Abatement cost for selectivity negative emissions technology in power plant Indonesia with aim/end-use model

Z D Nurfajrin¹*, B Satiyawira¹
¹Universitas Trisakti- Jl. Kyai Tapa No.1, Grogol Jakarta 11440, Indonesia
zakiahdarajat.zdn@trisakti.ac.id

Abstract. The Indonesian government has followed up the Paris Agreement with Law No. 16 of 2016 by setting an ambitious emission reduction target of 29% by 2030, and this figure could even increase to 41% if supported by international assistance. In line with this, mitigation efforts are carried out in the energy sector. Especially in the energy sector, it can have a significant impact when compared to other sectors due to an increase in energy demand, rapid economic growth, and an increase in living standards that will push the rate of emission growth in the energy sector up to 6.7% per year. The bottom-up AIM/end-use energy model can select the technologies in the energy sector that are optimal in reducing emissions and costs as a long-term strategy in developing national low-carbon technology. This model can use the Marginal Abatement Cost (MAC) approach to evaluate the potential for GHG emission reductions by adding a certain amount of costs for each selected technology in the target year compared to the reference technology in the baseline scenario. In this study, three scenarios were used as mitigation actions, namely CM1, CM2, CM3. The Abatement Cost Curve tools with an assumed optimum tax value of 100 USD/ton CO₂eq, in the highest GHG emission reduction potential, are in the CM3 scenario, which has the most significant reduction potential, and the mitigation costs are not much different from other scenarios. For example, PLTU – supercritical, which can reduce a significant GHG of 37.39 Mtoe CO₂eq with an emission reduction cost of -23.66 $/Mtoe CO₂eq.

1. Introduction
IPCC (Intergovernmental Panel on Climate Change) in 2007 has reported an increase in global earth temperature of 1.1 – 6.4 °C, encouraging sea level rise of around 16.5 – 53.8 cm in 2100. Of course, this can result in a land loss on the earth’s surface. According to estimates, if sea levels rise by about 1 cm, several islands in the South Pacific region and the Indian Ocean will completely disappear. The increase in the earth’s temperature makes the climate challenge to predict and is at risk of causing extreme weather. In the 2015 Paris Agreement, countries participating in emission mitigation efforts have agreed to limit the average global temperature increase to less than 2°C and an ambitious target of reaching 1.5°C. The Indonesian government followed up the agreement with Law no. 16 of 2016 concerning the ratification of the Paris Agreement on the United Nations Framework Convention on Climate Change [1,2].
For Indonesia, the increase in the earth's temperature threatens many islands due to rising sea levels. Based on these problems, the Indonesian government has supported efforts to mitigate greenhouse gas emissions in Indonesia. Through its INDC, Indonesia has set an ambitious reduction target of 29% by 2030, and this figure could even increase to 41% if supported by international assistance [3]. The Indonesian government has also stated its commitment to create clean and low-carbon national development and actively contribute to mitigating carbon emissions. The government launched an implementation directive for technical ministries called the RAN (National Action Plan) on GHG as stipulated in Presidential Regulation Number 61 of 2011 [4,5]. The basic principle established is that RAN-GRK does not hinder economic growth, improve people's welfare through sustainable development and protect the poor and vulnerable [6].

In the First Nationally Determined Contribution (NDC), Indonesia in 2016 has shown data on the National GHG emission inventory in 2010, with the forestry sector contributing 49% of total emissions of 110.5 MtCO$_2$eq, while the energy sector occupies the second position with a percentage of contributed emissions of 34% of the total emission of 647 MtCO$_2$eq which can be seen in Table 1.

