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ORIGINAL ARTICLE

Potential impact of introducing emission mitigation policies in Indonesia: how much will Indonesia have to spend?

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Abstract
Under the Nationally Determined Commitment (NDC), Indonesia voluntarily reduces GHG emission by 29% compared to the BAU level in 2030. While the national economics itself is still growing and advancing, the mitigation policies are expected to slow down the economy at some level. This study is trying to examine the potential impact of the emission mitigation policies on the Indonesian economy by utilizing a dynamic computable general equilibrium (CGE). The simulation result showed that the implementation of comprehensive mitigation technology would cause a GDP loss of around 1.7% by 2030 compared to the BAU level. If we look at the sectoral GDP, the agriculture sector is projected to experiencing the most significant shock by the emission mitigation policies (−13.4% compared to BAU level by 2030). But the energy sector might become a sector experiencing higher GDP under the mitigation action (3.5% compared to BAU level by 2030). It also showed that the utilization of renewable energies for power generation would increase significantly, especially after 2025, but still cannot fully replace the dominance of fossil fuel sources. There are several policy recommendations based on our simulation results, including that the government also needs to increase efficiency in using fossil fuels, especially coal and gas, during the process of building infrastructure for renewable energy utilization. In terms of employment, the government needs to prepare other sectors to absorb labor, especially from the agricultural sector. Another crucial thing is that considering the possible economic impact, especially in the mid-term period, the government needs to implement necessary mitigation policies immediately. Otherwise, the government may need to prepare more expenditure to introduce more technologies and policies in the future.

Keywords CGE · Emission mitigation · Mitigation technologies · Nationally Determined Commitment (NDC)

Abbreviations

AFOLU	Agriculture, forestry, and land use
AIM	Asia-Pacific Integrated Model
CCS	Carbon capture storage
CCT	Clean coal technology

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CES	Constant Elasticity of Substitution
DDPP	Deep Decarbonization Pathway Project
ASEAN	Association of Southeast Asian Nations
BAU	Business as Usual
CGE	Computable general equilibrium
CM	Countermeasures
G20	Group of Twenties
GDP	Gross domestic product
GHG	Greenhouse gases
INDC	Intended Nationally Determined Contribution
IO	Input–output
IPPU	Industrial processes and product use
LUCF	Land use change and forestry
MP3EI	*Masterplan Percepatan dan Perluasan Pembangunan Ekonomi Indonesia* (The Acceleration and Economic Development)
MSW	Municipal solid waste
NDC	Nationally Determined Commitment
PLTA	*Pembangkit Listrik Tenaga Air* (Hydropower Power Plant)
PLTD	*Pembangkit Listrik Tenaga Diesel* (Diesel Power Plant)
PLTGU	*Pembangkit Listrik Tenaga Gas-Uap* (Gas-Steam Power Plant)
PLTP	*Pembangkit Listrik Tenaga Panas Bumi* (Geothermal Power Plant)
PLTS	*Pembangkit Listrik Tenaga Surya* (Solar Power Plant)
PLTU	*Pembangkit Listrik Tenaga Gas* (Gas Power Plant)
RUEN	*Rencana Umum Energi Nasional* (National Energy Plan)
RUPTL	*Rencana Umum Penyediaan Tenaga Listrik* (General Plan for Electric Power Supply

1 Introduction

Indonesia's economy has advanced gradually but steadily as one of the best economies in the Group of Twenty (G20). It has become the largest economy in the Southeast Asia region. However, Indonesia still struggles to transform its economic structure and to become a developed country (Legowo 2017). To this end, the Indonesian government has established several masterplans to boost the country's economic growth. At the same time, the Indonesian government is significantly ambitious and committed to reducing its emissions. Under the Nationally Determined Commitment (NDC), Indonesia must reduce its total emissions by 29% (voluntary) or 41% (with foreign aid) by 2030 to be in line with the Business as Usual (BAU) levels. However, achieving this target is challenging due to its tendency to slow down the economy that Indonesia aims to boost by optimizing the use of all national resources. Thus, the government must consider the cost and impact of implementing mitigation policies on its economy as well as the environment.

The stated emission reduction target is challenging because Indonesia also faces certain environmental issues. For example, in the agriculture, forestry, and land use (AFOLU) sector, Indonesia experiences high and rapid deforestation and forest degradation along with seasonal forest fires caused by El-Niño or human activities (Chrysolite et al. 2017). Additionally, as a country with a dense population, Indonesia must ensure food sustainability by maintaining its agricultural production. Thus, massive land conversion is inevitable.

Although emission mitigation action from the land sector is usually considered cheaper than other sectors, the policy realization can be very challenging. It is very common for countries that intend to reduce emissions from land-use change and forestry, and they will need to prepare and implement a range of policies and instruments (Tacconi and Muttaqin 2019). Besides, for countries that are highly dependent on the land sector (e.g., commercial plantation and agricultural land), various Indonesian government policies related to this sector may also affect the economy.

The energy sector is also a problematic one for Indonesia. One of the most crucial issues is to manage the energy resources to meet national needs. As economic conditions improve and grow, the energy demand will also increase. However, crude oil sources, which have become one of Indonesia's primary energy sources, are becoming limited. In these circumstances, coal use is favored due to its availability and economical price. Nevertheless, its use may lead to a significant increase in GHG emissions (Hwang and Yoo 2014). Another solution is to utilize renewable energy. However, the technology employed for the utilization of renewable energy is mostly imported, and Indonesia's geographical challenges make the installation of supporting infrastructure difficult and expensive. From the business perspective, Indonesia still has a distorted energy market and high political economy constraints, especially about the energy and transportation sectors (Kaneko 2016; Luthfi and Kaneko 2016). These factors have considerably slowed the progress of renewable energy utilization.

The government has already established certain emission mitigation policies to achieve the national emission reduction target. However, several studies in various countries imply that emission reduction projects may slow down the economy at some level, especially for developing countries that have lower budget accumulation. The government is likely often to miscalculate that impact (Millar et al. 2016). Therefore, it must be ready to address a situation that may arise as a result of the emission mitigation actions (Dissanayake et al. 2020). Nevertheless, there is a lack of studies about it for developing countries, including Indonesia.

