Songklanakarin J. Sci. Technol.
35 (4), 421-427, Jul. - Aug. 2013

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Original Article

Assessment of CO_2 reduction potentials through clean coal technologies for future power plants in Indonesia

Monna Rozana[1,2], Athikom Bangviwat[1,2]*, and Christoph Menke[3]

[1] *The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangmod, Tung Kru, Bangkok 10140 Thailand*

[2] *Centre of Excellence on Energy Technology and Environment, Ministry of Education, Thailand.*

[3] *University of Applied Science Trier, Germany.*

Received 20 May 2012; Accepted 7 May 2013

Abstract

This paper presents CO_2 reduction potentials employing clean coal technologies for power plants in Indonesia. When low ranked coal from huge reserves cannot be excluded from coal-fired power plants to meet electricity demand, it is critical for Indonesia to adopt the best available clean coal technologies for its future coal-fired power plants in order to minimize CO_2 emissions in a long term. Several types of coal-fired technologies are considered to be the best match with Indonesia's situation by assessing CO_2 emissions from coal-fired power plants, levelized costs of electricity generation, and the cost of CO_2 avoidance. As a result, supercritical PC, IGCC, CFB, and PFBC technologies are presented as a consideration for policy maker in Indonesia.

Keywords: CO_2 emission, clean coal technologies, low ranked coal, levelized cost, cost of CO_2 avoided

1. Rationale Statement

Declining production of domestic oil and gas is pushing Indonesia towards greater utilization of coal-fired power generation. According to Perusahaan Listrik Negara (PLN), a national electricity producing company, 46% of electricity generation in Indonesia in 2010 is attributed to coal as shown in Figure 1, and projected to be increased to 64% in 2020. Moreover, the National Energy Committee has forecasted that the national energy mix in 2025 will be dominated by fossil fuels. Indeed, there is not only a significant decrease in oil consumption in that projection but also a great increase in coal shares as shown in Figure 2.

Indonesia is endowed by a large number of coal resources, with 21.131 billion tons of coal reserve and 105.187 billion tons as potential resources (MEMR, 2009a). Indonesia's coal reserve is mostly dominated by medium ranked calorie (47.17%), followed by low ranked calorie

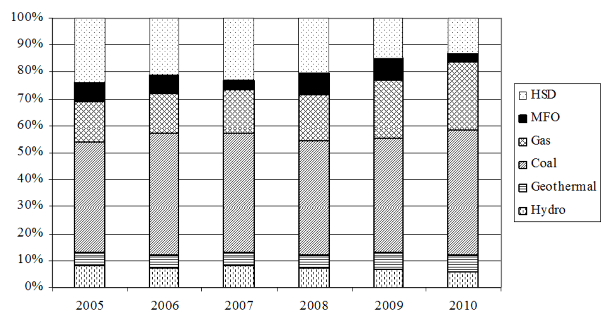

Figure 1. Electricity generation in Indonesia in 2010 by fuel type (PLN, 2011).

* Corresponding author.
Email address: athikom.bangviwat@hotmail.com

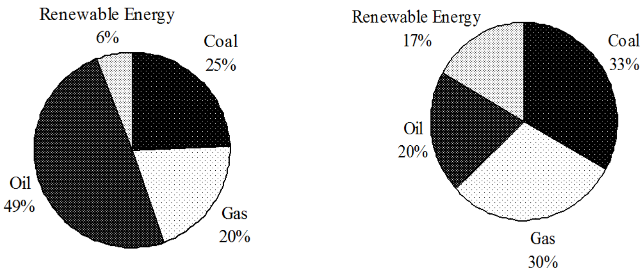

Figure 2. National Energy Mix 2010 (MEMR, 2009b) and 2025 (DEN, 2011).

(41.21%) as shown in Table 1. Indonesia's power plants consume around 40 million tons of coal every year. In addition, PLN has planned to build coal-fired power plants of about 30,000 MW in 2020 utilizing low and medium ranked coal to fulfill the electricity demand in Indonesia. It is figured that the utilization of low ranked coal/lignite and medium rank coal/subbituminous cannot be excluded from coal-fired power plant.