### Table 1. Projected BAU and GHG emission reductions from various sectors [3].

| No. | Sector | GHG Emission Level 2010* (Mtoe CO$_2$eq) | GHG Emission Level 2030 (Mtoe CO$_2$eq) | Annual Average Growth BAU (2010-2030) |
|-----|--------|----------------------------------------|----------------------------------------|---------------------------------------|
| 1   | Energy*| 453.2                                   | 1,669                                   | 4.50                                  |
| 2   | Waste  | 88                                      | 296                                    | 4.00                                  |
| 3   | IPPU   | 36                                      | 69.6                                   | 0.10                                  |
| 4   | Agriculture | 110.5                                 | 119.66                                 | 1.30                                  |
| 5   | Forestry** | 647                                   | 714                                    | 2.70                                  |
| TOTAL |        | 1,334                                   | 2,869                                   | 3.20                                  |

*Including fugitive; **Including peat fire; CM1 = Counter Measure (Unconditional mitigation scenario); CM2 = Counter Measure (Conditional mitigation scenario)

The IEA in 2019 statistical data has stated that for Indonesia's 2018 GHG emissions in energy use, the first position as a contributor to GHG emissions in Indonesia is occupied by the power generation sector, which is 39.85% of the total emissions in 2018, which is 542 Mton CO$_2$eq.

### Table 2. Share emission by energy sector in 2018 [7].

| No. | Sector                              | Total Emission (Mtoe CO$_2$eq) |
|-----|-------------------------------------|---------------------------------|
| 1   | Electricity                         | 216                             |
| 2   | Industry                            | 114                             |
| 3   | Transportation                      | 154                             |
| 4   | Residential                         | 23                              |
| 5   | Agriculture                         | 5                               |
| 6   | Commercial                          | 2                               |
| 7   | Final Consumption not elsewhere     | 1                               |
| 8   | Other Energy Industries             | 27                              |
| TOTAL |                                    | 542                             |

Viewed from the source of fuel used by the power generation sector, it turns out that coal plays a significant role. That could be the reason why the power generation sector is the largest emitter. In addition, the IPCC states that coal also has the most prominent emission factor compared to other power generation fuel sources with the fossil energy-burning activity in power plants is a significant contributor to GHG emissions in the energy sector, with a cumulative average growth rate for the 2010-2016 period.
of 7.66%. The Performance Report of the Directorate General of Electricity Indonesia, 2017 discusses the increasing growth rate in the use of fossil fuels as the primary fuel in power plants, which is so significant that it can be caused by the increasing demand for electricity which continues to increase in the context of energy fulfillment and equitable access to national electricity [8].

The increasing national electricity production trend is shown in Table 3, with an average growth rate of 6.63% of electricity production increasing from 169,786 GWh (2010) to 283,801 GWh (2018). This increase was obtained from coal power plants which grew to 58.41% in 2018, increasing from 38% in 2010. Electricity production from oil plants decreased to 5.6% in 2018. Electricity production This oil-fired power plant was dominated by small to medium-scale PLTDs operating in remote areas as a rural electrification improvement program. Meanwhile, the production of NRE power plants - PLTA (Hydroelectric Power Plant) and PLTP (Geothermal Power Plant) is still a priority, and other renewable plants such as PLTS (solar power plant), PLTBn (Biofuel Power Plant), PLTBm (Biomass Powe Plant), and PLTB (Wind Power Plant) - are still in an insignificant portion compared to fossil energy generation [8].

Table 3. Electricity production in Indonesia, 2010-2017 [8].

| Electricity Production (TWh) | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-----------------------------|------|------|------|------|------|------|------|------|
| 169.78                      | 183.42 | 200.32 | 216.19 | 228.56 | 233.98 | 247.92 | 254.62 |

The Indonesian government has issued a policy to reduce dependence on fossil fuels to increase national energy security. Primary energy supply needs to be increased based on new and renewable energy (EBT) to meet energy needs without burdening the trade balance and reducing GHG emissions. Presidential Regulation No. 79 of 2014 concerning KEN (National Energy Policy) states that the Indonesian government prioritizes the use of NRE with a minimum share of 23% in 2025 and increases to 31% in 2050. In addition, a 2019-2038 RUKN suppresses the portion of the fuel energy mix up to 0.1% in 2038 and increases energy efficiency by applying low-carbon technologies.