Several studies related to GHG actions in Indonesia exist but have not yet considered mitigation in all sectors. Mitigation in the AFOLU sector was first introduced by Hasegawa et al. (2016). Using the global Asia–Pacific Integrated Modelling/computable general equilibrium (AIM/CGE) combined with the AFOLU model, this study shows that if Indonesia aims to meet the latest Intended Nationally Determined Contributions (INDC) target. According to their result, approximately 58% of total reductions should come from agriculture, forestry, and other land-use sectors through the implementation of forest protection, afforestation, and plantation efforts. The study also shows a high carbon price in the year 2030. Thus, reaching the 2030 target would be economically challenging. However, there are no details about the exact economic impact of mitigation in this sector.

Related research for the energy sector has been carried out by Siagian et al. (2017). Their main finding was that the GDP changes are positive at 0.6% and 0.3% for Counter Measure 1 (CM1) and Counter Measure 2 (CM2), respectively, due to a substantial increase in coal use in the baseline scenario. This result is counter-intuitive because emission reductions usually generate negative impacts on the macroeconomy. Their study also stated that emission reductions could be satisfied through the electrification of end-user consumption where the electricity supply becomes decarbonized by deploying renewables for power generation. This reduction could be achieved mainly by the deployment of geothermal power plants.

A more comprehensive study that employs more detailed data was carried out under the Deep Decarbonization Pathway Project (DDPP). Indonesia's DDPP report states that it has the technical potential to profoundly reduce its energy-related CO_2 emissions to a level that will significantly contribute to the global efforts of preventing an increase of 2 °C in the temperature by 2050. The three decarbonization scenarios in that study ("Renewable Energy," "Renewable Energy + Carbon Capture Storage [CCS]," and "Economic Structural Change") will achieve approximately the same CO_2 emission level of 402 million tons in 2050, which translates into 1.3 t CO_2/capita. Unfortunately, the study only measures the emission reduction without further and separate consideration of the economic impact and the AFOLU sector analysis, respectively (Siagian et al. 2015). The separate results of DDPP for the AFOLU sector show that the rate of emissions until 2050 would remain high and would not be very different from the present emissions. These emissions can be significantly reduced only by improving land and forest management, optimizing land use for agriculture and timber plantation development, and enhancing mitigation policies and measures. Hence, by 2050, this sector could become a net sink. The report states that one of the main obstacles is the high cost of this mitigation, but no economic impact was introduced (Boer et al. 2016). As the documents list comprehensive technologies and mitigation targets, this study has borrowed several datasets from them.

Overall, this study attempts to simulate an emission mitigation policy on the Indonesian economy by utilizing a computable general equilibrium (CGE) specifically established for Indonesia (country model). We designed the model to give the best fit with the Indonesia condition that has not conducted in the previous research. By utilizing this model, we hope to fill the study gap on emission mitigation policies in developing countries, especially Indonesia, as we realize that there is still very lack of study on emission mitigation impact for the country. While it is very important as an input for the government and policymaker to decide further steps. This study also tried to introduce all mitigation policies and technologies stated on Indonesia's 2nd Biennial Update Report (2nd BUR) that states all Indonesian government plans to achieve a 29% emission reduction target. By considering the possible mitigation that the Indonesian government already planned, it is hoped that they may be able to prepare better in facing any possible socio-economic consequence of emission mitigation policies and consider better policy practice in the future.

2 Method

2.1 CGE model

This study employs a CGE model that has been established explicitly for a country scale. CGE is a computer-based simulation used to describe the whole economy and its sectoral interaction through a system of equations. The model is often utilized for policy analysis as it aims to connect all the sectors in the economy. The simulation usually begins with the BAU, followed by the introduction of certain policy shocks (e.g., climate change mitigation policy). The model then generates a new general equilibrium after the shock (Babatunde et al. 2017).

In the CGE model, the supply and demand in the economy are always assumed to achieve their equilibrium through the price mechanism. If the demand for goods/services exceeds its supply, the prices will increase until the demand decreases, hence achieving the equilibrium level. On the other hand, if there is an over-supply in the market, the prices will decrease until the producers decide to reduce their supply. Therefore, in the CGE model, agent interaction is mediated by market and price, and the price is determined

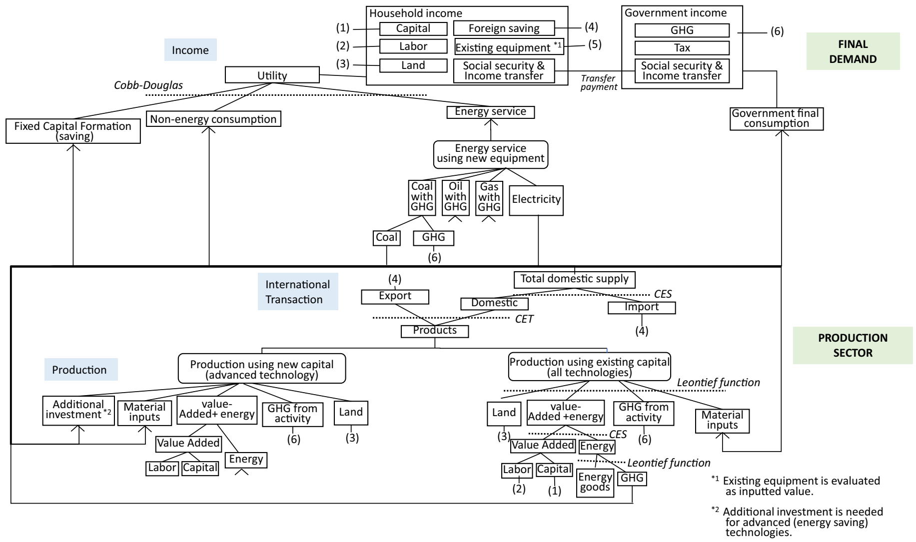

Fig. 1 CGE structure for this study. CES constant elasticity of substitution, CET constant elasticity of transformation. Value inside the bracket (…) shows the line connection

based on the supply–demand interaction in the market (Masui 2005).To built a CGE model, a dataset that describes the connection between supply and demand in the economy is needed. Therefore, some datasets like input–output table (IO table), social accounting matrix (SAM), or supply-use table are often utilized as the base data for the CGE model development.