In terms of energy security, the utilization of low ranked coal is likely to be an inevitable policy option in Indonesia's energy sector. Furthermore, as one of the signatories of Kyoto protocol, this policy has the potential to add negative implications to Indonesia's economy in terms of penalties attributed to emissions from coal combustion and the global climate agreement with CO_2 emission reduction target. Therefore, it is critical for Indonesia to adopt the best available clean coal technologies (CCT) when building the new coal-fired power plants, which will utilize low ranked coal as fuel, in order to minimize green house gas (GHG) emissions over a longer term. Thus, the objective of this paper is to analyze the CO_2 reduction potentials by employing several types of clean coal technologies for future power plants in Indonesia. At the end, the results of the assessment will be used as a recommendation for policy maker in Indonesia.

2. Methodology

The CO_2 reduction assessment is generally built using available data and assumptions within the appropriate system framework to foresee future conditions. The data is taken from national and international sources. The international agency provides 'the country factor', which can represent the costs for developing countries, in this case for Indonesia. Therefore, the cost data that provide a realistic picture for Indonesia is achieved by converting the international data using the country factor.

Several types of clean coal technologies were applied in this research: (1) supercritical pulverized combustion (SC), (2) sub-critical circulating fluidized bed (CFB), (3) pressurized fluidized bed (PFBC), (4) integrated gasification combined cycle (IGCC), (5) pulverized combustion with carbon capture and storage (PC-CCS), and (6) IGCC with carbon capture and storage (IGCC-CCS). Those technologies were chosen due to the current Government of Indonesia's policies and targets, which encourage the utilization of coal in power generation to replace diesel and marine fuel oil by 2028. The specification of each plant is shown in Table 2.

Meanwhile, the existing power plants in Indonesia employed subcritical PC. Moreover, it was assumed that there is not any retrofit for the existing coal-fired power plants. Only the new coal-fired power plants, as planned by the national electricity company, PLN (Perusahaan Listrik Negara), will be built by a single of technologies.

The CO_2 assessment for each type of power plant is categorized into three main parts: (1) estimation of CO_2 emissions from coal-fired power plants in Indonesia, (2) levelized costs of electricity generation, and (3) costs of CO_2 avoidance.

First, the CO_2 emission estimation for existing power plants is shown in Table 3 is calculated by the Tier 1 approach based on the IPCC 2006 Guidelines (IPCC, 2006). The following equation is used:

$$Emission_{CO2} = Fuel\ Consumption\ x\ Emission\ Factor \quad (1)$$

Table 4 shows the committed coal-power plants taken from the Electrical Supply Business Plan 2010-2019 by PLN. For new coal-fired power plants, which are operating since 2010, CO_2 emission estimations are counted by following formula:

$$Emission_{CO2} = Electricity\ Production\ x\ Emission\ Factor \quad (2)$$

Table 1. Indonesia's coal potentials (MEMR, 2011).

Quality		Resource (billion tons)		Reserve (billion tons)	
Class	Calorific value (kcal/kg)	Total	%	Total	%
Low	<5,100	21.228	20.18	8.709	41.21
Medium	5,100-6,100	69.726	66.29	9.968	47.17
High	6,100-7,100	132.206	12.57	2.272	10.7
Very High	>7,100	10.132	0.96	0.182	0.87
Total		105.187	100	21.132	100

Table 2. Power plant specification based on IPCC (2005) and Indonesia (2010).

Type of plant	Efficiency (%)
sub-PC	34
SC	40.3
IGCC	39.1
sub-CFB	37
PFBC	42.5
PC-CCS	25.4
IGCC-CCS	31.3

Table 3. Existing coal-fired power plants in Indonesia.