The biggest challenge today and in the future is how to meet energy demand by providing clean, reliable, and available energy in large quantities. Various poverty alleviation programs and policies will increase people's incomes and enable people to consume various electronic products that require electricity, increasing global energy demand. One thing that can be done in response to this challenge is optimizing alternative resources and increasing energy efficiency in Indonesia. As well as creating an integrated energy system in the context of sustainable energy efficiency improvements by integrating energy efficiency activities in the existing management system to take into account factors costs, environment, energy availability, and business risks [6,9].

Seeing the gap between actual conditions and what is expected, a tool is needed to support the government's efforts in assessing and selecting New and Renewable Energy under social, economic conditions and the availability of technology and resources in Indonesia. In line with this, it can be done by using the bottom-up AIM/end-use energy model based on an optimization model to determine the use of various technologies and energy sources used in the future. The Asian Pacific Integrated Model End-use (AIM/end-use) developed by the National Institute for Environmental Studies (NIES), Japan, is an appropriate energy optimization model used for very detailed technology selection by taking into account the total cost of the system to find a path with the lowest cost [10].

In addition, the AIM/end-use model has a deeper level of technical detail than the top-down energy model. This model is used to assess future energy demand and supply, uses an economic evaluation approach of simulated technology, and usually does not consider the macroeconomic impacts of energy or climate policies or related investments. One of the AIM/End-use energy model outputs that can assess the economic impact of GHG mitigation efforts is MACC (Marginal Abatement Cost Curve). Compared to several other indicators, such as the payback period, MACC is more appropriate to be a reference in making mitigation decisions because it reflects the cost of a mitigation option during the range of mitigation activities. Furthermore, it can guide the cost of reducing per unit of emissions during certain
mitigation activities compared to the costs of the activities that become the baseline. Generally, MACC is expressed in units of USD/ton CO$_2$eq [11,12,13,14,15,16,17,18].

Fabian, 2011 explains the advantages of MAC in the assessment of a GHG mitigation policy:

- the present marginal abatement cost for any given total reduction amount,
- give the total cost necessary to abate a defined amount of carbon emissions,
- allow the calculation of average abatement cost,
- extensive technological detail,
- the possibility of taking into account technology-specific market distortions,
- straightforward understanding of technology-specific abatement cost,
- MAC, on the bottom-up side, have a model that explicitly maps energy technologies in detail.

The fulfilment of Indonesia's Nationally Determined Contribution (NDC) emission reduction target requires substantial funds. Implementing the carbon market must be carried out by considering the various opportunities and risks related to the type of instrument and its scope. To address the opportunities and risks associated with the scope of the carbon market instrument, one of the government policy strategies that can be taken is to consider the potential and costs of the types of mitigation actions carried out. Abatement cost or MAC shows the costs of reducing per-unit emissions throughout the project. Moreover, it can make it easier for relevant stakeholders to identify outputs from climate change through the procurement of a budget that has several components such as RAN GRK (National Action Plan for GHG Reduction), RAD GRK (Regional Action Plan for GHG Reduction), Integrated Monitoring, Evaluation and Reporting System. [11,12,19,20,21].

2. Methodology

The AIM/end-use energy model is an energy model developed by Japan's National Institute for Environmental Studies (NIES) for processing data from the model using GAMS (General Algebraic Modeling System) software. The AIM/end-use energy model is a type of model that provides functions that were not present in the previous bottom-up model. The model can calculate changes in energy consumption from technology substitution caused by changes in energy prices in a bottom-up path. Therefore, it is possible to evaluate the efficiency of a single policy and how the effects occur when several policies are combined. By linking the technology selection model with the energy demand model, it is possible to estimate the energy efficiency based on the actual conditions. -respective technology [22,23,24].

Figure 1. The structure of the AIM/End-use model in the electricity sector.
The structure of the AIM/end-use model for the electricity sector in this study is shown in Figure 1, first determining the service demand for electricity demand up to the simulation target year based on the consideration of socio-economic factors. Furthermore, the AIM/end-use model will determine the type or type of technology to fulfill the service [10]. After determining the type of technology, the energy model will estimate the energy consumption and emissions resulting from the operation of the selected technology. Based on technology selection in this model, a roadmap for low carbon technology can be developed to achieve an emission reduction target [22]. The output of the AIM/end-use model is interpreted in the form of a pivot diagram in the form of the energy mix, emission level, service, stock, and installed technology. From the cost analysis, the output of this model is an abatement cost (AC) curve that estimates the potential for emission reductions against mitigation costs for each selected technology.