We have built an Indonesian model that consists of 38 sectors whose establishments are based on the aggregation and disaggregation of the 2010 Indonesia IO table that initially had 185 sectors (Badan Pusat Statistik 2015). This IO table is the latest dataset available during this study is conducted and has the most detailed sector classification to describe all the supply and demand of the country.

The model captures the equilibrium of supply and demand in the economy. The decision of sector classification is based on Indonesia's mitigation policies that cover "land-based" sectors (agriculture and forestry), energy, waste, and industry. In the economy, each sector is linked to another. In this model, the connection between the sectors is described in Fig. 1. The model consists of three main blocks as follows: a production block, a final-demand block, and an international transaction block. Each block relates to a specific type of elasticity of substitution.

Our CGE model is a dynamic-recursive model, which means that the model will make a sequential simulation for each year. This method is useful because we want to represent the Indonesia case, while the lack of data is often becoming a problem. Using recursive dynamic, the model can formulate using relatively small numbers of variables. Also, the recursive dynamic process can minimize the terminal condition problems (Masui 2019). Moreover, we also need to accommodate the research objective in this study to assess the Indonesian emission mitigation policies by 2030. Using a dynamic CGE country model gives us more flexibility in parameter adjustment and gives a better description of Indonesia's situation and policies. To design a model that gives the closest description to the real situation, we also utilized some national statistics as supporters and anchors for our modeling work.

Another problem that we want to accommodate is the base data for this model. As mentioned before, the base data for this model is IO table, with 2010 as the base year. Thus, we need to set the model to give a simulation result that able to describe the real condition and maintain the reliability of the model. The dynamic process helps us achieve this objective as we can do the calibration test and compare the result with the statistic. It is also important to ensure model consistency. Thus, we do calibration tests and compare our results with the statistics. Our calibration test checked the simulation results in BAU level from 2010 to 2019 with the statistic. From that test, we found that the deviation between our simulation and the statistic is < 5%, which means the model is reliable enough to describe the condition in Indonesia. The result of this calibration process and the recursive model can be found in Appendix 2.

2.1.1 Production

The first block, i.e., the production block, consists of a set of production factors, including capital and labor, which are aggregated as composite value-added. Land is also considered as a capital input, specifically for land-based sectors (agriculture and forestry). Therefore, land is also included in this production block in the model. Each subsector has a nested production function. The top of the nested production function is assumed to use the Leontief production function, which means that each input is set and cannot be substituted by another. The other parts have been set using constant elasticity of substitution (CES).[1]

The primary factors, such as capital composite and labor, consist of aggregated CES function. The capital is substitutable by composite energy inputs by the CES function. While this block involves capital, it will experience some rate of depreciation each year. For this study, the depreciation rate is assumed to be 5%/year. As this model is a recursive-dynamic, the capital in the model will be updated every year during the simulation process for an annual update of the model. Thus, in the model, the production in each sector is disaggregated into subsectors using existing capital stock and new capital stock. If the mitigation policy is introduced, capital efficiency is updated and will later affect the production mechanism (Fig. 2).

2.1.2 Final demand (household and government consumption)

This block consists of households and the government. The household sector receives income by providing inputs such as capital, labor, and land. In this model, the households share their income with the government via the tax mechanism, while the government can transfer income to the household (e.g., social transfer, pension, health insurance, and so on). This income also becomes the constraint by which the household optimizes its utility, and the government optimizes social welfare. Moreover, the household and government consumption's initial value are based on the information from the IO table (final demand side).

[1] The CES function assumes that elasticity of substitution among the inputs is constant. When the elasticity of substitution parameter is defined as σ, it means σ% of relative input change to 1% of relative price change.

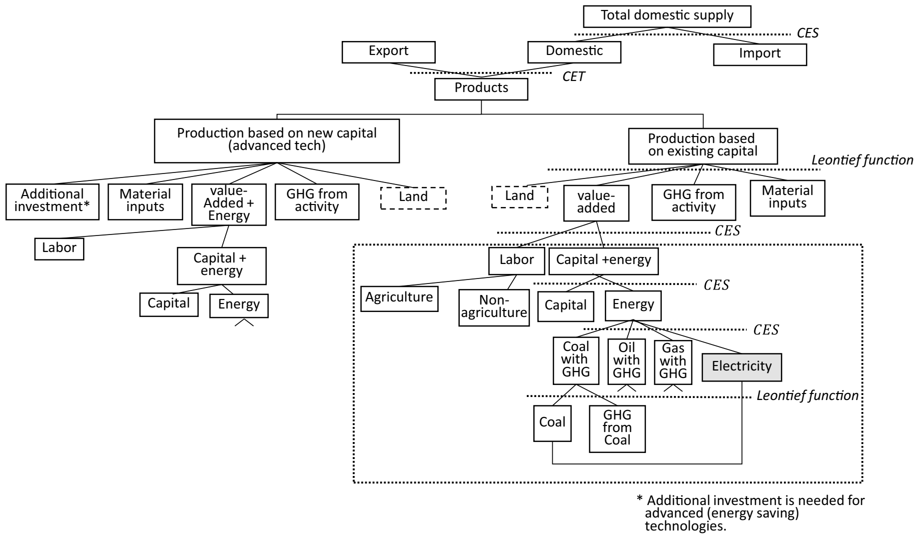

Fig. 2 Structure detail of the production block

2.1.3 International transaction

For international trade, the model uses the "small-open economy" assumption, which assumes that the economy is so small that it will not significantly impact the rest of the world. The goods domestically produced/consumed and imported/exported are assumed to be imperfectly substitutable. The market gathers all the products and production factors and connects all the economic agents. The supply and demand of every factor and commodities are balanced through the price mechanism in the market. Nevertheless, the Armington assumption, a general assumption used for international trade in the CGE model, is used to distinguish between each good. The model assumes imperfect substitutions between import, export, and domestic goods, due to which a difference in price may exist (Hosoe et al. 2010). In the case of an export-domestic supply decision, producers supply more to the market at a higher price. In the case of import-domestic decisions, consumers select goods from the cheaper market.

