analyses for Investigating the Future Expansion of the Electric Power System in Indonesia". This study has five objectives: (i) investigate the power sector before and after the accelerated program of 10,000 MW phase I and II; (ii) analyze the relationship between economic growth and electricity consumption; (iii) develop a model of expansion in the power generation cost minimization goals and minimization of CO_2 emissions; (iv) conduct optimization model plant system for the Java-Bali system; (v) propose policies to achieve a low power system CO_2 emissions. This study combines two approaches, namely the econometric and linear programming to answer the five research objectives.

Keywords*: Electricity, Economic Growth, CO_2 Emmision, Power Plant*

RESEARCH BACKGROUND

An available electric supply is one of the basic elements of national economic competitiveness that is important for sustaining long-term economic growth. As shown in **Table 1**, electricity consumption per capita in Indonesia is still below the average level of the lower middle income countries. If we compare the electricity consumption among the ASEAN countries, Indonesia is slightly above the Philippines. Electricity power consumption per capita in China is four times larger than in Indonesia, but electricity consumption in Indonesia is still slightly higher than in India. The Indonesian government has a target of increasing electricity consumption per capita to about 2,500 kWh in 2025 and 7,000 kWh in 2050 (Soerawidjaja 2011). Thus, the government needs to made a great effort in promoting new investment in the power supply.

Due to power shortages, the low electrification ratio, and the electricity subsidy policy, enhancing electricity production with the least cost is more important than mitigating CO_2 emissions. However, Indonesia has demonstrated a strong commitment to reducing CO_2 emissions. Following the Conference of Parties (COP) 13 in Bali, COP 15 in Copenhagen, COP 16 in Cancun, the Indonesian government published the National Action Plan for Greenhouse Gas Emissions Reduction 2011. Carbon reduction from the power sector will be obtained by promoting renewable energy and implementing demand-side efficiency, especially from the household sector. This study argues that Indonesia needs broader, more gradual and multiple approaches to ease the transition toward the low-carbon power system. This research identifies five areas that decisions makers need to focus on: (i) demand-side management; (ii) technology switching from steam-coal subcritical to supercritical and ultrasupercritical[3]; (iii) fuel switching from oil or coal to natural gas; (iv) price incentives for less carbon intensive power plants; and (v) renewable energy targeting.

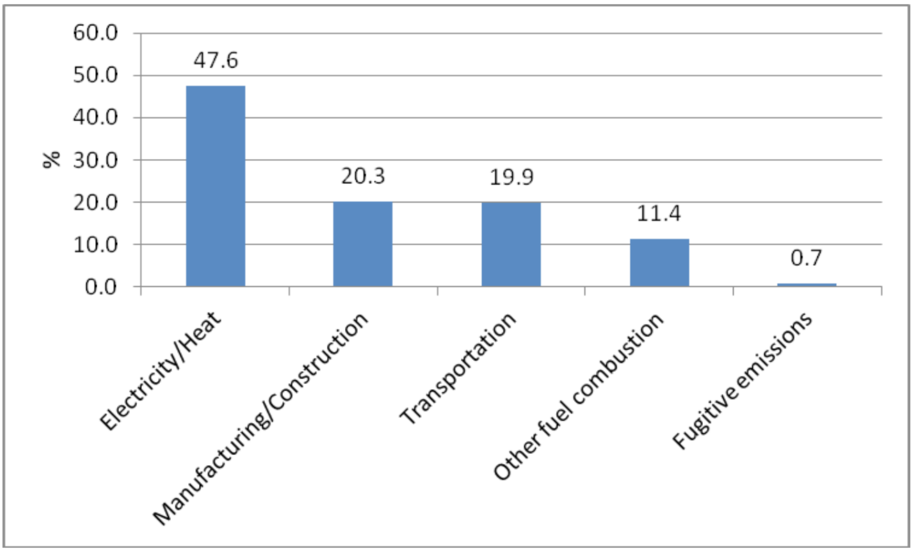
Table 1. Electricity Production and Consumption in 2009

Country	Electricity production (GWh)	Electric power consumption (GWh)	Electric power consumption (kWh per capita)
China	3,695,928	3,503,397	2,631
Lower middle income	2,007,887	1,575,710	644
India	899,389	689,537	571
Indonesia	155,470	140,111	590
Thailand	148,389	140,492	2,045
Malaysia	105,081	100,996	3,614
Vietnam	83,191	78,934	918
Philippines	61,921	54,422	593

Source: World Development Indicators

However, electricity and heat have the highest contribution to CO_2 emissions from the energy sector and the share will increase in the future if the systems planned depend on carbon intensive sources (see **Figure 1**). Thus, the power system will be trapped in a carbon 'lock-in' situation if there is no well-designed green power system in the future. This research aims to address 'the green path' power system with regard to two main issues: securing the power supply and achieving low CO_2 emissions in Indonesia.

[3] There are three types of steam coal technology: subcritical, supercritical, and ultrasupercritical. They are different in terms of investment cost and efficiency. Ultrasupercritical has a more advanced technology than the others.



