THE SELECTION OF NEGATIVE CARBON EMISSION TECHNOLOGY OF FUEL COMBUSTION PROCESS IN COAL POWER PLANT

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ABSTRACT

Integrating biomass with carbon capture and storage (CCS) is commonly called as BECCS (Biomass Energy and CCS). BECCS could be used as one of solutions to deal with carbon emission reduction expecilally when it is integrated with power plants that is the main contributor of carbon emissions from energy sector in Indonesia. Currently, the combustion system in most power plants in Indonesia still uses direct combustion. However, more efficient power plants considered as CCT (clean coal technology) have been built and start to be operated, i.e. fluidized bed, ultra super critical, etc. For future development, there are other CCT with more efficient and significantly reduce CO_2 emissions can be considered to be built, i.e. IGCC or other CCT equipped with CCS. This paper discusses the development of 'end-use model' used as a tool for the selection of cleaner (compare to the existing) technology for coal power plant in Indonesia, particularly the introduction of an integrated system of clean combustion technology and CCS for coal base combustion system in power plant. Concerning the CCS, there are various type of flue gas quality, in which most of them has low CO_2 content. The low CO_2 content will affect to the CO_2 separation process and in turn will also cause to the increasing of investment cost of power plant. The end use model is developed based on "bottom-up energy model of AIM/end-use" to obtain energy projection or pathway, the associated CO_2 emission reduction, and costs in the power plants under the baseline and mitigation scenario, where BECCS is considered as negative emission technology. This tool is also used to select appropriate technology for combustion process in the power plant in Indonesia. There are two mitigation scenarios developed using this tool, i.e. CM1 (moderate scenario) and CM2 (ambitious scenario). The aim of CM1 is to keep the increasing global temperature not more than 2^oC while CM2 is to keep the temperature not exceed 2^oC. The modelling results the mitigation under CM1 can reduce 44.9% CO_2 emission level from power sector in Indonesia under the baseline (BL) in 2050 while under CM2 can reduce up to 96.2%. The total cost needed for achieving the mitigation in 2050 under CM1 is 104.5 Trillion USD while under CM2 125.1 Trillion USD

Keywords: AIM/end-use, baseline, BECCS, biomass energy, bottom-up model, CCS, climate change, clean coal technology, mitigation, negative emission technology, coal, power plant,

INTRODUCTION

In Indonesia, CO_2 emission from fuel combustion is the second largest of CO_2 emission sources after LUCF (Land Use Change and Forestry). According to Indonesia Third National Communication (TNC) 2017, the largest source of CO_2 emission from fuel combustion is power plants, in which about 54% of the fuel used in the power plant is coal. CO_2 emission from the power plant increases according to the increasing of electricity demand, where electricity demand increases inline with population and economic growth. Looking at the level of carbon emission in the world, non-OECD Asian country is the third largest contributor of CO_2 emission, where Indonesia is the largest contributor among non-OECD countries (IEA, 2017). The Indonesia TNC document shows the contribution of Indonesia to the global carbon emission in 2014 is 1,844,329 GigaGram CO_2e. The main contributing is LULUCF category including peat fire (53%), followed by energy (33%), agriculture (6%), waste (5%) and IPPU (3%). Carbon dioxide (CO_2) is the dominant CO_2 emissions, which contributed 87% followed CH_4 9.7% and N_2O 3.3%. During 2000-2014, the Indonesia CO_2 emissions level has increased with average rate of 4.4% per year, in which Land-based category especially forestry has significantly contributed to this level, i.e. agriculture (0.9%) and forestry (12.8%). Followed by energy (5.2%), IPPU (0.7%), and waste (3.6%). This level is estimated to increase continuously until 1,669,026 GigaGram CO_2eq in 2030 CO_2 and up to 311,529 GigaGram CO_2eq in 2050 [CREP ITB, 2014].

In response to this global situation, Government of Indonesia (GoI) plans to reduce the national emissions level in order to contribute to the global endeavor in combating global climate change. In 22 April 2016, GoI ratified the Paris Agreement of the UNFCCC (United Nations Framework Convention on Climate Change) that has been approved by Indonesian Law No. 16/ 2016. The Paris Agreement aims to keep the increasing of global average temperature below 2°C (compare to the level of pre-industrialization) and continue the efforts to keep the increasing temperature not more than 1.5°C. As developing country, contribution of Indonesia in the Paris Agreement in 2030 is not significantly if compared to developed countries. However, to meet further target for CO_2 reduction in 2050, GoI has to develop more aggressive mitigation plans, in which more reduction measures have to be introduced. One of the measures discussed in this paper is BECCS in power generation.

Currently, although several relatively new power plant technologies considered as clean coal technology (CCT) have been built and start to be operated, i.e. fluidized and ultra super critical coal technologies, however, fuel combustion system in most Indonesai power plants still uses direct combustion technology. For future development, there are possibilities to improve it with more significant reduce CO_2 emissions technology, i.e. negative emission technologies. One of them is integrating a biomass base fuel combustion technology with carbon capture and storage (CCS), which is commonly called as BECCS (Biomass Energy and CCS). BECCS could be used as one of solutions to deal with carbon emission reduction expecilally when it is integrated with coal power plants, the main contributor of carbon emissions from energy sector in Indonesia. This paper discusses the development of 'end-use' model that can be used as a tool for the selection of cleaner (compare to the existing) technologies for improving coal power plant in Indonesia and the evaluation of the impact of integrating biomass energy and CCS for CCT in power plant.