Again, those blocks interact and connect through the market and are balanced by the price mechanism. In other words, the CGE model makes a strong assumption that the economy is always in a state of equilibrium. Like most CGE models, in principle, the model determines the price and quantities in equilibrium condition by solving the cost-minimization set in each nested block (Nordhaus 2013). Hence, the result of the CGE model is highly dependent on exogenous parameters and its settings. In the next section, the data and assumptions made in this study will be introduced.

2.2 Data

2.2.1 Indonesia IO Table 2010

The primary data for this model is the Indonesian IO Table (2010). The IO table is a matrix that depicts a macroeconomic system of interrelated goods and services. Each

Table 1 Growth rate of exports and imports

No	Year	Import growth (%)	Export growth (%)
1	2011	31%	29%
2	2012	8%	−7%
3	2013	−3%	−4%
4	2014	−5%	−4%
5	2015	−20%	−15%
6	2016	−5%	−3%

Source: Calculated from Badan Pusat Statistik (2019a) and (b)

row in the matrix describes the intermediate demand and final demand; the matrix columns capture the supply side. As the preparation of an IO table is a time-consuming process, in Indonesia, this table is only prepared every 4 or 5 years. It is based on the assumption that although the current prices and the production processes change each year, the economic structure did not change significantly during the drafting of the table (Badan Pusat Statistik 2016). This study uses the Indonesian IO Table of 2010 as the base data, and it makes 2010 as the base year for our analysis (Badan Pusat Statistik 2015).

The original sectors amounted to 185, but for this study, the data were aggregated into 38 sectors (Appendix 1, Table 3). The land-based sectors consist of paddy, corn, and cassava; other agricultural commodities include rubber, palm oil, other plantations, livestock, wood, and forest (sectors 1–10). Regarding electricity, the sector is also disaggregated in the model based on its sources such as electricity from coal, oil, gas, renewables-non biofuel, and renewables-biofuels.

2.2.2 International trade

Export and import values follow the value in the input–output model. As mentioned before, this model using a small-open economy. Thus, information about international trade is needed. As the IO table only provides information for the target year (2010), the export and import growth rates need to be updated during the simulation. The growth from 2011 to 2017 follows the statistics, and it can be observed that the growth varies on a yearly basis. However, international trade can hardly be predicted based on these annual trends only. Therefore, from 2017 onward, we assume that the international growth follows the same growth as the GDP (5.1% per year from 2018 to 2025, and 5.2% per year from 2025 to 2030) (Table 1).

2.2.3 Population

Population data are needed for labor projection in the model. In this study, the population data are taken from the official statistics published by Badan Pusat Statistik (2013), which provides the population data of 2015 that are then projected onto 2035. The updated data in Badan Pusat Statistik (2018) that provide the statistics from 2015 to 2017 are projected onto 2045. Based on these publications, the annual population

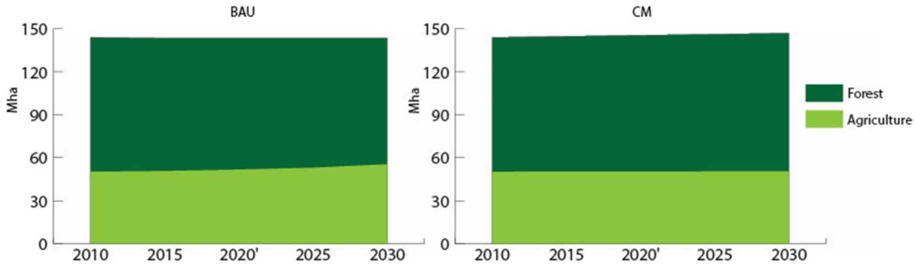

Fig. 3 Land area in the BAU and CM scenarios. The agricultural land includes cropland, plantation, and livestock land

growth is estimated to be 1.3–1.4% from 2010 to 2015, 1.1% for 2015–2020, 1% for 2020–2025, and 0.9% for 2025–2030.

2.2.4 Land use change and forestry treatment

Ten sectors are classified as land-based (LAND). These sectors need an area of land as input to produce their output. The value of the area required for these sectors is decided exogenously, based on a previous study that can be found in Malahayati and Masui (2019). In the CM scenario, the forest area is slightly greater than in the BAU scenario due to the consideration of the mitigation measures (yield improvement and reforestation) for land-use change and forestry (LUCF) (Fig. 3).

2.2.5 Data for electricity generation

There is only one electricity sector in the Indonesian IO table. However, electricity can be produced from different power generations, and each power generation may utilize a different energy source. In this study, we want to disaggregate the power plants (pp) into oil pp, gas pp, coal pp, renewable pp (all renewables excluding biomass and waste pp), and bio pp (biomass and waste pp). To achieve this kind of disaggregation, we need additional information related to power generation.

All information in the IO table is stated in monetary value. So, to match the electricity statistics with the IO table and do the disaggregation process, the electricity provision cost is needed. Also, the CGE model is based on the price mechanism and all decisions will be depend on supply and demand, which are based on the price. Thus, the simulation of power generation in the model will also depend on the proportion of its provision price. This electricity provision cost information has been taken from the Basic Costs for Provision of National Electric Power in 2015 stated in the General National Energy Plan (*Rencana Umum Energy Nasional*/RUEN) (Table 2).

As for the electricity provision cost for the coal power, we follow the decided price according to the Ministry of Energy and Mineral Resources Decree No. 1772 K/20/MEM/2018, the average cost of basic National Electric Power provision is approximately IDR 1025/kWh. This value is assumed to be the price of coal pp, considering that most of Indonesia's power plants are coal-generated power plants.