Source: World Resources Institute

Figure 1 Share of CO_2 emissions as total share of the energy sector in 2007

This study has five objectives: (i) to investigate the electricity sector before and after the fast-track program; (ii) to elucidate the relationship between economic growth and electricity consumption; (iii) to develop a power plant expansion model considering cost minimization strategy and CO_2 emissions minimization strategy; (iv) to apply the optimization model to the Java-Bali system in order to find the optimal electric power expansion plan; (v) to propose policy options dealing with a 'green-path' power system in the future. The main findings are summarized as follows.

We define the research framework into three major elements: (i) analysis on the Indonesian electric power system, (ii) investigating the relationship between economic growth and electricity consumption, and (iii) analysis the power expansion model in the Java – Bali system. In element one, we focus on the supply side analysis and in element two, we focus on the demand side analysis. Both in element one and two, we used the national data analysis. In element three, we combine both the supply and demand side analysis (integrated resource planning/IRP). We develop three strategies using a power expansion model or optimization models. First, we develop a strategy for minimizing generating costs and use the results to investigate the electricity sector-based approach as a proposed post-Kyoto-Protocol framework[4]. Second, we simultaneously investigate minimizing generating costs and minimizing CO_2 emissions. Third, we run our model on our strategy to minimize generating costs with CO_2 emissions constraints applied. As seen from **Figure 2,** we implement four strategies to reduce CO_2 emissions in the system: (i) fuel mixed or fuel switching; (ii) technology switching; and (iii) demand response.

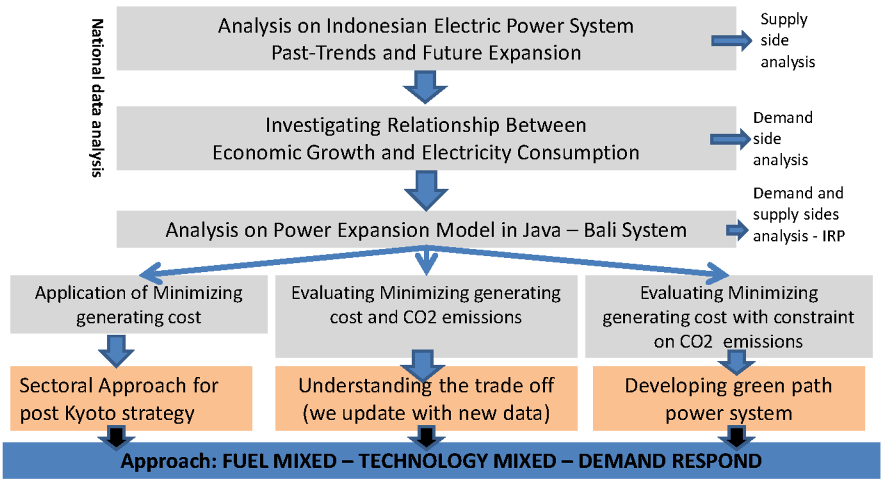


Figure 2. Research framework

FINDINGS

Chapter 2 highlights that in accordance with Electricity Law No 30/2009, the central and local governments have a major role to play in developing infrastructure in the power sector. Now the power planning and regulations can be provided not only by the central government but also by the provincial and district or city governments. Based on the new law, power system planning has moved from a centralized to a more decentralized system. In terms of pricing policy, the central government needs to obtain approval from the Parliament

[4] The sectoral approach is designed for developing countries to meet voluntary 'no-lose' GHG emissions targets in a particular sector. The no- lose target means that there is no penalty for not meeting the target, but there are positive incentives for exceeding it (Schmidt et al., 2008).

(*Dewan Perwakilan Rakyat*/DPR), while the local government needs to obtain approval from the regional parliament (*Dewan Perwakilan Rakyat Daerah*, DPRD). Interaction between the economic and political dimensions may lead to uncertainty in pricing policy. This is what happened once the pricing policy became subject to a long decision process.

Before the fast-track program, we identify four major findings. First, electricity production from coal started to increase in the mid-1980s, and has grown by about 14% per year. Second, the share of PT.PLN to the national installed capacity declined from about 90% in the early 1990s to about 80% in 2005. Third, the Asian financial and economic crisis in 1997/98 reduced the growth of PT.PLN's installed capacity from 10.4% per annum between 1990 and 1997 to about 2.1% between 1998 and 2007. On the other hand, the private sector showed consistent growth from about 7.3% before the Asian economic crisis to about 8.1% after the crisis. Fourth, between 1986 and 2005, the diversification index was stable in terms of installed capacity between non-renewables and renewables.

The fast-track program is very important for supporting the power supply in the medium term. Unfortunately, this program cannot work effectively due to financial, technical and institutional problems. If the fast-track program can be implemented effectively, there will be five consequences of this program. First, the program will increase the national installed capacity between 17,753 MW and 21,175 MW by 2014 (see **Table 2**). Second, the Java-Bali system will obtain the highest share of newly installed capacity, or 70% of new total capacity, will be constructed in Java-Bali. Third, most of the additional geothermal power plant capacity depends on collaboration between PT. PLN and independent power producers (IPP). Fourth, the gap in capacity inequality among regions tended to increase in the first fast-track program from 1.74 in 2006 to about 1.78 in 2009, but it will decrease in the second fast-track program to about 1.69 in 2014. Fifth, the first fast-track program caused the diversity index of power generation to decline from 1.49 in 2006 to about 1.31 in 2009, because this program was mainly based on steam-coal power generation. Although in the second fast-track program the diversification index is expected to increase to about 1.43, it is still below the level before the fast-track program.