Plant name	Capacity (MW)	Operation year	Annual consumption (million tons)	Technology	Fuel type
PLTU Suralaya	3400	1984	11.914	Sub-PC	Sub-bituminous
Suralaya 1 and 2	800	1984			
Suralaya 3 and 4	800	1989			
Suralaya 5, 6 and 7	1800	1997			
PLTU Bukit Asam	260	1987	1	Sub-PC	Sub-bituminous
PLTU Paiton	800	1994	2.8	Sub-PC	Sub-bituminous
PLTU Ombilin	200	1996	0.63	Sub-PC	Sub-bituminous
PLTU Asam-asam	130	2000	0.59	Sub-PC	lignite
PLTU Paiton I	1230	2000	3.879	Sub-PC	Sub-bituminous
PLTU Paiton II	1220	2003	3.847	Sub-PC	Sub-bituminous
PLTU Lati	14	2003	0.069	Sub-PC	Sub-bituminous
PLTU Sangatta	14	2004	0.069	Sub-PC	Sub-bituminous
PLTU Sintang	14	2005	0.069	Sub-PC	Sub-bituminous
PLTU Sarolangun	14	2005	0.064	Sub-PC	Sub-bituminous
PLTU Tanjung Jati B	1320	2005	4.163	Sub-PC	Sub-bituminous
PLTU Kupang	30	2005	0.137	Sub-PC	Sub-bituminous
PLTU Palu	30	2005	0.137	Sub-PC	Sub-bituminous
PLTU Cilacap	450	2006	1.419	Sub-PC	Sub-bituminous
PLTU Tarahan 3 and 4	200	2006	0.771	Sub-PC	Sub-bituminous
PLTU Amurang	110	2006	0.347	Sub-PC	Sub-bituminous
PLTU Sibolga	200	2006	0.631	Sub-PC	Sub-bituminous
PLTU Bangka	30	2006	0.137	Sub-PC	Sub-bituminous
PLTU Tarahan 1 and 2	200	2007	0.771	CFB	lignite
PLTU Labuan Angin	230	2007	1.048	CFB	lignite
PLTU Peranap	500	2007	2.278	CFB	lignite
PLTU Banjarsari	200	2007	0.911	Sub-PC	Sub-bituminous
PLTU Lubuk Linggau	130	2007	0.592	Sub-PC	Sub-bituminous
PLTU Cilegon	450	2008	1.419	Sub-PC	Sub-bituminous
PLTU Labuan	630	2010		CFB	lignite

Source: MEMR (2009a), Othman *et al.* (2009), PLN (2009), Das and Ahlgren (2010). PLTU means "coal-fired power plant" in Indonesian language.

A new power plant has a potential lifetime of 30 years. It is assumed that ancillary units consume a 5% of the output electricity, and capacity factor is 80% (Zhao *et al.*, 2008). For CO_2 emission calculation, the amount of electricity consumed in the ancillary unit is not considered, therefore the gross electricity is calculated. From these figures, the gross electricity production amounts to:

Table 4. Committed coal-fired power plants (PLN, 2009).

Year	Cumulative capacity (MW)
2010	12,006
2012	17,464
2014	24,986
2016	29,560
2018	34,241
2020	43,806
2022	50,818
2024	57,830
2026	64,842
2028	71,854

$$\textit{The gross electricity production (MWh/year)} = \textit{Capacity (MW)} \times \textit{capacity factor} \times 8760\ \textit{(hrs/year)} \quad (3)$$

Second, the notion of levelized costs of electricity generation (LCOE) is a tool for comparing the unit costs of different technologies over their economic life (IEA, 2010). LCOE were calculated for all technologies for a discount rate of 11% and the lifetime of the plant of 30 years. All costs are calculated in real US dollars using 2010 as the base year. The formula applied to calculate for each coal-fired power plant the levelized costs of electricity generation is the following:

$$LCOE = \Sigma\,[Investment + O\&M + Fuel)*(1+r)^{-t}] \,/\, \Sigma\,[Net\ Electricity*(1+r)^{-t}] \quad (4)$$

where 'Investment' is investment costs in years 't', 'O&M' are the operations and maintenance costs in year 't', 'Fuel' are fuel costs in year 't', r is the discount rate, 'Net Electricity' is the amount of electricity produced in year 't', which equals to *Capacity (MW) x capacity factor x 8760 (hour/year) x [1- ancillary units]*, and with $(1+r)^{-t}$ the discount factor for year 't'.