Table 2 Basic costs for provision of National Electric Power in 2015

No	Power plant	Represented power plant	Price (IDR/kWh)
1	Diesel (PLTD)	Oil pp	3992
2	Gas and steam (PLTGU)	Gas pp	1843
3	Gas (PLTG)	Gas pp	806
4	Steam (PLTU)	Gas pp	661
5	Coal*	Coal pp	1025
1	Solar (PLTS)	Renewable-non-biofuel pp	8786
2	Geothermal (PLTP)	Renewable-non-biofuel pp	1058
3	Hydro (PLTA)	Renewable-non-biofuel pp	388
4	Bioenergy PP	Waste-biofuel	3000

The cost of coal pp is based on MEMR Decree No. 1772 K/20/MEM/2018. Source: Dewan Energi Nasional (2017)

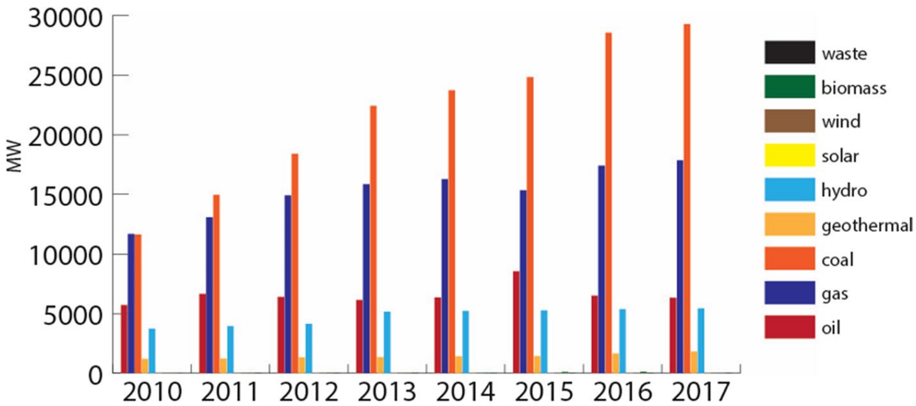

Fig. 4 Summary of Power plant (pp) installed capacity (MW) in Indonesia 2010–2017. Source: Kementerian Energi dan Sumber Daya Mineral 2015, 2016, 2017, 2018a, b

To continue the disaggregation process, we also need information on electricity generation. The detail of electricity generation information is available in the physical unit and can be found in Indonesia Energy Balance Table (Kementerian Energi dan Sumber Daya Mineral 2018a).

Furthermore, we studied the government plan for electricity supply through the General Plan for Electric Power Supply 2019–2028 (*Rencana Umum Penyediaan Tenaga Listrik*/ RUPTL) (Kementerian Energi dan Sumber Daya Mineral 2019). In this document, the government stated the existing installed capacity and future expansion plant for its power generation. From 2010 to 2017, Indonesia continued to rely heavily on fossil fuels, especially coal, gas, and oil, to generate power (Fig. 4). After 2017, it was planned to expand the use of renewable sources of energy. Unfortunately, as shown in Fig. 5, the expansion plan for renewable use still seems unclear and unsustainable. Later, we used this projection to set the maximum capacity of the power generation in the simulation (upper limit).

The upper limit is needed as CGE is a model with an optimization principle; the model tends to select the cheapest options based on the price. If we do not set an upper limit, the

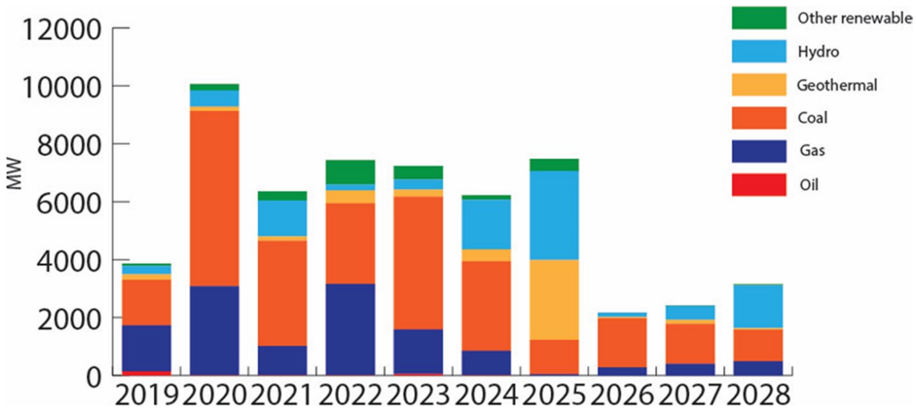

Fig. 5 Power plant expansion plan 2019–2028 (MW). Source: Kementerian Energi dan Sumber Daya Mineral (2019)

model will select the most affordable energy sources. In this case, the model will keep choosing (e.g., coal) due to their relatively lower price. That simulation will not be entirely rational because coal resources are limited and must be substituted with other energy sources, especially in terms of renewables in the future. Hence, we utilized the data from the general plan of power generation (*Rencana Umum Penyediaan Tenaga Listrik/RUPTL*) before deciding the upper limit, which is based on the installed capacity and future expansion plans mentioned above. In that way, the model will not only choose the energy source based on the price but also regarding its availability.

2.2.6 Relative international price of fossil fuel

As a small open economy is adopted in the model, the international price of fossil fuels plays an important role in determining energy export and import. Indonesia is a net exporter of coal and a net importer of oil. Thus, any international price change in the future may affect its international energy policy. For simplicity, we used relative price (current price compared to the price of the previous year) rather than the nominal price.

The calculation of future fossil fuel prices is based on the estimation made by the International Energy Agency (IEA) and Institute of Energy Economics Japan (IEEJ) (Sadamori 2018; IEA 2019, 2020). This information needs to be set to minimize logical error during the simulation. Without set up of this international price, the model may keep choosing to, for example, export the coal as it will be more profitable. However, this logic is not really fit because, in the future, the international price for coal and other fossil fuel will be decreased along with the reduction of the global demand. Therefore, the coal export will not be as profitable as now.