Table 2. Changes in Installed Capacity Before and After the Fast-Track Program (in MW)

No	Year/Period	Hydro	Steam	Gas	Combine Gas-Steam	Geothermal	Diesel	Combined Oil-Gas	Total
1	2006 (Before the fast-track)	3,532	12,990	2,727	7,895	800	3,001	12	30,958
2	After the I fast-track (2006-2009)	3,532	20,690-24,112	2,727	7,895	800	3,001	12	38,658-42,080
3	After the II fast-track (2010-2014)	4,736	23,902-27,324	2,827	9,455	4,777	3,001	12	48,711-52,133
4	Change (No. 3 – No. 1)	1,204	10,912-14,334	100	1,560	3,977	0	0	17,753-21,175
5	Installed capacity in 2010*	3,709	12,290	3,460	7,840	1189	4,343	38.8	32,870
6	Change between 2006–2010	117	-700	733	-55	389	1,341	27	1,912

Source: *Calculated from President Decree No 71/2006 and Minister of Energy and Mineral Resources Regulation No 02/2010; * data obtained from MEMR (2011).*

The first and the second fast-track programs are based on a supply-side approach. Policy makers also need to promote demand-side policies, such as electricity conservation and power-saving policy. This research argues that new power investment can not only boost electricity consumption but also improve access to electricity utilities. However, energy conservation can reduce electricity demand and minimize unnecessary new investment in power generation. Will electricity saving policy or power conservation policy affect economic growth? **Chapter 3** investigates the relationship between electricity consumption and economic growth. In the case of Indonesia, there is no general conclusion. There are many econometric techniques available to estimate the relationship, and this study applies three approaches. First, it investigates the long-term relationship by applying bivariate and trivariate analysis, and conducting the Granger causality test. Second, it performs a variance decomposition analysis. Third, before applying the trivariate method, the Bayesian model averaging (BMA) technique is performed to obtain intermittent variables.

The study applies time series data analysis between 1971 and 2007. There are five major findings of this study. First, the bivariate vector autoregressive (VAR) analysis showed that there is no causal relationship (the neutral hypothesis) between economic growth and electricity consumption[5]. Second, applying the Hodrick-Prescott filter also supported the neutral hypothesis. Third, the BMA technique suggests that a percentage of the productive population needs to be included in the model. Fourth, Johansen's technique showed that there is no long-run relationship in the bivariate and trivariate analysis. The trivariate analysis also supported the neutrality hypothesis between electricity consumption and economic growth. Five, the variance decomposition analysis confirmed the neutral hypothesis between economic growth and electricity consumption. Thus, in terms of policy implication, the government still has more space to implement the electricity conservation policy, while promoting new power investment. Although we may argue that an electricity-saving policy will not have a significant impact on economic growth, we need to be careful to implement the energy-saving program, especially in the case when there is a shortfall in power supply. Pasquier (2011) suggests three steps before conducting a conservation program: (i) analyse the

[5] No causal relationship (neutral hypothesis) implies that neither conservative nor expansive policies in relation to electricity consumption have any effect on economic growth

cause and duration[6]; (ii) identify opportunities for energy savings; and (iii) implement a comprehensive and balanced package.

Before applying the mathematical analysis of the power expansion model, this study attempts to narrow down the analysis of the power-generating sector in the Java-Bali system. There are four reasons for selecting the Java-Bali region. First, following the fast-track program, the Java-Bali system obtained the highest share of additional capacity. Second, currently the share of installed capacity in the Java-Bali region is about 71% of the national power capacity, and the share of electricity production relative to national production is about 76.5%. Third, the Java-Bali system is coincident, while outside of Java-Bali is non-coincident[7]. Finally, about 50% of the CO_2 emissions from the energy sector are driven by the power sector. Thus, pursuing a green path for the power system in the Java-Bali system can contribute significantly to reducing CO_2 emissions at the national level.

Both power expansion and electricity conservation can, in theory and empirical studies, be done simultaneously. This study develops an optimization mathematical model to investigate power plant expansion models in Indonesia in the last two chapters. Based on the same structure of the model, the study deploys three types of analysis. First, by pursuing a strategy of minimizing the generating cost, the study investigates the possibility of obtaining carbon credits from the power sector. Second, instead of following the minimizing generating cost, the study also investigates the impact of minimizing CO_2 emissions strategy on the generating system. Third, the study developed the 'green path' power system in Indonesia with the following strategies: (i) obtaining an upper bound of CO_2 emissions, that is CO_2 emissions under minimizing generating cost[8]; (ii) obtaining a lower bound of CO_2 emissions that is CO_2 emissions from minimizing CO_2 emissions; and (iii) by pursuing minimizing generating cost, the study introduces a new constraint into the

6 There are two types of electricity shortfalls (Pasquier 2011): (i) energy constraint when demand exceeds energy input available for electricity generation. This happens because hydro power drops due to draught or fuel/supply disruption; (ii) capacity constraint when the functioning infrastructure is insufficient to meet demand during the peak hours because of plant breakdown, loss of transmission or distribution capacity, or growth in peak demand outstripping capacity.