Common fuel prices that remain constant over the entire lifetime of the power plant are assumed for evaluating electricity generation costs (IEA, 2010). Low rank coal is typically not traded on an international level. Hence, for these coals national fuel price assumptions are used. Coal price for lignite is taken from the National Electricity Company (2010) for about 50 US$/ton.

Third, the most widely used measures for the cost of CO_2 capture is the cost of CO_2 avoidance. This value reflects the average cost of reducing CO_2 emissions by one unit while providing the same amount of useful product as a 'baseline plant'. To calculate the cost of emission reduction, it is necessary to define a baseline from which the options for reductions could be measured. For a coal-fired power plant the cost of avoiding CO_2 can be defined as a way to compare the carbon dioxide mitigation costs of different plants as shown in following equation:

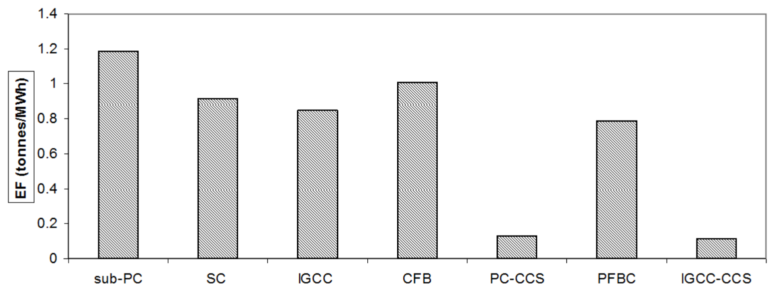

Figure 3. CO_2 emission comparisons. Source: IPCC (2005), IEA (2008a), Wang and Nakata (2009), EPA (2010), Indonesia (2010), Finkenrath (2011).

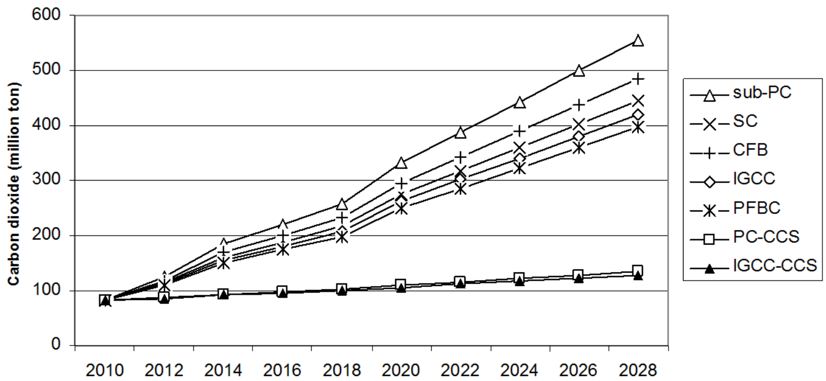

Figure 4. Projected CO_2 emission.

$$CAE = [(LCOE)_A - (LCOE)_B] / [ER_B - ER_A] \quad (5)$$

where *CAE* is the cost of avoided emissions (US$/ton CO_2), LCOE is the cost of electricity (US$/MWh), ER is the carbon dioxide emissions (ton CO_2/MWh), and the indices A and B represent the reference and proposed plants, respectively. The base year is 2010 and predictions are made until 2028. Since subcritical pulverized combustion (sub-PC) technology is mostly utilized in Indonesia's existing coal power plant, therefore sub-PC is used as a baseline plant.

3. Results

3.1 CO_2 reduction analysis

Figure 3 presents the carbon dioxide emissions of the seven types of power plants in this study. The conventional subcritical PC has the highest carbon dioxide emission factor of 1.186 ton/MWh. It is shown that IGCC with carbon capture and storage and PC with carbon capture and storage give the lowest average carbon dioxide emissions of all plants, followed by PFBC.

IGCC-CCS scenario offers the lowest CO_2 emission, which is about 36 percent of the emission projection from existing coal-fired power plants from 2010 through 2028. This is followed by the PC-CCS scenario, where in new power plants the amine based solvent monoethanolamine (MEA) for CO_2 capture in pulverized form (IPCC 2005; IEA 2008b).