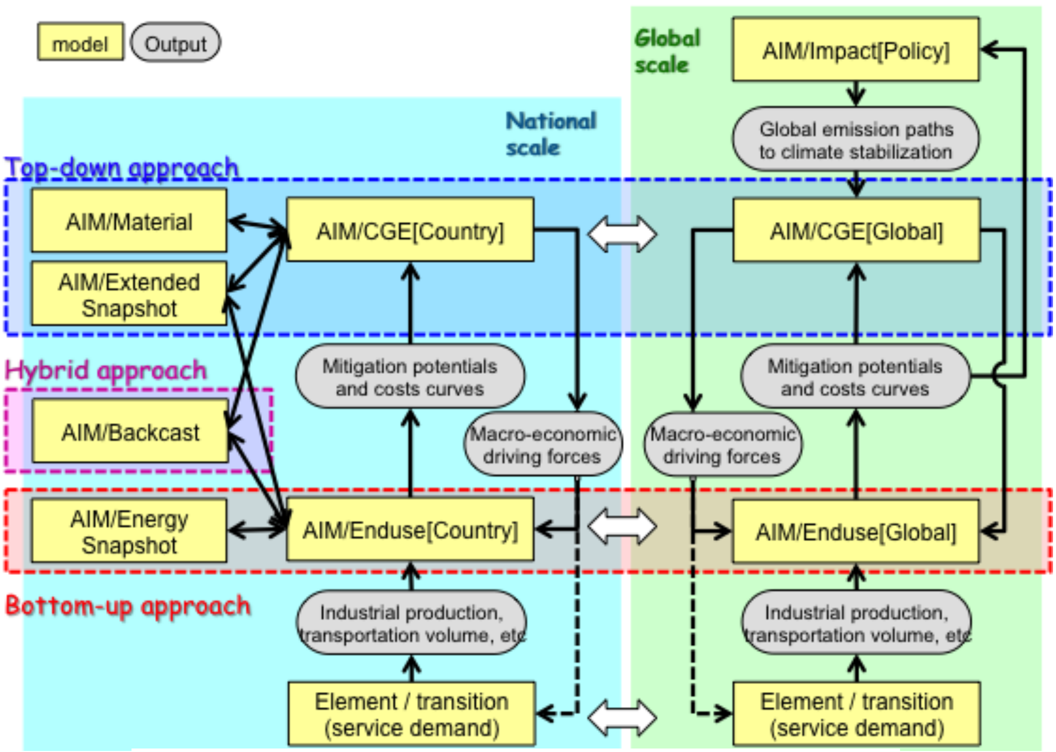
Concerning the CCS, there are various type of flue gas quality, in which most of them has low CO_2 content. The low CO_2 content will affect to the CO_2 separation process and in turn will also cause to the increasing of investment cost of power plant. The end use model is developed based on "bottom-up energy model of AIM/end-use" to obtain low carbon development pathway of power generation and to estimate the reduction of associated CO2 emissions and costs of investment under the baseline and mitigation scenario including the additional costs (MAC), where BECCS is considered as negative emission technology.

METHODOLOGY

In this study, energy model of AIM/end-use (Asian Pacific Integrated Model) developed by Japan's National Institute for Environmental Studies (NIES) is used as a tool to estimate CO_2 emissions development for the period of 2015 – 2050 in Indonesia and to evaluate the impact of introducing of clean and low carbon technology in power sector to the total CO_2 emissions from energy sector in Indonesia. AIM/end-use is developed as part of a bottom-up model that has been used to estimate CO_2 emissions and absorptions potential in Asia-Pacific (Mikiko, 2000). The bottom-up model comprises CO_2 emission (AIM/emission), climate change (AIM/climate), and impact (AIM/impact) models. The AIM/end-use is part of AIM/emission model that has been used to develop energy development/projection and the associated CO_2 emissions on the basis of technology model simulation for processes in power by material and energy flows between the raw material and end service, which is widely used for the study of global climate change (Wen, 2015).