The relative price of energy used for this study is summarized in Fig. 6.

2.3 Scenario

There are only two scenarios introduced in this model:

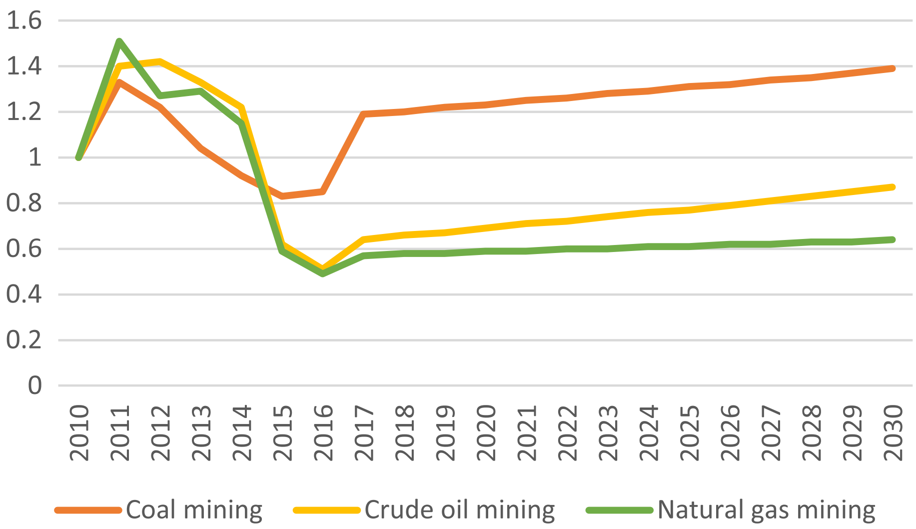

Fig. 6 Summary of Relative International Price of fossil fuel 2010–2030. Sources: Sadamori 2018; IEA 2019, 2020

1. Business as Usual (BAU) and
2. Counter Measures (CM), where emissions are reduced by 29% from BAU level in 2030 along with mitigation technologies from all sectors.

The simulation will compare the macroeconomic condition, labor force, and energy utilization for power generation between BAU and CM scenarios.

To limit the GHG emission to 29%, we treat the emission as "goods" by introducing an "emission certification/emission right." Thus, the emission must also undergo the supply–demand mechanism in the market. The total emission is endowed by the government and regarded as a kind of "emission certification." Under the CM scenario, this emission certification is 29% lower than the BAU level. If the total demand for certification exceeds the total supply, certification price becomes positive and leads to a higher energy and production price. To prevent higher production costs, each sector must introduce new capital/technologies that cause lower emissions or reduce its production level. As the transition cannot happen all at once, the combination of old and new (lower-emission technologies) is possible in the model. Besides, the model will determine the combination based on the technology-constraint profit maximization mechanism.

This model's mitigation technology can take two forms, reducing either GHG emissions and/or energy use. To achieve such a reduction, some additional costs from the related sector's increase in capital will be necessary. Moreover, Indonesia also did not provide detailed and comprehensive quantitative emission reduction targets for each mitigation technology. As information about technological expenses and the emission mitigation potential per technology/policy is limited, most additional costs are assumed to be similar to efficiency improvement.

The assumption of mitigation technologies used in this simulation is described below.

2.3.1 Agriculture

There are several emission mitigation options listed in Indonesian Biennial Update Report and National Communication (Boer et al. 2017, 2018). However, there is still limited information regarding the mitigation potential for each technology, while we need some value for parameter setting under the CM scenario. To accommodate this problem, we looked at some literature and compared it to the previous research using similar datasets like Hasegawa et al. (2014) and Hasegawa and Matsuoka (2015) to ensure that our assumptions are rational not having too much and does not have too much discrepancy with the previous studies. We also borrow some storylines and assumptions from Indonesia Deep Decarbonization Pathway Project (DDPP) document for Indonesia (Boer et al. 2016). Moreover, our parameter setting for the CM scenario in this study is as follows:

Water management Water management is linked to the irrigation system to ensure water supply for crops, especially for paddy fields that must be flooded during the growing phase. It is assumed that 60% of emissions from rice cultivation comes from water management. Rice cultivation shares 33.49% of emissions from agriculture, and it is assumed that water management shares 60% of emissions from paddy cultivation. Additionally, fixing the irrigation system is expected to reduce water management's impact by approximately 40% (Elliott et al. 2014). In this context, the simulation was conducted for 15 years, and a rough calculation resulted in emission reduction from water management of around 0.5% per year for the paddy sector. Irrigation is not as crucial for other crops as for the paddy sector; hence, the introduction of water management should reduce emissions by only 0.1% per year. Additional capital would be required to fix the irrigation system. For some crops, such as corn and cassava, and other agricultural products, such as rubber, palm oil, and wood, the additional capital is assumed at the same proportion as the further GHG reduction (~0.1% per year). However, for rice, which might be more expensive and complicated, additional capital should be around 0.3% per year.

Low-emission cultivar For paddy fields, specifically, a conversion from the IR64 variety to *Ciherang* is assumed. The average emission from the *Ciherang* cultivar is almost 50% lower than that of IR64. The average emission from *Ciherang* cultivar per ha per session is around 114.8 kg and is 202.3 kg per ha per session for IR64 (Malahayati and Masui 2018a). This is a ~43% reduction for the low-emission cultivar. It is assumed that 40% of emissions from the paddy sector come from rice cultivar. Rice cultivation contributes around 33.49% of all emissions in the agriculture sector; this value is then multiplied by 40% and 43%. Another consideration is that, in some land types and climates, the IR64 still grows better than the *Ciherang* cultivar, so a further assumption is made by combining these two cultivars at a 50:50 ratio. While emission technology's assumption started in 2016, the value is divided for a project of around 15 years, and approximately 0.2% of emission reduction from the paddy sector remains per year. To reach this 0.2% level, a further rise in the cost of 0.2% is assumed.