PFBC, IGCC, and Supercritical PC scenarios have become the other choices of getting lower CO_2 emissions. Supercritical PC has become the norm for new coal-fired power plants worldwide, and its use is expected to increase significantly.

3.2 Levelized costs of electricity generation

The cost estimation in this study was of 'preliminary' type. Preliminary costs are appropriate for the purposes of evaluating alternative technologies. Figure 5 presents an investment cost comparison for all scenarios. The capital investment per MW of the installed capacity of a PC power plant with carbon capture and storage is 2,090,000 US$/MW. Once carbon dioxide capture is incorporated, the capital investments increase by 65% and 24% for PC and IGCC, respectively.

The cost of electricity production is mainly affected by fuel costs and capital costs. The effects of operating labor, maintenance, and chemicals on the final electricity cost are less significant. Figure 6 shows the breakdown of the cost components per MWh for all plants. For subcritical PC plants, fuel cost accounts for 34% of the total cost. Assuming a price for lignite of 50 US$/ton, a subcritical PC power plant can produce electricity for 45.6 US$/MWh or 4.56 US cents/kWh. The supercritical PC is next in ascending order (47.79 US$/MWh), followed by CFB (48.51 US$/MWh), PFBC (50.10 US$/MWh), IGCC (55.83 US$/MWh) and IGCC

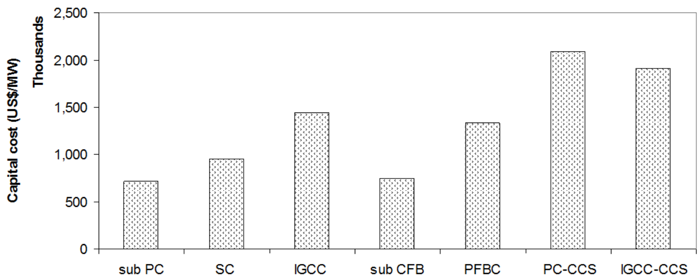

Figure 5. Capital investment comparisons. Source: IPCC (2005), PLN (2009), Wang and Nakata (2009), IEA (2010), Kaplan (2010), Finkenrath (2011).

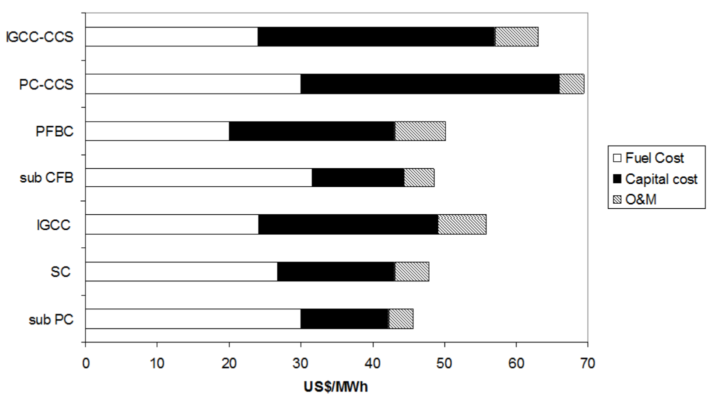

Figure 6. Power production cost comparison.

with carbon capture and storage (63.08 US$/MWh). The subcritical PC with carbon capture and storage yields the highest electricity cost of all plants (69.37 US$/MWh). It is worth noting that the major factor that affects the change in the final cost of electricity for subcritical PC with carbon capture and storage is its capital cost.

The levelized cost of electricity generation (LCOE) discounts the time series of expenditures to their present values in a specified base year by applying a discount rate. While many factors contribute to the cost differences observed in Figure 6, systematic studies of the influence of different factors indicate that the most important sources of variability in reported cost results are assumptions about the power plant efficiency, fuel type, and plant capacity factor (Rubin *et al.*, 2007).