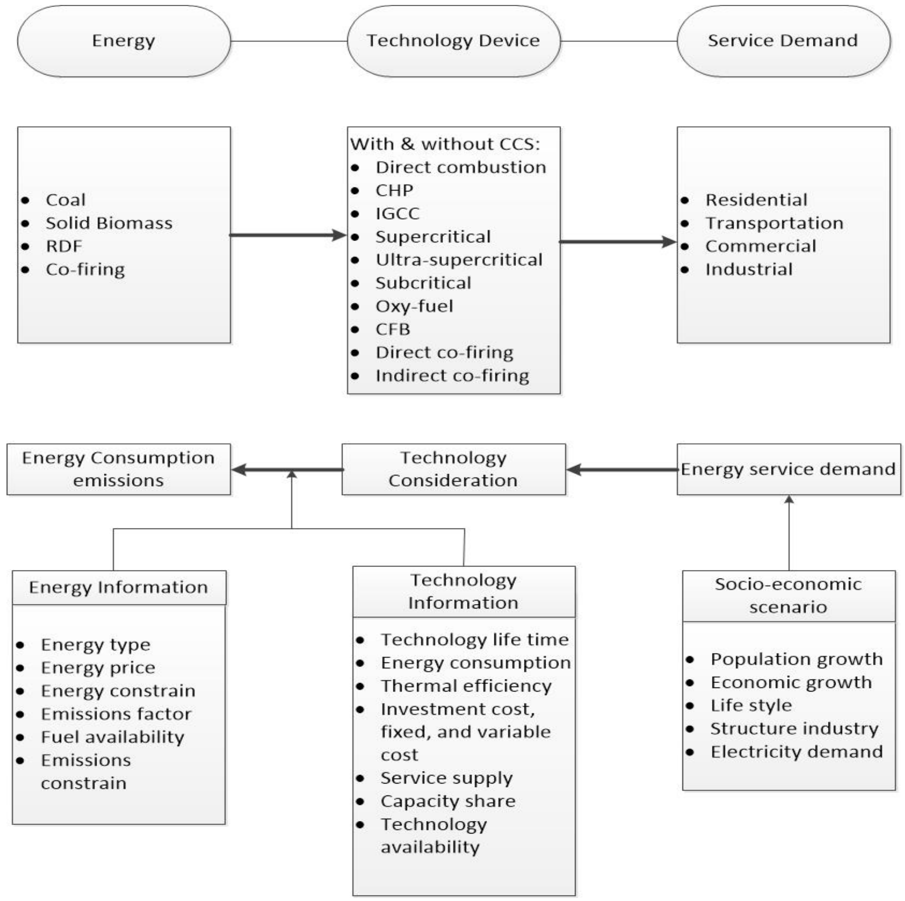
AIM/end-use model relies on framework of linear programming for a bottom-up energy system, which starts with how primary energy is converted into secondary energy for final services (Chunark, 2014). Based on a recursive dynamic model concept to solve problems over several years, the total cost of selected technology systems is minimized on a yearly basis with some constraints. The total costs referred to capital costs (for purchasing of specific types of equipment), operation and maintenance requirements, and energy prices. Energy and carbon tax also be provided in the model to investigate the impact of the energy system (Chunark, 2014). Figure 1 shows the structure of AIM/end-use model while the operation steps of the model is presented in Figure 2.

Figure 1: The structure of the AIM/end-use energy model (NIES, 2015)



Source: Adapted from AIM/end-use NIES Japan 2015

Figure 2: The operational of AIM/end-use model (Hibino, 2006)



Source: Adapted from AIM/end-use NIES Japan 2006

Refer to Figure 2, in general, energy processes starting from the use of fuel and what type of technology is used, and finally what final energy can be produced from the process as a services request thinking in AIM/end-use models differs from the general process pattern where technologies/devices can be determined based on market demand or service demand that is affected by several factors, i.e. population, economic growth, lifestyle, production structure (industrial and commercial), and end-use energy (electricity) consumption. There are also some considerations in determining technology to be used, such as lifetime, energy consumption, thermal efficiency, investment costs, fixed and variable costs, service supply, capacity share, and the availability of technology. In this paper, clean combustion technologies in power plants are discussed, i.e. more efficient direct combustion, combine heat and power (CHP), integrated gasification combine cycle (IGCC), supercritical, ultra-supercritical, subcritical, oxy-fuel, circulated fluidized bed (CFB), direct and indirect co-firings. In accordance to the AIM/end-use energy model (Figure 1 and 2), there are several important parameters that have to be defined, i.e. time horizon of projection is 2015-2050, the base year is 2010, unit of price is 1000 \$ US, unit of energy is toe, unit of CO2s is tCO_2eq, the region is Indonesia at the national level, the sub-sector is coal based power plant, and the emission factor of each type of energy used in this study (see Table 1).

Table 1: Emissions factor from energy (Eggleston, 2006)

No.	Type of energy	Emission Factors, tCO_2eq/toe
1	RDF	0
2	Biomass	0
3	Coal	4.0
4	Biomass - CCS	-1.0

Developing scenarios in the AIM/end-use is important with the main purpose is to compare various mitigation scenarios with the baseline for estimating CO_2 emission reductions and for developing scenario for the achievement of desired target from power sector, where the negative emissions is to be implemented. In this study, 3 scenarios have been developed to achieve the reduction target, i.e. baseline (BL) or business as usual (BaU) and two mitigation scenarios (CM1 and CM2) such as presented in Table 2.

Table 2: Baseline and two mitigation scenarios

BL (Baseline)	Mitigation (CM1 & CM2)
Envisions the forecast of emissions level that can be happened in the absence of specific measures and policies or regulations that lead to the occurrence of the reduction of CO2 emission or the enhancement of CO2 sequestration in the power development plan.	Envisions the forecast of emissions level that can be happened if there are efforts, specific measures and policies or regulations that lead to the occurrence of emission reduction or sequestration enhancement in power development plan, i.e. efficiency, advance technologies, renewables, and CCS. CM1 is mitigation to keep the increasing global temperature not more than 2°C. CM1 is mitigation to keep the increasing global temperature below 2°C
Base year for projection scenarios is 2010 and the target year is 2050	