The Figure 1 shows an overview of the AIM/end-use framework built to evaluate the potential for energy savings and GHG emission reductions in the Indonesian electricity sector. The AIM/End-use model framework consists of the essential elements of energy, devices, and services. This model uses energy, coal, biomass, natural gas, oil, biofuels, hydropower, geothermal, wind power, solar power, nuclear, and co-firing. Co-firing is a blend of biomass and coal; co-firing is considered very potential to reduce the use of coal in power plants. Biomass feedstock for co-firing can be biomass waste, which is processed in wood pellets or wood chips. The device element consists of various types of technology for each type of fuel used. At the same time, the service is classified into two types, namely internal service and final service. Internal service is the output of one device and, at the same time, is the input of the next device, while the final service is the final service or product produced in a process.

2.1. Marginal Abatement Cost Curve (MACC)

The abatement cost curve is used to evaluate the potential for GHG emission reductions by adding a certain number of costs for each selected technology in the target year compared to the reference technology in the baseline scenario. The abatement cost in each technology is calculated based on the total cost that meets the requirements, and the technology with the abatement cost lower than the selected carbon price will be selected. The basic concept of calculating the cost of reduction is described in the following formula:

\[
\text{Abatement cost} = \frac{\text{Mitigation Cost}}{\text{emission GHG reduction}}
\]

GHG emission reduction is defined as the sum of the difference in GHG emission levels from the reference technology in the baseline scenario and the selected low-carbon technology in the mitigation scenario. Meanwhile, mitigation costs are additional costs that include investment costs and O&M costs for the selected technology to the cost of the reference technology. However, if the mitigation cost of the selected technology is lower than the reference technology, then the mitigation action of the selected technology will not only reduce emissions but also reduce the total cost (investment and O&M cost).

2.2. Model assumptions and parameters

Parameters of energy consumption, electricity production for each type of power plant in this study refer to data published by the Directorate General of Electricity (Statistics of Electricity Indonesia). Specifications of Indonesia's existing technology are based on data published by the Indonesian agency for the National Energy Council [8]. This study sets 2010 as the base year, considering the provisions of international agreements and NDC. Mitigation action planning in the Indonesian power generation sector is developed for a time interval of 10 years to the target year (2050). Parameters used in the AIM/End-use model include energy parameters, including price, fuel, and emission factors resulting from combustion activities at the power plant. The following parameter is the technical technology parameter. Data for these various parameters are collected from relevant literature, as shown in Tables 4 and 5.
2.3. Energy price
Various types of energy are used as energy sources in power plants. Analysis in the AIM/end-use model requires the input of price data for various types of energy from 2010 to projections in 2050. The price data for each type of energy is presented in Table 4.

| Energy         | 2010 | 2018 | 2020 | 2025 | 2030 | References |
|----------------|------|------|------|------|------|------------|
| Coal           | 116  | 90   | 80   | 85.6 | 96.5 | [25,26,27] |
| Natural Gas    | 180  | 301  | 301  | 301  | 301  | [26,28]    |
| Oil            | 616  | 595  | 595  | 595  | 595  | [24,25]    |
| Biomass        | 296  | 296  | 296  | 296.2| 296.2| [29]       |
| RDF            | 59   | 59   | 59   | 58.6 | 58.6 | [30]       |
| Bio-fuel       | 1180 | 685  | 685  | 685  | 685  | [31]       |
| Geothermal     | 845  | 632  | 632  | 632  | 632  | [24,25]    |