As shown in Figure 7, LCOE in 2010 is referred to existing coal-fired plants. For the new coal-fired power plants as planned by the national electricity company, PLN (Perusahaan Listrik Negara) a single technology will be implemented. It is useful to note that based on a recent study that among the clean coal technologies systems shown in Figure 7 the one with the lowest cost (in terms of LCOE) is a subcritical PC power plant scenario using lignite coal with high plant utilization in 2028; it is followed by a supercritical PC. In contrast, the highest LCOE value is a subcritical PC power plant with a carbon capture and storage (PC-CCS).

3.3 Cost of avoiding CO_2

The mitigation costs for all plants are shown in Table 5. As the subcritical PC is used as reference plant, the supercritical PC has the lowest CO_2 mitigation cost of all plants ($8/ton CO_2 avoidance), followed by PFBC and IGCC-CCS ($11 and $16/ton CO_2 avoidance, respectively). A number of factors are contributed to make supercritical PC the most advantageous in terms of mitigation cost such as the lower capital cost and minimal CO_2 emission.

Figure 8 allows a comparison of the CO_2 mitigation costs for all scenarios. The mitigation cost corresponds to the slope of a line connecting a reference plant to another plant, which is calculated with the equation mentioned above.

As can be seen in Figure 8, the followings are clean coal power generation technologies that result in CO_2 reduction at lower cost as well as in an increase in te combustion efficiency: supercritical PC, IGCC, CFB, and PFBC. These technologies are utilized internationally and can also further decrease SO_2 emission with a flue-gas desulfurization (FGD) unit installed. Therefore, supercritical PC, IGCC, CFB, and PFBC are technologies suitable for a long-term development.

4. Conclusion

Having its unique resource status, coal is undoubtedly the dominant energy resource in Indonesia especially in the electricity producing sector. Considering the abundance of coal and its comparatively low price, this situation is likely not to be changed in the near future. Side effects of coal combustion should not be ignored. Clean coal technologies has

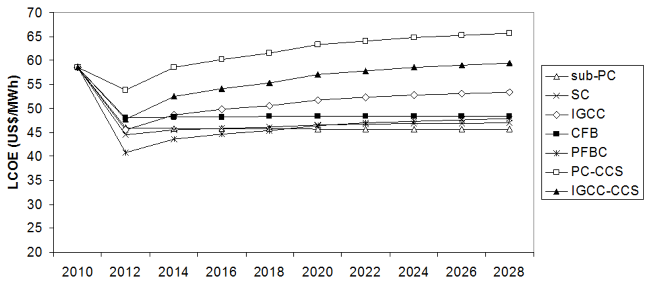

Figure 7. Levelized costs of electricity generation.

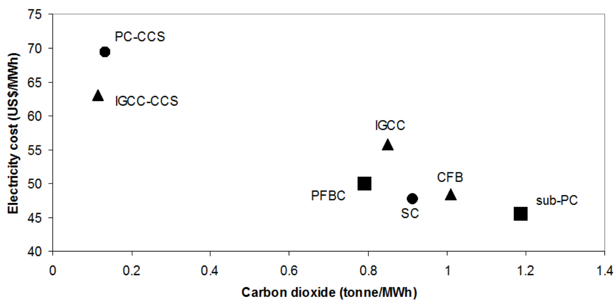

Figure 8. CO_2 mitigation cost comparison chart.

Table 5. CO_2 mitigation cost comparison (cost of avoiding CO_2).

Plant	Emission factor (ton/MWh)	LCOE (US$/MWh)	Mitigation costs (US$/ton CO_2 avoided)[a]
1. subcritical PC	1.186	45.60	-
2. SC	0.913	47.79	8.02
3. IGCC	0.85	55.83	30.45
4. CFB	1.01	48.51	16.53
5. PFBC	0.79	50.10	11.36
6. PC-CCS	0.133	69.37	22.57
7. IGCC-CCS	0.115	63.08	16.32

[a] With subcritical PC as reference plant.

been proven to be strong and efficient methods to meet both the electricity demand and environmental requirements.

Based on emission and cost assessment of CO_2 reduction options, the policy makers should concern supercritical PC, IGCC, CFB, and PFBC as technology choices that will be employed in the construction of new coal-fired power plants in order to minimize CO_2 emission in the future. In addition, the implementation of carbon capture and storage can reduce large quantities of CO_2 emission from existing subcritical pulverized coal-fired power plants.