RESULT AND DISCUSSIONS

Model Validation

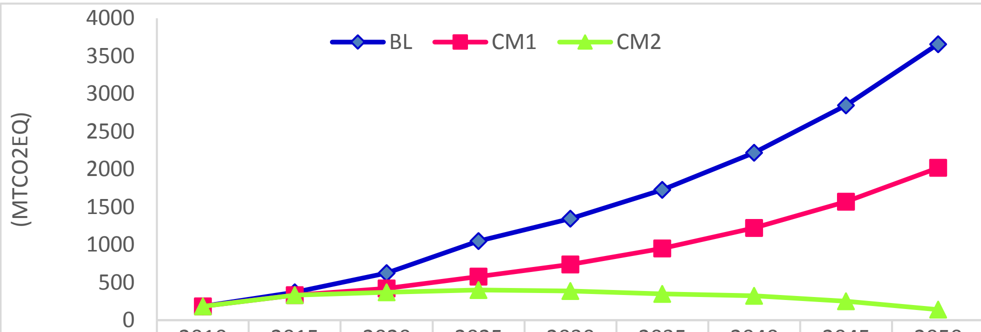
After the model has been developed, the model was validated using 2010-2015 data of coal base power plant in Indonesia to see validity and similarity of the model with the real condition of power sector. The validation is used to check validity of input data for the five years. The validation result shows that there is no significant discrepancy between model and real data. The model shows baseline emission level has increased from 184 $MTCO_2e$ (2010) to 370 $MTCO_2e$ (2015) with the rate of 50,27%/year, while CM1/CM2 scenarios are estimated to achieve 146 $MTCO_2e$ lower than the baseline in 2015, i.e. 330 $MTCO_2e$ with the rate of 44.24%/year. As comparison, the national CO_2 inventory showed that power sector contributed around 323,213 $MTCO_2e$ (2015).

The Projection of CO2 Emission Under Baseline and Mitigation Scenarios

Baseline scenario is referred as business as usual (BaU) with an assumption there is no mitigation effort, assuming the technology used in the beginning year to the year of CO2 emission estimation is the same where the combustion technology applied is conventional. Two mitigation scenarios (CM1/CM2) are developed with assumptions the clean coal technologies such as efficient plants, CHP, co-firing (with biomass) and integrated clean coal technology with the CCS are applied. Figure 3 presents the projection of baseline emission level and the CO_2 emission level under the two mitigation scenarios for the period of 2010 until 2050. It should be noted the base year of these projections is 2010.

It can be seen in Figure 3, baseline emissions level is estimated to increase at 7.8% per year (19.7 times) from 184 $MTCO_2e$ (2010) to 3657 $MTCO_2e$ (2050) as this scenario assumes there is no mitigation efforts or improvement in power generation plants. The technology used in the base year until the target year will be the same, i.e. conventional combustion technology with low thermal efficiency, which results higher CO_2 emissions.

Figure 3: Forecasting of CO_2 emission



	2010	2015	2020	2025	2030	2035	2040	2045	2050
BL	184	370	623	1048	1346	1728	2218	2848	3657
CM1	184	330	421	576	740	951	1222	1570	2017
CM2	184	330	368	400	388	347	321	251	140

In the other hand, the projection of CO_2 emission level under low/medium mitigation target scenario (CM1) will increase at a lower rate compared to the projection of baseline emission, i.e. 6.2% per year from 184 $MTCO_2e$ (2010) to 2017 $MTCO_2e$ (2050). With low CO_2 emissions rate, the projection level of CO_2 emission under CM1 is lower than baseline emissions. Mitigation under this scenario is moderate actions with low reduction potential. This scenario assumes reduction target of the commitment of Indonesia to keep increasing global temperature not more than 2°C can be achieve by implementing more efficient coal combustion technology (fluidize bed, sub-critical, ultra-supercritical, PLTSa or waste power plant (MSW/RDF) power plant, combine heat and power for coal and biomass power generation.

For the high or ambitious mitigation target scenario (CM2), the projection of CO_2 emission level will decrease 0.7% per year. With negative growth of emissions under the CM2, the projection of CO_2 emission level will reduce significantly after 2025 due to the introduction of negative emissions measures/technologies, i.e. IGCC (coal or co-firing), integrating IGCC with CCS, and BECCS. The reduction potential under these mitigation scenarios is discussed in the following sections and summarized in Table 3.

CO_2 Emission Reduction Potential Under Mitigation Scenarios

As discussed previously, in 2050, mitigations under CM1 scenario resulted significant reduction of the CO2 emission level up to 44.9% below the baseline, i.e. 1644 MtCO2eq while CM2 scenario resulted more reductions (if compared to CM1 scenario) up to 96.2% below the baseline, i.e. 1644 $MtCO_2e$. Compare to the emissions projection level under CM1, the projection level under CM2 shows that there is a significant change to the level after 2025, and make the growth of the CO_2 emissions level become negative. It can be realized by applying clean technologies for combustion systems of electricity generation, i.e. substitute the use of coal fuel with biomass/RDF and integrating the system with CCS.

The above system could result in reducing CO_2 emission level significantly at a negative rate. Table 3 presents the amount of CO_2 emissions reduction and % reduction from the baseline by each scenario while Table 4 presents the results of AIM/end-use modeling, in which the model selects the best available technology to be applied in Indonesia power sector base on availability, techno-economic feasibility, and also the associated emissions.

Table 3: The GHG emission reduction potential under mitigation scenario in 2050

Year	Mitigation Scenario	Reduction Potential ($MtCO_2eq$)	% Reduction
2050	CM1	1.644	44.9%
	CM2	3.521	96.2%

Table 4: CO_2 emission based on technology

Year	Technology	$MtCO_2eq$		
		BL	CM1	CM2
2010	*Direct Combustion (Coal)*	184	184	184
2015	*Direct Combustion (Coal)*	370	274	274
	CHP (Coal)	-	52	52
2025	*Direct Combustion (Coal)*	1,039	254	127
	PLTSa (MSW based Power)/RDF	-	141	141
	CHP (Biomass)	-	11	4
	IGCC (Coal)	-	-	59
	CHP (Coal)	-	169	72
	IGCC (co-firing biomass - coal) w/ CCS	-	-	-176
2050	*Direct Combustion (Coal)*	3,625	108	-
	PLTSa (MSW based Power)/RDF	-	958	96
	CHP (Biomass)	-	64	13
	CHP (Coal)	-	367	245
	IGCC (Biomass) w/ CCS	-	-	-1,495