2.4. Emissions Factor
The parameters used in the simulation of this AIM/end-use model include technical parameters and emission parameters. Emission parameters consider the emission factor values of various energy sources used. According to the 2006 IPCC guidelines, the main types of GHG emitted from combustion activities at the power plant are CO₂, CH₄, and N₂O, equivalent to CO₂e units. In addition to factor emission data, other parameters such as calorific value and carbon content of various types of energy are presented in the following Table 5.

| Fuel          | Calorific Value (TJ/Gg) | Carbon Content (%) | (tCO₂/TJ) | (tCH₄/TJ) | (tN₂O/TJ) | (tCO₂e/TJ) |
|---------------|-------------------------|-------------------|-----------|-----------|-----------|------------|
| Coal          | 0.76                    | 42.92-73.82       | 99.178    | 0.001     | 0.0015    | 997.205    |
| Oil           | 1.73                    | 85                | 75.200    | 0.003     | 0.0006    | 752.036    |
| Natural Gas   | 45.20                   | 71                | 57.600    | 0.003     | 0.0001    | 576.011    |
| Biofuel       | 27.00                   | N/A               | -         | 0.003     | 0.0006    | 0.0036     |
| Biomass       | 0.63                    | N/A               | -         | 0.030     | 0.004     | 0.034      |

2.5. Data Technology
Low carbon technologies are accounted for and evaluated explicitly in the AIM/End-use model. The goal of implementing low-carbon technology is to improve energy efficiency and reduce GHG emissions. In this research, there are 43 technologies related to the process in power plants that will be used. In detail, the technical parameter data such as investment costs, OM costs, technology lifetime, energy efficiency, capacity factor, and capacity are obtained from various related kinds of literature.

2.6. Projection of Electricity Production and Consumption
Figure 2 shows electricity production and electricity consumption rate (kWh/capita) in 2010-2050. Actual data on national electricity production from 2010 to 2018 was obtained based on inventory data in the electricity statistics of DJK ESDM, projected data for 2019-2030 was obtained based on RUPTL 2019-2028 and NDC Indonesia, with an average annual growth rate of 6.17%. Then the long-term projection data until 2050 is projected to increase by considering the annual average growth rate of 3.53%. The level of electricity production increased from 169.8 TWh in 2010 to 1126 TWh in 2050. Along with the increase in electricity production, the consumption rate also experienced an increasing trend from 0.77 kWh/capita to 2.91 kWh/capita. The level of electricity production 2010-2050 is applied to all scenarios built to see the mitigation potential of each scenario.
Figure 2. The level of electricity production in the Indonesian electricity sector at the “inventory” and “projected” levels.

2.7. Scenario model
Scenario analysis is an approach to measure the potential for energy savings or emission reductions in a simulation model framework. This study built four scenarios: baseline (BAU) and several alternative mitigation scenarios (CM1, CM2, CM3). Alternative mitigation scenarios are used to carry out more ambitious energy efficiency and GHG emission reductions. The comparison of several scenarios in this study is described in detail in Table 6, as follows:

| Skenario | Deskripsi Skenario |
|----------|--------------------|
| BAU (Baseline scenario) | The business as usual (BAU) scenario is a baseline scenario without any intervention efforts to reduce GHG emissions. Baseline scenario assumptions: there is no effort to increase the energy efficiency of conventional power plants, the mix of fuel oil power plants remains the same since the base year. There has been no additional renewable energy generation since the base year. According to the planning scheme for existing plants, the increase in electricity demand is met by constructing conventional coal plants (subcritical), PLTD (Diesel Power Plant), and gas generators. |
| CM1 | Mitigation actions in the CM1 scenario to achieve long-term targets have been aligned with the Indonesia NDC (CM1) follow-up scenario for the electricity sector. |
| CM2 | Mitigation actions in the CM1 scenario to achieve long-term targets have been aligned with the Indonesian NDC (CM2) follow-up scenario for the electricity sector. In this scenario, there is an implementation of IGCC’s advanced technology since 2035. |
| CM3 | The utilization of renewable energy sources is more significant than the NDC target, the level of utilization of renewable energy takes into account the availability of fuel and technology readiness, where co-firing has been started since 2030, the use of CCS technology integrated into fossil power plants (coal and gas), and the use of nuclear energy starting in 2040. |
Table 7. Detailed scenarios for CM1 and CM2 NDC Indonesia in the energy sector.