Furthermore, the Government of Indonesia also needs to enhance the environmental monitoring systems for coal-fired power plants. All coal-fired power plants should be required to install flue gas desulphurization units and continuous emission monitors. Information about clean coal technology should be disseminated to increase public awareness about this option that will benefit energy needs but also addresses environmental and public health concerns.

Acknowledgment

This work is funded by the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Thailand, and the Centre of Excellence on Energy Technology and Environment under the Ministry of Education, Thailand.

References

Das, A. and Ahlgren, E.O. 2010. Implications of using clean technologies to power selected ASEAN countries. Energy Policy. 38, 1851-1871.

DEN. 2011. National Energy Policy Scenario for Indonesia 2050. Proceedings of National Conference of Energy Policy Scenario for Indonesia 2050. Yogyakarta, Indonesia. Dewan Energi Nasional (DEN), Jakarta, Indonesia.

EPA. 2010. Available and emerging technologies for reducing GHG from coal-fired electric generating unit. Sector Policies and Programs Division Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. http://www.epa.gov/nsr/ghgdocs/electric generation.pdf.

Finkenrath, M. 2011. Cost and Performance of Carbon Dioxide Capture from Power Generation. OECD/IEA. France. http://www.iea.org/publications/freepublications/publication/costperf_ccs_powergen-1.pdf

IEA. 2008a. Energy Policy Review of Indonesia. International Energy Agency (IEA). OECD/IEA, France. http://www.iea.org/publications/freepublications/publication/Indonesia2008-1.pdf.

IEA. 2008b. CO_2 Capture and Storage. International Energy Agency (IEA). OECD/IEA, France. http://www.iea.org/publications/freepublications/publicationCCS_2008.pdf

IEA. 2010. Projected Costs of Generating Electricity. International Energy Agency (IEA). OECD/IEA, France. http://www.worldenergyoutlook.org/mediaweowebsite/energymodelProjectedCostsofGeneratingElectricity2010.pdf

Indonesia. 2010. Indonesia's Technology Needs Assessment on Climate Change Mitigation. Republic of Indonesia. Jakarta, Indonesia.

IPCC. 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Intergovernmental Panel on Climate Change, New York, USA.

IPCC. 2006. IPCC guidelines for national greenhouse gas inventory. IPCC IGES. Hayama, Japan.

MEMR. 2009a. Blue Print of National Energy Management 2010-2025, Ministry of Energy and Mineral Resources, Jakarta, Indonesia.

MEMR. 2009b. Handbook of Energy and Economics Statistics of Indonesia. Ministry of Energy and Mineral Resources. Jakarta, Indonesia.

MEMR. 2011. Indonesian Coal Reserves and Future Management Challenge Perspective. Proceedings of National Conference of Energy Policy Scenario for Indonesia 2050, Yogyakarta, Indonesia.

Othman, M.R., Martunus, R. Zakaria and Fernando, W.J.N. 2009. Strategic planning on carbon capture from coal fired plants in Malaysia. Energy Policy. 37, 1718-1735.

PLN. 2009. The Electrical Supply Business Plan 2009-2018. PT. PLN (Persero) Direktorat Perencanaan dan Teknologi, Jakarta, Indonesia.

PLN. 2011. Electricity System Development Outlook 2011-2040. Proceedings of National Conference of Energy Policy Scenario for Indonesia 2050, Yogyakarta, Indonesia.

Rubin, E.S., Chen, C. and Rao, A.B. 2007. Cost and performance of fossil fuel power plants with CO_2 capture and storage. Energy Policy. 35, 4444-4454.

Wang, H. and Nakata, T. 2009. Analysis of the market penetration of clean coal technologies and its impacts in China's electricity sector. Energy Policy. 37, 338-351.

Zhao, L., Xiao Y., Gallagher, K. S., Wang B. and Xu, X. 2008. Technical, environmental, and economic assesment of deploying advanced coal power technologies in the Chinese context. Energy Policy. 36, 2709-2718.