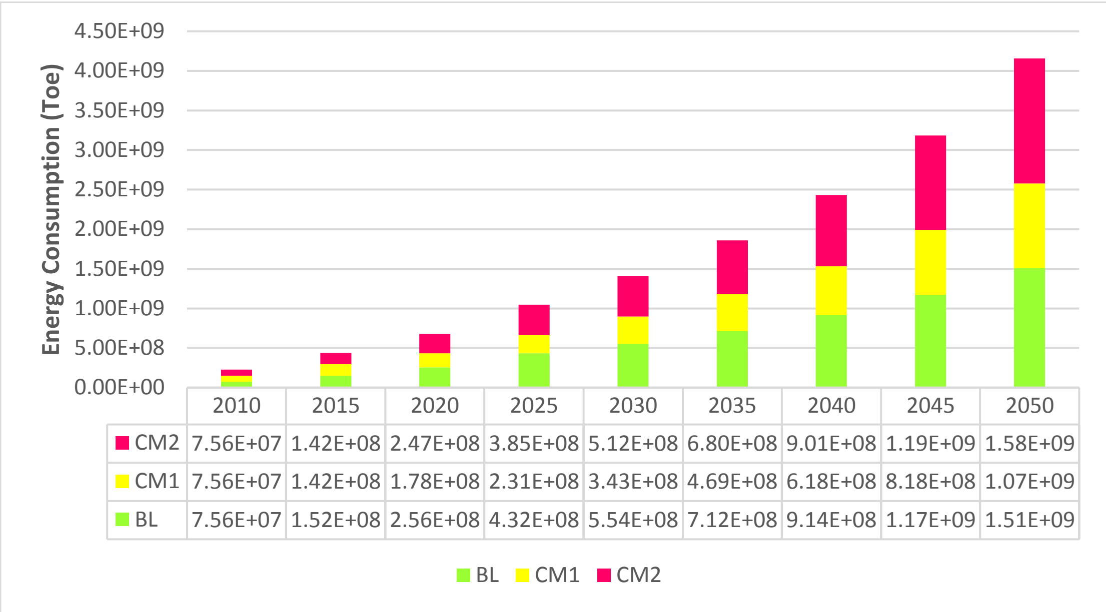
It can be seen in Table 4, the baseline emissions has increased from 184 $MTCO_2e$ (2010) to 370 $MTCO_2e$ (2015) with the rate of 50,27%/year as most of combustion technologies used in the Indonesia power plants are coal based direct combustion (although some CCT, i.e. fluidized bed, sub-critical, and ultra-supercritical are also deployed). This level is estimated to keep increase with the rate of 86.9 $MtCO_2eq$ (8%) per year to achieve 1,039 $MTCO_2e$ (2025) and 3,625 $MTCO_2e$ (2050) as it is assumed that there is no mitigation under this baseline scenario since 2010.

Table 4 also shows the emission under CM1 and CM2 mitigation scenarios are estimated to achieve 146 $MTCO_2e$ lower than the baseline in 2015, i.e. 330 $MTCO_2e$ with the rate of 44.24%/year. Since CM1 is assumed as moderate mitigation scenario, under this scenario the emission level will increase slightly lower than the baseline. CM2 is assumed as an ambitious mitigation scenario where several aggressive mitigation actions (i.e. IGCC Co-firing t integrated with CCS) are deployed so that this scenario will lead a negative carbon emissions level. In 2050, the GHG emission level under the CM2 will decline at an average rate of 1.09 $MtCO_2eq$ (-1%) per year could achieve -1.495 $MtCO_2e$.

Energy Consumption

GHG emissions under the baseline and two mitigation scenarios discussed previously are generated from the power plants, which are operated for producing electricity to fulfill the electricity demand in the country. The energy (electricity) demand is projected to increase inline with the population and economic growth. Energy model AIM/end-use can also estimate the energy consumption according to the desired scenario. Figure 4 presents the projection of energy (electricity) demand under each scenario, baseline as well as two mitigation scenarios that has to be fulfilled by the power plant 2010 to 2050.

Figure 4: Annual energy consumption



It can be seen in Figure 4, the BL scenario has the highest growth of energy consumption while CM1 and CM2 scenarios despite having implemented CCS at power plants also have smaller level of energy consumption compared to the BL scenario due to energy efficiency is implemented in the demand side. The projection of energy consumption under CM1 and CM2 scenarios compared to the BL scenario can be seen in Table 5. In 2025, CM2 scenario has increased from the BL scenario of 229 Mtoe or an increase of 53%. In contrast to the conditions in 2050, where the CM2 scenario experienced a decrease in the amount of energy consumption by 16% or 240 Mtoe, although not significantly with the CM1 scenario which decreased the amount of energy consumption by 70% or 106 Mtoe.