| No. | Scenario                                | BAU                          | Mitigation Scenario CM1 | Mitigation Scenario CM2 |
|-----|-----------------------------------------|------------------------------|-------------------------|-------------------------|
| 1.  | Efficiency in final energy consumption | In-efficiency in final energy consumption | 75%                     | 100%                    |
| 2.  | Implementation of clean coal technology in power plant | 0%              | 90%                     | 100%                    |
| 3.  | Renewable energy in electricity production | Coal power plant | 19.6% (committed 7.4 GW based on RUPTL) | Electricity production of 132.74 TWh |
| 4.  | Implementation of biofuel in the transportation sector (Mandatory B30) | 0%              | 90%                     | 100%                    |
| 5.  | Additional gas distribution lines       | 0%              | 100%                    | 100%                    |
| 6.  | Additional compressed-natural gas fuel station (SPBG) | 0%              | 100%                    | 100%                    |

3. Result and discussion
The initial step is to validate from 2010 to 2015 to see the reliability of the data entered. For the first five years, there was no increase in GHG emissions due to the absence of the application of renewable technology. The BL (Baseline) scenario can also be referred to as the freezing scenario because there is no mitigation effort in this scenario, assuming the technology used from the beginning to the end of the year is the same, namely conventional direct combustion. Meanwhile, the CM1 and CM2 scenarios have applied technology upgrades according to the predetermined scenario model.

Figure 3. Results of Forecasting GHG Emissions Mitigation Efforts 2010-2050 in various scenarios.

In 2050, CO₂ mitigation is carried out by several mitigation efforts in the CM1 scenario of 578.35 Mtoe CO₂eq or 43%, the CM2 scenario of 632.43 Mtoe CO₂eq or 47%, and the CM3 scenario of 959.92 Mtoe CO₂eq 71% so that it can be proven that applying clean electricity generation technology and upgrading the use of fuel and technology can reduce CO₂ emissions in the atmosphere.
Table 8. Emission calculation result data and percentage of GHG emission reduction against Baseline scenario each year.

| YEAR | BL | CM1 | CM2 | CM3 |
|------|----|-----|-----|-----|
|      | Mtoe CO\textsubscript{2}eq | Mtoe CO\textsubscript{2}eq | Emissions reduction compare with BL scenario | Mtoe CO\textsubscript{2}eq | Emissions reduction compare with BL scenario | Mtoe CO\textsubscript{2}eq | Emissions reduction compare with BL scenario |
| 2010 | 133.31 | 133.31 | 0% | 133.31 | 0% | 133.31 | 0% |
| 2015 | 211.59 | 211.59 | 0% | 211.59 | 0% | 211.59 | 0% |
| 2020 | 280.50 | 236.18 | 16% | 221.10 | 21% | 221.10 | 21% |
| 2025 | 448.71 | 267.88 | 40% | 235.80 | 47% | 235.79 | 47% |
| 2030 | 630.33 | 426.35 | 32% | 387.03 | 39% | 343.76 | 45% |
| 2035 | 879.52 | 611.77 | 30% | 559.25 | 36% | 495.36 | 44% |
| 2040 | 1100.49 | 765.53 | 30% | 702.45 | 36% | 536.02 | 51% |
| 2045 | 1269.15 | 805.38 | 37% | 743.84 | 41% | 500.84 | 61% |
| 2050 | 1359.17 | 780.81 | 43% | 726.74 | 47% | 399.25 | 71% |

Table 8 presents data on GHG emission reductions for the BL scenario and abatement cost values based on the selected technology in 2050. AIM/end-use will select available technologies to be applied in Indonesia based on technology availability, economics, and an environmental perspective, namely emissions, which it produces.