7 Coincident means that the power system is integrated and we can observe power demand simultaneously.

8 Upper bound is CO_2 emissions when we minimize generating cost and lower bound is CO_2 emissions when we minimize CO2 emissions.

system that is CO_2 emissions, and it simulates a gradual increase of CO_2 emissions from the lower bound to the upper bound.

Chapter 4 found that Indonesia can participate actively in a sectoral agreement (SA) if new additional steam power plant capacity is based on ultrasupercritical technology (**Table 3**). For example, if between 2010 and 2019, new additional steam-coal technology is based on the ultrasupercritical technology, and the government chooses a less stringent baseline such as A = 0.6, the cumulative emissions reduction is about 67 million tons, or about a 27.3% reduction from the business-as-usual scenario (BAU)[9]. This indicates that Indonesia can sell more than 60 million tons of CO_2 to developed countries. Indonesia will obtain more credits by selecting the less stringent parameter in the negotiation process. The sectoral agreement in the power sector is a complement to the Clean Development Mechanism and National Action Plan. This study argues that pursuing several strategies to curb CO_2 emissions will have more benefits in terms of scale effect. This can also reduce the risks if one of the programs cannot work effectively. The study found economic benefits of adopting a more advanced technology, such as supercritical and ultrasupercritical. For instance, if the price of coal and natural gas price increases by 100%, those technologies will cause a lower increase in generating cost compared with a subcritical technology. Similarly, the study also found that the demand side management can effectively reduce CO_2 emissions. We also observe that technology switching from subcritical to ultrasupercritical has a minor impact on generating cost. Thus, Indonesia can propose technology switching and demand side management as strategies to obtain carbon credits.

[9] *A* = weight for the existing capacity, A has value between 0 and 1. The higher "A," the less stringent the baseline. The negotiation over the baseline, once there has been an agreed measure of the CO_2 intensity of existing plants, would focus on the value for parameter A. BAU = emissions intensity without demand-side management under subcritical scenario. We observed that emissions intensity tends to decrease for two reasons. *First*, while oil consumption tends to decrease, natural gas consumption tends to rise. *Second*, the new power generating will be more efficient in energy consumption. For example coal consumption to produce one unit MWh will decrease from about 0.886 tons in 2006 to about 0.838 tons in 2019. However, the emissions intensity is still higher than in China, which was about 0.339 in 2009. The government can effectively reduce emissions intensity by combining demand-side management policy with renewable energy targeting or increasing electricity production from power plants with low emission intensity.

Box 1 Sector-Based Approach in the Power Sector

Schmidt et al. (2008) included Indonesia as one of 10 candidate countries that could participate in a sector-based approach to electricity. According to Schmidt et al. (2008), there is a three-step process to establish 'no-lose' targets:

1. Experts assess and define energy intensity benchmarks in each sector to use as a starting point for discussions
2. Non-Annex I countries pledge a carbon intensity level that they can meet without assistance
3. Annex I countries negotiate with developing countries on specific financial and other support – through a Technology Finance and Assistance Package – to encourage non-Annex I countries to ultimately commit to stricter 'no-lose' emissions intensity levels. Schmidt et al. (2008) argued that a Technology Finance and Assistance Package is needed because this can provide greater support for developing advanced technology than a simple awarding of carbon credits. It is possible that the revenues from the emissions reduction credit (ECR) would be insufficient to fund the initial level of investment and technology transfer.

The analysis from **Chapter 5** confirms that if the Java-Bali system focuses on minimizing CO_2 emissions, the availability of power plants other than steam-coal power plants will become the key. This also implies that a supply of natural gas needs to be secured. The lowest CO_2 emissions can be achieved with a combination of four policies, namely, minimizing CO_2 emissions, adopting supercritical technology, using high-rank coal (5,100 kcal/kg instead of 4,200 kcal/kg)[10], and implementing a 5%–10% demand-side management policy. From a data set for 2011–2020, the study found that the share of electricity production from renewable power plants will increase to about 16% in 2020 while the share of independent power producers (IPP) increases to about 50%.

On average, generating cost under a strategy of minimizing CO_2 emissions will increase by about 85% (for data set 2010–2019) than minimizing generating cost between 2006 and 2019. This is because power plants with low emissions intensity have higher generating costs than power plants with higher emissions intensity. The price difference between the two objectives will also tend to

[10] We define this as fuel switching.