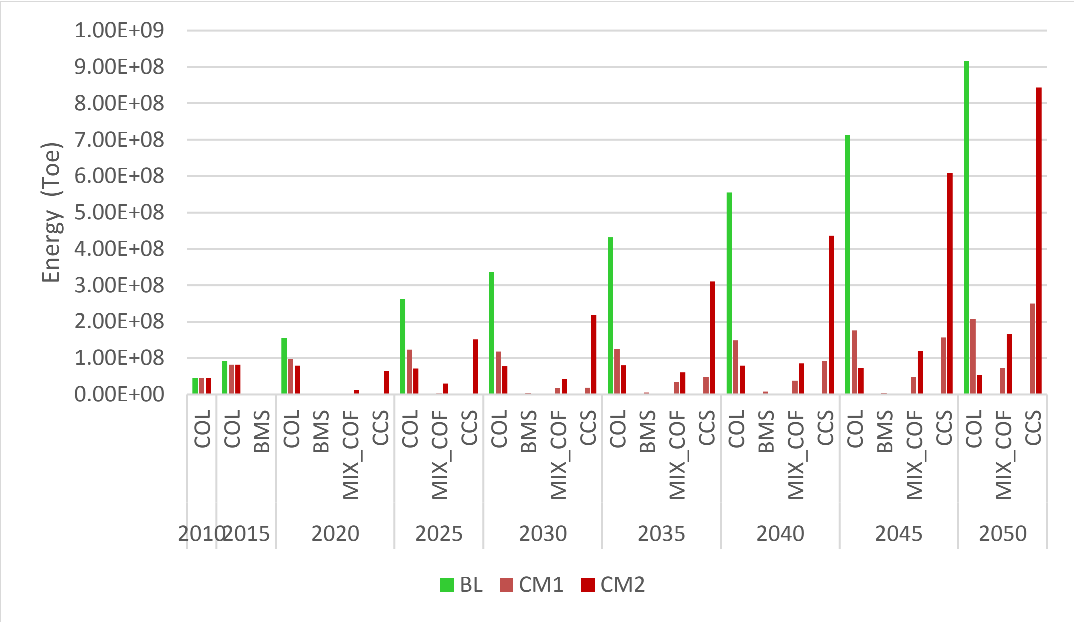
In Figure 4, can be seen in energy consumption of some of the energy used and the technology used, whereas in the scenario BL that only use coal fuel has increased significantly by 869 Mtoe in 2050 from 2015, as well as fuel use it, as well as the technology used, in the BL scenario is the direct combustion that has a small thermal efficiency of 20%. Small thermal efficiency in a combustion technology will lead to greater energy consumption. While for scenario CM1 and CM2 have used fuel other than coal that is biomass and RDF that can reduce coal consumption.

CM2 scenario which is applying CCS technology, it requires a lot of energy consumption. In 2050, it can be seen as a result of the use of CCS, with the largest energy consumption of 1495 Mtoe, higher than the energy consumption in the BL scenario that uses only coal and conventional combustion technologies. There are several reasons that result in high energy consumption in CCS.

Table 5: Total reduction of energy consumption from the scenario BL

Scenario	Toe					
	2015		2025		2050	
CM1	-1,33E+08	-87%	8,34E+07	19%	1,06E+09	70%
CM2	-1,33E+08	-87%	-2,29E+08	-53%	2,40E+08	16%

Figure 5: Energy demand per type of energy source and CCS (own use)



COST

Cost is a sacrifice to obtain a certain output. The sacrifice can be money, goods, energy, time, and opportunity. However, the economic analysis of the value of the opportunity (to obtain something) is missing for some other activities are also considered as a cost. The AIM / end-use energy model can look at several conditions in the next year, such as, the total cost of selecting a technological system at its minimal annually for various related constraints based on the recursive dynamic model concept. The total cost aims to compare capital cost on the purchase of equipment in the specific type of service, operating cost and maintenance requirements, as well as energy prices. Energy and carbon tax also be provided in the model to investigate the impact of the energy system.

Total cost calculated from AIM/end-use model is divided into four types, such as MNT (Total operating cost, which includes energy cost, material cost, maintenance cost, etc.), RCA (Total an investment cost), RCI (Total initial investment cost), there are four types of costs that can be seen the difference from several scenarios that exist.

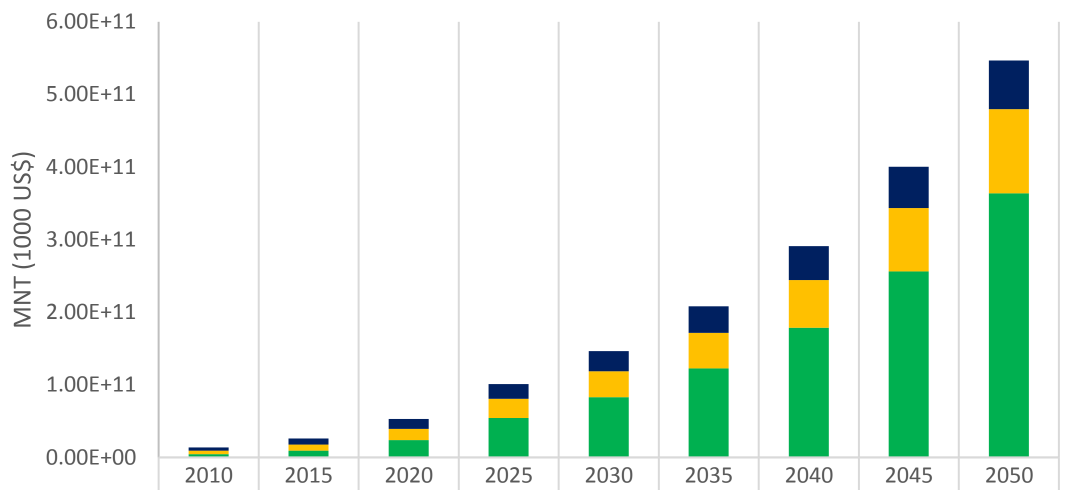
Table 6: Kind of cost calculation result