Table 9. GHG emission reduction and abatement cost based on selected technology.

| No. | Scenario | Technology | Reduction of GHG Emissions (Mtoe CO\textsubscript{2}eq) | Abatement Cost ($/ton CO\textsubscript{2}eq) |
|-----|----------|------------|-------------------------------------------------|----------------------------------|
| 1.  | CM1      | PLTGU – Combined Cycle Power Plant (CCGT) | 33.09 | -109.75 |
|     |          | PLTG – Open Cycle Gas Turbine (OCGT) | 16.21 | -98.68 |
|     |          | PLTU – USC (Ultra Supercritical) | 8.10 | -31.16 |
|     |          | PLTA – Large Hydro | 47.49 | -24.81 |
|     |          | PLTU – (Supercritical) | 37.39 | -23.66 |
|     |          | PLTB – Small Onshore | 5.21 | -22.88 |
|     |          | PLTS – Solar PV Utility-Scale with Li on Battery Storage | 1.05 | -17.80 |
|     |          | PLTD – Biofuel | 7.98 | 28.68 |
|     |          | PLTBm – Small | 2.37 | 38.67 |
|     |          | PLTP – large | 45.08 | 99.64 |
|     |          | PLTGU – Combined Cycle Power Plant (CCGT) | 33.09 | -109.75 |
|     |          | PLTG – Open Cycle Gas Turbine (OCGT) | 16.21 | -98.68 |
|     |          | PLTU – USC (Ultra Supercritical) | 8.10 | -31.16 |
|     |          | PLTA – Large Hydro | 54.39 | -24.68 |
|     |          | PLTU – (Supercritical) | 37.39 | -23.66 |
|     |          | PLTB – Small Onshore | 12.11 | -21.84 |
|     |          | PLTS – Solar PV Utility-Scale with Li on Battery Storage | 4.50 | -10.35 |
|     |          | PLTD – Biofuel | 7.98 | 28.68 |
|     |          | PLTBm – Small | 2.37 | 38.67 |
|     |          | PLTP – large | 67.15 | 100.89 |
| 2.  | CM2      | PLTGU – Combined Cycle Power Plant (CCGT) | 33.09 | -109.75 |
| 3.  | CM3      | PLTGU – Combined Cycle Power Plant (CCGT) | 33.09 | -109.75 |
The emission reduction cost curve or MACC is a graph depicting the MAC and the mitigation potential of all the mitigation activities considered. MACC can be an effective policy-making tool because it can provide a simple means to identify what mitigation activities are the most cost-effective and provide excellent mitigation potential. Visually, mitigation activity is considered carried out up to a specific time or in the target year of 2050.

![Figure 4. Marginal Abatement Cost Curve in 2050 based on Selected Technology.](chart)

This curve is displayed as a line sorted from the most cost-effective to the most expensive to reduce costs. The Y-axis represents the value of the abatement cost, while the X-axis represents the magnitude of the mitigation potential, as shown in Figure 4. Meanwhile, for the line under the X-axis or the abatement cost is negative, the activity can be carried out during the life of the mitigation activity. Provide economic income when compared to activities in the baseline scenario. Based on Table 8 and Figure 4, it is found that several types of technology have added economic value for Indonesia, with low mitigation costs, but have a large enough impact in efforts to reduce GHG emissions. The CM3 scenario...
has the most significant reduction potential, and the mitigation costs are not much different from other scenarios. For example, PLTU – supercritical, which can reduce GHG emissions after significant and direct coal-fired PLTBm, 37.39 Mtoe CO$_2$eq with an emission reduction cost -23.66 $/Mtoe CO$_2$eq.

4. Conclusion

Based on the studies that have been carried out, it can be concluded that Indonesia has enormous potential for renewable energy to be applied to the electricity sector in the long term. Reducing emissions in the CM1 scenario by 578.35 Mtoe CO$_2$eq or 43%, in the CM2 scenario by 632.43 Mtoe CO$_2$eq or 47%, and CM3 scenario by 959.92 Mtoe CO$_2$eq 71%. We have an abatement cost value that can provide economical income for Indonesia. However, in mitigation activities with a relatively high-cost value, the government can implement a policy or program with the target that the value of the mitigation cost can decrease in the long term.

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