Table 3. Emissions Credit from Sectoral Approaches (Without Demand Side Management)

Year	Emissions intensity ($tonCO_2/MWh$)				Electricity production (GWh) w/o DSM	Emission credit (thousand ton CO_2)			Total Emission (Ton CO_2) BAU
	Baseline – ultrasupercritical								
	A = 0.6	A = 0.4	A = 0.2	A = 0		A = 0.2	A = 0.4	A = 0.6	
2010	0.714	0.718	0.722	0.726	146,577	0.000	0.000	0.000	109,515,762
2011	0.715	0.712	0.710	0.708	161,707	356	711	1,067	126,646,026
2012	0.697	0.697	0.696	0.696	178,720	71	143	214	139,003,422
2013	0.680	0.677	0.673	0.669	197,849	752	1,504	2,255	150,614,102
2014	0.656	0.641	0.627	0.613	217,400	3,121	6,243	9,364	158,944,493
2015	0.654	0.643	0.631	0.620	241,461	2,775	5,549	8,324	176,899,483
2016	0.652	0.642	0.633	0.623	266,939	2,551	5,102	7,653	197,065,209
2017	0.642	0.628	0.613	0.599	288,787	4,192	8,384	12,577	207,204,045
2018	0.597	0.588	0.578	0.568	311,839	3,042	6,083	9,125	209,688,861
2019	0.623	0.608	0.592	0.577	355,512	5,506	11,012	16,518	245,763,933
Average	0.663	0.655	0.648	0.640					
Cumulative emissions credit						22,366	44,732	67,098	
Share of emissions reduction from total emission in 2019 (%)						9.10	18.20	27.30	

Note: BAU = emissions intensity without demand-side management under subcritical scenario; Emissions credit = (emission intensity at corresponding A – emission intensity when A=0) x electricity production; we do not obtain carbon credit in 2010 because emissions intensity at corresponding A is lower than BAU; w/o DSM = without demand-side management increase from about 36% in 2010 to about 117% in 2020 (for the 2011–2020 data set)[11]. This indicates that pursuing a strategy of minimizing CO_2 emissions will become more and more expensive in the future. With this situation, it becomes difficult to pursue low CO_2 emissions or power systems will be 'locked in' to high CO_2 emissions in the future. Minimizing CO_2 emissions will still be costly to implement, or both economically and politically or it is not a feasible strategy. However, if minimizing CO_2 emissions becomes the only objective, the study suggests that the government needs to pursue scenario 4 (technology and fuel switching with 10% demand-side management) that will lead to a 60% increase in generating cost compared to all scenarios under minimizing generating cost. However, a 60% increase in generating cost is still very high. Alternatively, if minimizing generating cost becomes an objective, to obtain the least CO_2 emissions, the government still needs to pursue both fuel, technology switching, and demand side management. This will lead to an increase in generating cost by 17% and reduction in CO_2 emissions by about 19.5%.[12].

The analysis in **Chapter 5** shows that the current power planning will lead the Java-Bali system to a carbon 'lock in' situation for four reasons. First, steam coal will become the backbone of the primary energy supply in the Java-Bali system. Between 2010 and 2020, the share of steam-coal installed capacity will increase from 46% to about 60%. Second, because of the rising role of IPP's steam power plants, unless emissions targets are set for IPP, only PT.PLN has more capacity to diversify output, and it can help to reduce CO_2 emissions. If the government only considers minimizing generating cost, the share of CO_2 emissions from steam-coal power plants will increase from about 84% in 2010 to about 94% in 2020, while with minimizing CO_2 emissions, the share increases from about 55% to about 71%. Third, the study obtains the 'bad luck' curve when we represent relationship between CO_2 emissions and generating cost. This indicates that generating cost need to be increased progressively in order to obtain the same amount of CO_2 emissions reduction. Four, the abatement cost, or the cost to reduce one ton of CO_2 emissions, also tends to increase. There are three main factors that affect the abatement cost: (i) flexibility in utilizing an energy mix

[11] We forecast generating cost for old power plant by using autoregressive moving average (ARMA) model and the levelized cost for new power plant. Because ARMA model considers oil price in the model, we obtain huge price gap between minimizing generating cost and minimizing CO_2 emissions.

[12] In this analysis we compare scenario I (subcritical technology-lignite-no demand side) with scenario II (supercritical technology-subituminous-10% demand side management).

with less carbon intensity, such as gas; (ii) the availability of renewable energy; and (iii) the state of steam technology.

Although utilizing a more advanced steam-coal technology can help Indonesia to minimize CO_2 emissions, there is a 'squeezing effect[13] (see **Table 4**).' This means by adopting supercritical technology, marginal abatement cost will be higher than subcritical technology. When we adopt a more advanced technology, the opportunity to squeeze the emissions becomes higher than without adopting new technology. Thus, marginal abatement costs of more advanced technology will be more expensive than a less advanced technology due to the 'squeezing effect.' Alternatively, it is necessary to open the technology space or to diversify technology options, such as promoting renewable energy. Thus, the space or share of renewable energy also needs to be increased. Because minimizing CO_2 emissions will be costly, the study suggests the Indonesia needs to pursue the gradual approach of a 'green path' power system that is represented by the long dash (**Figure 1**). By providing price incentives with certain targets for CO_2 emissions, Indonesia will have more capacity to manage CO_2 emissions in the future. The study suggests that the long-term price signal of about US$ 11-12 cent/kWh can be proposed instead of US$ 9.7 cent/kWh for geothermal power plants, which is currently being offered by the government. With this price, CO_2 missions can be reduced between 24% and 26% compared to minimizing generating cost scenario (**Figure 1**).