Urea and ammonium sulfate fertilizer combination Urea fertilizer is utilized in all agriculture and plantation sectors. However, it may lead to high N_2O emissions. To minimize emissions from urea utilization, the fertilizer can be mixed with any ammonium sulfate fertilizer, such as ZA, which has a lower nitrogen content. The urea nitrogen content is 46%, while that of ZA is 21% (De Klein et al. 2006; Alabama A&M University, Auburn

University 2018); replacing urea with ZA may lower nitrogen emissions by 50%. However, this is not such a wise option for farmers because they tend to double the amount of ZA fertilizer when replacing urea entirely. Apparently, a reduction of 25% of total nitrogen emissions can be achieved from the combination of urea and ZA. Urea fertilization contributes about 4.5% of the total emissions in agriculture. Based on this information, for a 15-year emission mitigation project, emissions can be reduced by approximately 0.1% thanks to this technology.

More efficient fertilizer Although an efficient fertilizer such as NPK (nitrogen (N), phosphorus (P), and potassium (K)) is available in the market, some farmers prefer to use single-content fertilizers and mix them themselves, which frequently leads to an overdose. However, emissions can be reduced to some extent. For example, in ammonium phosphate fertilizer, the nitrogen content is 18%, while in NPK,[2] the nitrogen content is only 15%. Replacing the fertilizer with NPK reduces direct nitrogen emissions from soils by approximately 17%. Nonetheless, the price of NPK fertilizer is so much higher than any other kind of fertilizer that replacing it with NPK would be very costly for farmers. As a result, it is assumed that farmers continue to use 50% of their previous fertilizer.

Direct N_2O emissions from the soil contribute around 30% of the agricultural sector's emissions (De Klein et al. 2006; Rochette et al. 2008; Zhang et al. 2016). However, this technology's implementation may reduce around 3% of emissions from agriculture or around 0.2% per year. Thus, the fertilizer industry must also increase its investment in the production of more NPK fertilizer. In this study, the proportion of capital investment is considered equal to the potential GHG reduction (~0.2% per year).

Manure utilization for biogas The emissions from manure can be minimized if it is gathered and then utilized for developing biogas. By compiling the emissions from manure management and direct N_2O from manure, these sectors contribute 6.44% of agriculture emissions(calculated from Boer et al. (2018). If 50% of the total manure from this source can be collected and used for biogas, half of the emission can be cut or approximately 0.2% of emission reduction per year can be achieved. For the establishment of dome digesters and support of biogas development, it is assumed that the same portion of additional capital is required in the building sector (~0.2% per year).

Liming This is usually used for plantation crops when the land is considered acidic and cannot support plants' growth. As the use is limited to the acidic soil, there is limited information on the potential emission mitigation by applying this liming technology. For this study, we assume that the emission reduction through a decrease in liming use is expected to be around 1% per year, in line with the assumption of reduction rate of the total area used for the commercial plantation. However, not all commercial plantations are in acidic condition. From the literature, we found that at least 1/3 of land in the tropical area tends to have an acidic condition (Munawar 2011). Thus we divided the value by three, and we assume that the liming may contribute around 0.3% of emission reduction. Furthermore, it is assumed that the chemical industry must increase its capital by the same amount (0.3% per year).

[2] The NPK used here is NPK 15 (N): 15 (P): 15 (K).

2.3.2 IPPU

More efficient production process The assumption is based on the annual trend of additional emission and reduction. Between 2000 and 2016, emissions in the industrial process and product use (IPPU) sector averaged an increase of 0.2% annually. Some technologies focused on the cement, chemical, and metal-based industries to reduce emissions as follows: (a) enhancement of the use of alternative materials (blended cement program) for the replacement of clinkers by decreasing the “clinker to cement ratio” from 80% in 2010 to 75% in 2030; (b) efficiency improvement of ammonia production plants to reduce the use of natural gas as feedstocks as well as an energy supply in the ammonia plant and CO_2 recovery in the primary reformer of fertilizer industry; (c) improvement of the processing system in the smelter industries; (d) use of a secondary catalyst in nitric acid production; (e) claims of GHG emission reduction potential in aluminum smelters. However, during 2015 and 2016, those technologies could achieve only 0.16% of the anticipated emission reduction (Boer et al. 2018). Concerning this trend, mitigation focuses on the three following main industries: cement, chemical, and metal-based industries. The continued improvement of technology in these industries may reduce emissions by 0.2% per year. As there are still some restrictions regarding information about costs, a capital improvement of 0.2% per year in the machinery (other industries) sector is assumed.

2.3.3 Waste

Waste management installation The assumption for waste treatment is one of the most difficult due to a minimal monitoring system of waste emissions. The statistics show that emission reduction in 2015 and 2016 only accounted for 0.014% compared to the BAU level by using some waste technologies(Boer et al. 2018; Dewi et al. 2019). This value is too small because most waste management treatment activities are not recorded due to inadequate monitoring facilities. This main reduction in waste management of Municipal Solid Waste Treatment (MSW) was brought about by altering open dumping to sanitary landfill and recovering landfill gas. In Indonesia’s IO Table, solid waste is mostly calculated in the waste and recycling sector, while wastewater is recorded in the water sector.

Hence, a GHG reduction rate of 0.1% per year in the waste and recycling service and 0.05% in the water supply sector is assumed. It is also assumed that capital cost improvement is needed to construct a waste management facility. The assumption of capital improvement is in the same proportion as emission reduction.

2.3.4 Energy

The emissions from energy include fuel combustion and fugitive emissions. The mitigation technology will also be related to these two activities, but the emission reduction in fuel combustion will contribute more as it involves more sectors. In general, the key to emission mitigation in the energy sector is to increase the investment in order to introduce more efficient technology that will demand less energy without affecting normal activity (add new capital). Moreover, there is more use of renewable energies for power generation. Most of the energy efficiency assumptions we adopt from the assumption and target stated in DEN (2019). Here are our scenario settings to get the similar target and assumption stated in the document.