Year	Unit	Item	BL	CM1	CM2
2010	mil.US$	MNT	4.593.895.895	4.593.895.895	4.593.895.895
		RCA	3.785	3.785	3.785
		RCI	35.685	35.685	35.685
2015	mil.US$	MNT	9.252.765	8.302.878	8.302.878
		RCA	1.474	1.740	1.740
		RCI	13.896	16.400	16.400
2025	mil.US$	MNT	54.492.290	23.967.809	21.970.983
		RCA	2.831	1.838	2.802
		RCI	26.683	17.322	26.416
2050	mil.US$	MNT	363.939.405	104.464.439	125.135.790
		RCA	6.616	9.813	7.154
		RCI	62.364	92.506	67.443

TOTAL ANNUAL OPERATING COST

Operating costs are costs incurred to operate a system or operate a system and are also used in a production process consisting of direct materials, direct labour, and factory overhead. The cost of production is also called the product cost. That is the costs which can be associated with a product where this cost is part of the supply.

Figure 6: Total Annualize Operating Cost (MNT)



	2010	2015	2020	2025	2030	2035	2040	2045	2050
CM2	4.59E+09	8.30E+09	1.39E+10	2.02E+10	2.76E+10	3.64E+10	4.64E+10	5.70E+10	6.70E+10
CM1	4.59E+09	8.30E+09	1.51E+10	2.62E+10	3.60E+10	4.91E+10	6.59E+10	8.71E+10	1.16E+11
BL	4.59E+09	9.25E+09	2.40E+10	5.45E+10	8.28E+10	1.23E+11	1.79E+11	2.56E+11	3.64E+11

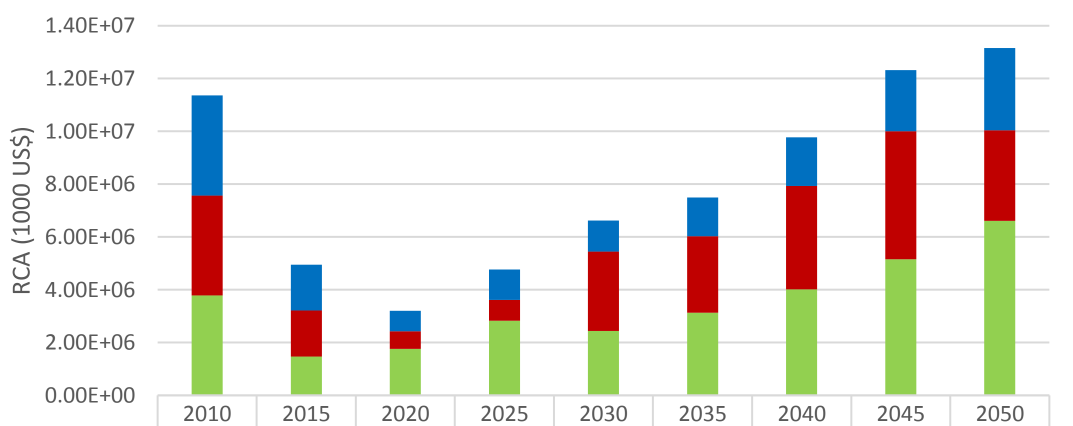
In the above figure, it can be seen the result of the total annual operating cost with a system in the power plant that has been selected. The BL scenario with no mitigation effort has a total operating cost that continues to increase sharply every year, very different when compared to CM1 and CM2 scenarios. This is greatly influenced by the selection of clean technology, with higher thermal efficiency, it will result in a smaller operating cost with near-perfect combustion and less energy consumption. The thermal efficiency of a technology is closely related to O&M (Operation and Maintenance) costs, as the smaller the thermal efficiency, the greater the O&M cost because the technology is increasingly in need of great maintenance and larger fuel supply to produce the same electrical capacity has great thermal efficiency.

The O&M cost itself has an understanding as the cost used to operate the system so that the system can operate properly and also used in terms of maintenance of a system in its operation. Operational and maintenance costs are usually carried out routinely during the operational life of a system.

TOTAL ANNUALIZED INVESTMENT COST

The investment can also called investment or capital formation is an expense or capital expenditure for investments or companies to purchase capital goods and paraphernalia to mine production capacity available in the economy. The addition of this amount of capital goods allows the economy to produce more goods and services in the future, therefore it is necessary to invest annually to replace old capital goods that have been thirsty and need to be depreciated (Abdul, 2005).