Table 4. Upper and Lower Bounds of CO_2 Emission (in Tons)

Year	Subcritical			Supercritical		
	Lower bound (minimizing CO_2 emission) (1)	Upper bound (minimizing generating cost) (2)	With supercritical in 2017 (3)	Lower bound (minimizing CO_2 emissions) (4)	Upper bound (minimizing generating cost) (5)	With supercritical in 2017 (6)
2010	89,580,995	104,039,184	104,039,184	84,519,829	95,159,616	95,159,616
2011	106,291,481	127,884,325	127,884,325	99,556,171	115,786,504	115,786,504
2012	114,532,331	142,874,950	142,874,950	107,171,304	128,796,240	128,796,240
2013	126,024,098	152,584,303	152,584,303	117,448,106	137,627,453	137,627,453
2014	138,818,180	162,810,339	162,810,339	129,071,738	147,071,085	147,071,085

[13] Squeezing effect means in more advanced technology the gap between upper and lower bound is lower than less advanced technology.

2015	149,668,708	174,719,136	174,719,136	138,819,274	157,607,088	157,607,088
2016	158,260,151	184,474,897	184,474,897	146,534,039	166,208,940	166,208,940
2017	171,088,274	197,534,729	163,001,334	158,053,170	177,904,615	148,271,607
2018	181,501,840	210,542,813	174,248,590	167,753,097	189,934,313	158,520,223
2019	186,502,035	216,704,246	181,002,748	172,460,281	195,480,806	164,775,061
2020	191,618,553	222,284,694	193,547,601	177,678,810	200,970,521	176,487,714

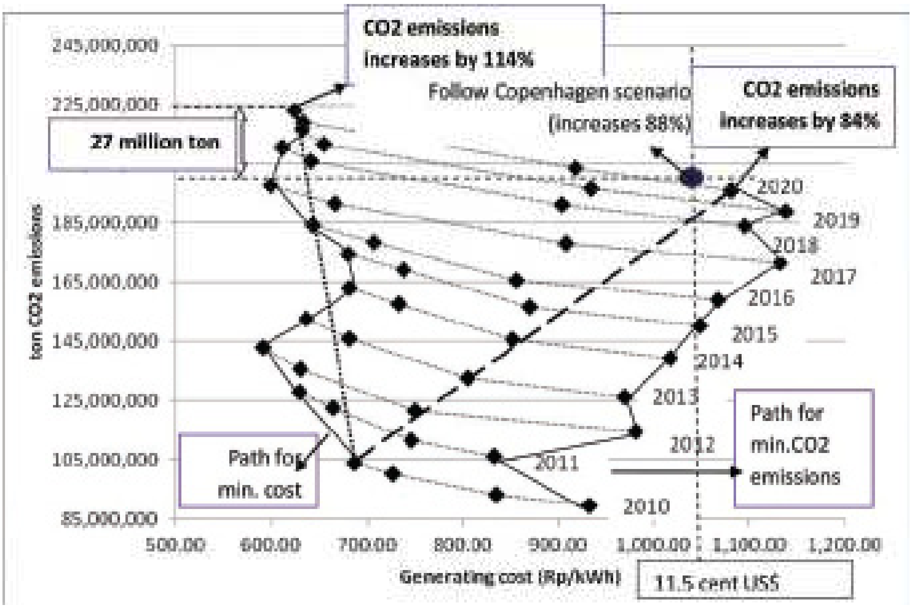


Figure 1. Green path subcritical technology scenario[14]

FUTURE PROBLEMS

We need to collect precise information by conducting surveys at the plant level. The surveys need to cover the following information: (i) availability factor; (ii) generating cost; (iii) emissions intensity; and (iv) efficiency. We also need to study deeply the behavior of the load duration curve (LDC) based on three

[14] This figure shows the path of generating cost and CO_2 emissions both for minimizing generating cost (path for min. cost) and minimizing CO2 emissions (path for min. CO_2 emissions). The left path represents minimizing generating cost and the right path indicates minimizing CO_2 emissions.

dimensions: (i) time; (ii) session; and (iii) economic sector. This is important for providing more information on the future behavior of LDCs and there are also some possibilities to implement demand side management at different load categories such as between the peak load and base load. Finally, there is still uncertainty about the primary energy supply, generating cost, emission intensity, and availability factor. Thus it is necessary to develop a power plant expansion with several scenarios. More robust optimization techniques or stochastic optimization is necessary for further study.

POLICY IMPLICATIONS

Power expansion and CO_2 emissions reduction need to be pursued simultaneously. Indonesia's electricity system can play an important role in Indonesia's transition to a low-carbon economy. However, the study argues that Indonesia needs a broader approach or multiple approaches to ease the transition. Four areas that decision makers need to focus on are recommended as follows: demand-side management, technology switching, fuel switching and price incentives that reflect the cost of service. The policy needs to maintain a balance between supply and demand-side investments.

Indonesia's transition toward a low-carbon electricity system will depend on 'hard' technology and 'soft' technology. 'Hard technology' means an ability to adopt more advanced technology for steam-coal power plants while deploying more renewable energy into the system. 'Soft technology' means an ability to design and to plan power systems that not only can minimize upward pressure on generating cost, but can also reduce CO_2 marginal abatement cost in the future[15]. Political and legal reforms are needed to enable both 'hard technology' and 'soft technology' to work effectively. The strategies to control CO_2 emissions from the electricity sector rest on three pillars (IEA, 2009): (i) significant improvements in energy efficiency of electricity end users that can reduce pressure to build more capacity in the future; (ii) policy incentives to move toward a decarbonization of power supply; and (iii) enhanced R&D in low-carbon generation technology. Following our research findings, the study offers nine (9) policy recommendations.

[15] The marginal abatement cost is influenced by three factors: (i) flexibility in utilizing an energy mix with lower carbon intensity such as gas; (ii) availability of renewable energy; and (iii) the state of steam technology.

1. Indonesia needs more solid and comprehensive instruments and a stronger political will, commitment and actions, both at the national and local levels to develop the green power sector. New power investment needs to optimize the primary energy supply at the regional level and provide more incentives to improve the power supply from renewable energy, such as through land concessions, easing of construction permit procedures, favorable long term contracts, cheap loans for required capital goods, and subsidies to minimize exploration risks for finding new renewable energy sites.

2. The capacity to conduct demand- and supply-side investment will improve if the government gradually switches the electricity subsidy from the final consumer to the upstream level. However, reducing electricity subsidies needs to be done gradually to provide time for producers and consumers to upgrade and to prepare their infrastructure, while the government will also have time to improve the personnel skills and management capacity. As Victor in 2009 (as cited in Bazilian & Onyeji, 2012) argued, 'serious reforms involve not only reducing subsidy demand, but also augmenting the government's ability to put in place alternative policies that would be more cost-effective.'

3. Promoting natural gas utilization not only will help the Java-Bali system to reduce dependency on oil, but also to reduce CO_2 emissions. By increasing the share of natural gas in the primary energy mix, the Java-Bali system can reduce marginal abatement cost on CO_2 emissions. However, the infrastructure for distributing and storing the natural gas needs to be improved. The infrastructure trap on natural gas causes Java-Bali to be unable to fully obtain the economic and environmental benefits of natural gas[16]. It is also important to note that although the current policy plans to reach 'zero oil consumption,' the strategy needs to be done within a robust planning system. This is important because the transition process should not negatively affect economic development.

4. A renewable energy targeting policy will not have an impact on the output mix in the future if generating costs from renewable energy is much higher than fossil fuels. Thus, renewable energy targeting needs to be complemented with efforts to prioritize and to enhance green power

[16] Infrastructure trap is lack in natural gas infrastructures such as pipe and LNG terminals

investment. A suitable reference price is important to enhance green power investment in the future. The current regulated price is not attractive enough to boost rapid investment in renewable energy due to high risks in explorations or high capital cost. The model suggests that the Java-Bali system can reduce CO_2 emissions 26% below the business-as-usual scenario with 'green' generating cost of about 11– 12 cents USD/kWh in 2020, instead of offering 9.70 cents US$/kWh as based on the current regulation. If government offers a much higher price on renewable energy, such as between 10 and 17 cents USD/kWh, we expect that Indonesia will have more opportunity to reduce CO_2 emissions in the future[17]. Renewable energy policy in Japan provides some insights on how Indonesia needs to promote the inclusion of renewable energy into the power system. In 2003, Japan enacted the Renewable Portfolio Standard (RPS) Law. According to this law, the utilities companies are obliged to supply a certain share of their electricity from renewable energy. However, the share is very low, about 1.35% of electricity output in 2010 and 1.63% of electricity output by 2014 (Moe, 2012; Takase & Suzuki, 2011). The law also compels the utilities to buy surplus electricity from rooftop photovoltaic at a price two times higher than the current price offered under voluntary net-metering by the utilities (Takase & Suzuki, 2011). However, due to a large amount of bank credits, relative to their targets, there is a lack of incentives to invest in renewable energy (Takase & Suzuki, 2011)[18]. After the Fukushima disaster, in June 2011 Prime Minister Naoto Kan planned to increase the share of renewable energy in the power supply to about 20% by 2020, and on August 2011 he extended the feed-in tariff (FIT)[19] (Huenteler et al. 2012). The FIT starts in July 2012. However, Hoppmann et al. (2012), as cited in Hueteler et. al., (2012) argue that 'the generous FIT incentivized firms to reallocate resources to new production capacity and in relative terms, away from R&D.' Thus, the FIT needs to be evaluated from an industrial policy perspective. Lessons from Germany show that 'market

[17] Ministry of Energy and Mineral Resources plans to increase the price of geothermal between 10 and 17 cent USD/ kWh (http://bisniskeuangan.kompas.com/read/2012/07/18/02550513/Harga.Listrik.Panas.Bumi.Naik)

[18] Banked means for use in the future years. Because there is more banked credit than the target, there will be excess supply in the future.