Figure 7: Total annual investment cost



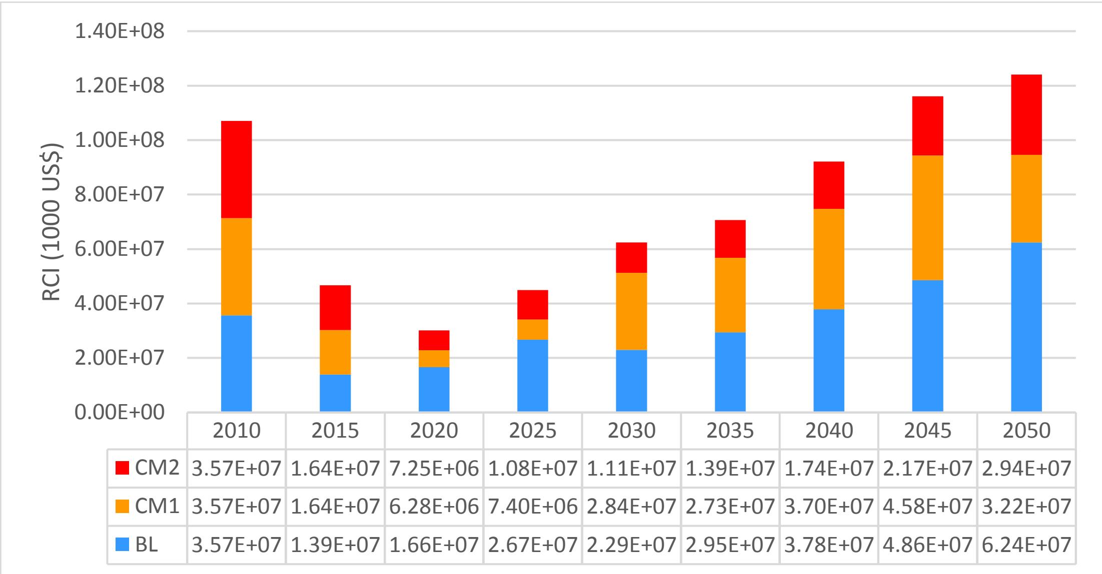
	2010	2015	2020	2025	2030	2035	2040	2045	2050
CM2	3.79E+06	1.74E+06	7.69E+05	1.15E+06	1.18E+06	1.48E+06	1.84E+06	2.31E+06	3.12E+06
CM1	3.79E+06	1.74E+06	6.66E+05	7.85E+05	3.01E+06	2.90E+06	3.92E+06	4.86E+06	3.42E+06
BL	3.79E+06	1.47E+06	1.76E+06	2.83E+06	2.43E+06	3.13E+06	4.01E+06	5.15E+06	6.62E+06

TOTAL INITIAL INVESTMENT COST

The initial investment cost is the costs that must be incurred at the beginning before the production activities are held. This fee is usually used for the purchase of machines (production facilities), installations, buildings, and so on. These initial costs tend to be large and have strategic values that include long-term time dimensions. Usually the time for investment costs is set for more than one year. The one-year limit is set on the basis of the habit of planning and realizing the budget for a period of one year. While total initial investment cost is the total cost of initial investment of production process.

It can be seen in Figure 8, the total initial investment cost of CM1 scenario increase much higher than the scenario of BL and CM2 in 2050, with an increase from 2015 by 76.106 1000.US$ or 82.3%, with some technology selected for CM1 scenario in 2050 is among his direct coal combustion, biomass CHP biomass, coal CHP, biomass direct combustion, co-firing IGCC with CCS, indirect co-firing, coal IGCC, and PLTSA.

Figure 8: Total initial investment cost



	2010	2015	2020	2025	2030	2035	2040	2045	2050
CM2	3.57E+07	1.64E+07	7.25E+06	1.08E+07	1.11E+07	1.39E+07	1.74E+07	2.17E+07	2.94E+07
CM1	3.57E+07	1.64E+07	6.28E+06	7.40E+06	2.84E+07	2.73E+07	3.70E+07	4.58E+07	3.22E+07
BL	3.57E+07	1.39E+07	1.66E+07	2.67E+07	2.29E+07	2.95E+07	3.78E+07	4.86E+07	6.24E+07

CONCLUSION

The 'end-use model' has been developed and has been used as a tool for the selection of cleaner (compare to existing) technology for coal power plant in Indonesia, particularly the introduction of an integrated system of clean combustion technology and CCS for coal base combustion system in power plant. The model is developed based on "bottom-up energy model of AIM/end-use" to obtain energy projection or pathway, the associated CO_2 emission reduction, and costs in the power plants under the baseline and mitigation scenario, where BECCS is considered as negative emission technology. The model is also can be used to select appropriate combusion technology in Indonesia power plant.

There are two mitigation scenarios developed, i.e. CM1 (moderate scenario) and CM2 (ambitious scenario). The aim of CM1 is to keep the increasing global temperature not more than 2°C while CM2 is to keep the temperature not exceed 2°C. The modelling results the mitigation under CM1 can reduce 44.9% CO_2 emission level from power sector in Indonesia under the baseline (BL) in 2050 while under CM2 can reduce up to 96.2%. The total cost needed for achieving the mitigation in 2050 under CM1 is 104.5 Trillion USD while under CM2 125.1 Trillion USD.

It is concluded that the use of BECCS integrated with clean coal technology can reduce emissions up to 44.9% or 1,644 MtCO2eq in scenario CM1 and 96.2% or 3521 in CM2 scenario below the baseline emissions in 2050. The CM2 scenario, which is an ambitious mitigation scenario, by applying CCS to the scenario can result in an average emission reduction of -1% annually from 2015-2050.

Optimal technology selection is carried out based on cost and emission reduction in CM2 scenario using IGCC technology with co-firing fuel integrated with CCS has emission reduction up to -176 MtCO2eq. Referring to the cost, the largest total operating cost in the scenario of BL in 2050 is 363,939,405 1000.US$ which requires high operational cost when compared with other scenario. As for total investment cost, CM2 scenario in 2050 that requires the greatest cost of 67.443 1000.US$ which is caused because the investment cost for CCS requires considerable cost.

ACKNOWLEDGEMENT

Contribution of the Center for Research on Energy Policy and the Department of Chemical Engineering – Institute of Technology Bandung in preparing this paper for this journal is highly appreciated.

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