[19] According to Huenteler et al. (2012: p7) 'A feed-in tariff guarantees the power producer a fixed electricity purchase tariff for a specified period (often 10–20 years), typically in combination with preferential grid access for the electricity produced.'

subsidies rather than research funding tend to create incentives to favor deadweight effects over long-term research' (Hueteler et al. (2012). It is important to note that energy efficiency needs to be placed as the filter to minimize vested interests in promoting renewable energy (Moe, 2012).We suggest that the National Energy Council (Dewan Energi Nasional) needs to play a more active role in this area.

5. Based on the current power planning scenario, in the future, the share of electricity production from the private sector will increase rapidly and steam power plants will become the main source of power supply from the private sector. Diversification in energy sources needs to be considered in preparing a strategy for the power-purchase agreement (PPA). Benchmarking on plant efficiency, minimum technology requirements, and emissions intensity standards needs to be set as a basis for setting up purchasing power agreements (PPAs). These conditions need to be evaluated regularly.
6. Instead of constructing subcritical and supercritical steam-coal power plants, PT.PLN needs to enhance investment in ultrasupercritical steam technology[20]. There are three benefits of utilizing a ultrasupercritical technology: lowering exposure to rapid increases in fuel cost, reducing emissions intensity, and helping the deal with the carbon credit negotiations under the sectoral agreement mechanism.
7. The study showed that demand-side management can help to reduce generating cost and CO_2 emissions. Investment in energy efficiency such as machines, equipment, and appliances needs to be supported by the government. Energy saving from the adoption of best practice of commercial technologies in the manufacturing sector can be classified in several ways such as motor systems, combined heat and power, steam systems, process integration, increased recycling, and energy recovery (IEA, 2007). According to the IEA (2007), the manufacturing sector can improve its energy efficiency by 18% to 26%, while reducing the sector's CO_2 emissions by 19 to 32% based on proven technology. The motor system has the highest contribution in terms of energy and carbon saving

[20] Investment cost on ultrasupercritical technology is 33% higher than subcritical. In 2017, the first ultrasupercritical technology will start to operate with capacity (2 x 1,000 MW) in central Java. This is the first public private partnership (PPP) for power generation, and J-power-Itochu-Adaro won the bid.

(IEA, 2007). The type of energy also determines the level of efficiency. For example, coal is less efficient that other energy sources because of ash content and the need for further gasification (IEA, 2007). In the case of the industrial sector, Sambodo & Oyama (2011) found that the government needs to improve efficiency in the textile, chemical, basic metals, and other manufacturing industries. They argue that incentives and disincentives can be applied to enhance energy use and clean energy utilization.

8. In Indonesia, there are four regulations that attempt to enhance energy and electricity conservation: (i) Instruksi Presiden No 10/2005, (ii) Peraturan Menteri Energi dan Sumber Daya Mineral No 31/2005, (iii) Peraturan Pemerintah No 70/2009 and (iv) Instruksi Presiden No 13/2011. PT.PLN also provides a 20%–50% discount for industrial customers with electricity consumption above 200 kva if they can shift the working hours to night time. Next, PT.PLN also will reimburse fuel consumption for firms that use their own generators during peak hours. In early 2008, PT.PLN planned to distribute for free about 51 million light emitting diodes (LED) to more than 17 million household customers, but on 3 April 2008 this program was suspended (PT.PLN 2008). We argue that campaigns for power saving need to be enhanced. The government also needs to build capacity in monitoring, evaluation, and enforcement in power saving both at the central and local levels. Currently, the Minister of Energy and Mineral Resources is helped by four general directorates, and one of them is the Director General of New Energy, Renewable and Energy Conservation. Energy conservation is managed by only one director. This is one of the reasons why energy conservation policies have not worked effectively. Indonesia needs to learn from Japan that it is very effective to implement energy efficiency policies. Japan has an energy-saving law that requires companies in the industry, transportation, and commercial sectors to report their emissions records and plans for further energy saving each year (Takase & Suzuki, 2011). Japan includes the energy efficiency policy under the climate change policy framework (Takase & Suzuki, 2011). Japan's 'Top-runner' program is believed to be one of the world's most successful environmental policies (Huenteler et al., 2012). The 'Top-runner' program is designed to improve efficiency for household and office appliances and for motor vehicles (Takase & Suzuki, 2011; Huenteler et al., 2012). Manufactures of the appliances and vehicles are required to improve the average efficiency

of their products to a level above that of the current 'top-runner' or the most efficient products on the market. The government also set up advisory committees (Takase & Suzuki, 2011; Huenteler et al., 2012).

9. Finally, good power planning models need to cover and to measure three dimensions: (i) the economic and business dimension (minimizing generating cost, tariff reflects cost of service and reduces price uncertainty); (ii) the natural resources and environmental dimension (utilizing local resources, reduce CO_2 emissions, reduce marginal abatement cost and improve diversification index); and (iii) the social dimension (reduce inequality in regional capacity to balance electricity consumption).

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