Energy efficiency in the commercial and industrial sector There is a target to achieve energy efficiency for at least 10% of large energy consumers. As the employment of more efficient machinery and technologies is encouraged, the commercial and industrial sectors are assumed to achieve at least a 0.1% per year reduction in electricity consumption. The industry sector can also reduce approximately 0.2% of coal and oil due to the regulation and the investment of new technologies. Indeed, these sectors will need capital improvement. Thus, capital improvement is assumed at the same rate as the ratio of electricity consumption.

Energy efficiency in the household sector The household sector should be able to reduce the consumption of oil (kerosene). The consumption reduction ratio is assumed to be 0.1% per year for each energy type. This will also require capital improvement from the industry in line with energy consumption reduction.

For *power generation*, the efficiency improvement is captured by the reduced use of primary energy, especially fossil fuel power generation. The coal pp, oil pp, and gas pp are expected to reduce coal, oil, and gas use by approximately 0.1% per year. For this reduction, there should be some development and adjustment of the power plants to support the new technology. One technology introduced is the development of Clean Coal Technology (CCT), which is anticipated as being widely established in Indonesia to reduce the use of oil and gas and increase coal use. At the same time, the cost of CCT will be relatively expensive compared to energy consumption reduction. In this study, each fossil-fueled power plant is assumed to add 0.2% per year of additional capital to support the new technologies. We also set a higher limit for fossil fuel sources and a lower limit for renewable energies and biomass/waste sources to support Indonesia's plan to achieve around 23% in the national energy combination by 2025 (Dewan Energi Nasional 2017, 2019).

2.4 Study limitation

There are several limitations in this study. First, the mitigation here only considers GHG mitigation and not yet including other pollutants (e.g., PM 10, PM 2.5). In addition, we have not taken into account the co-benefits analysis of implementing GHG emission mitigation policies. The results obtained in this simulation are simulations of a direct impact if Indonesia limits its GHG emission levels to 29% lower than BAU levels. Further research related to co-benefit calculations needs to be done for further studies to see how much Indonesia benefited from the mitigation projects. Also, the data and assumptions used are the most recent data at the model simulation and manuscript writing time. Given the dynamics of policy in Indonesia, there can be data and policy updates at any time. Thus, further studies and analyses using more updated data and policies can be conducted in the future.

3 Simulation result

3.1 Macroeconomics impacts

As an economic model, the main simulation result from this CGE simulation is the macroeconomic impact, especially the GDP. The GDP result comes from the sum from the consumption, investment, government expenditure (consumption), and trade balance (export and

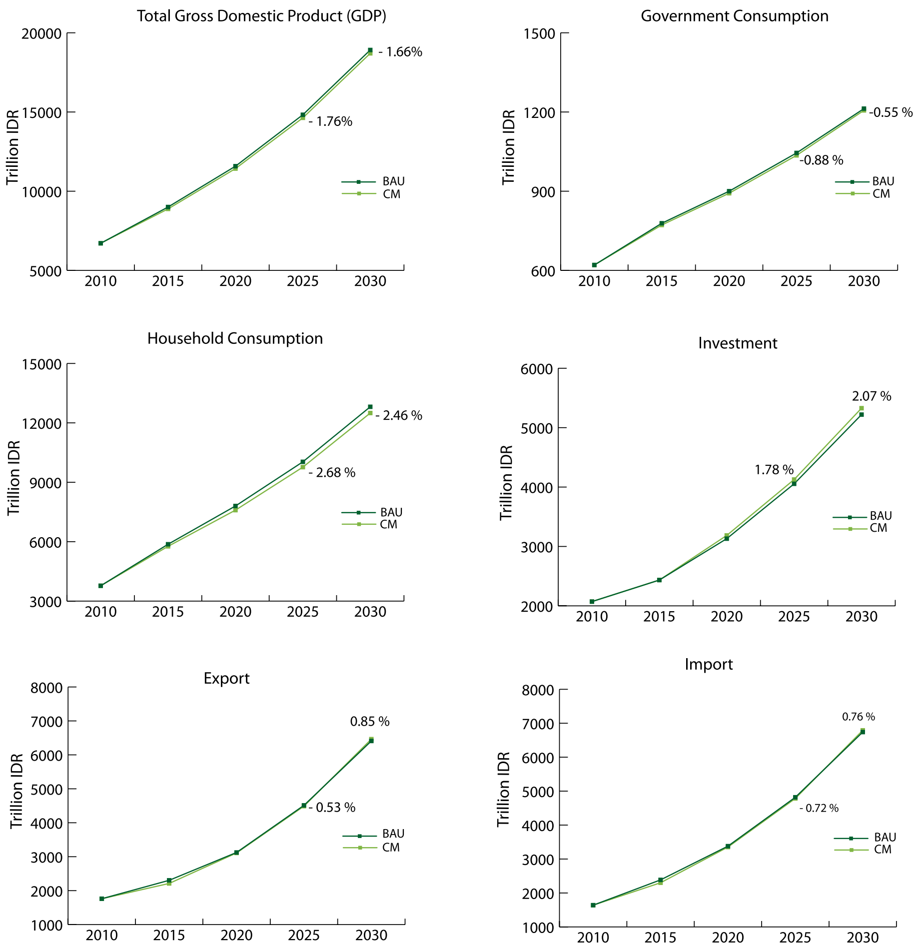

Fig. 7 Summary of macroeconomic impact on Emission Mitigation Policies toward 2030

import). Through the introduction of emission mitigation policies in all sectors, the total GDP loss should be around 1.66% compared to the BAU level by 2030 (Fig. 7). According to several experts' estimations, the emission mitigation policies will lead to an increase in investment. This is encouraged by the provision of more efficient technologies to support emission mitigation. The model projects that the investment will grow by 2.07% compared to the BAU level by 2030; it is an increasing growth compared to 2025 (1.78% compared to the BAU level). However, the share of investment in Indonesia's economic structure is still small, especially if it is compared to household consumption. The investment improvement cannot offset the reduction in other variables, particularly household consumption.

More than 50% of Indonesia's GDP consists of household consumption. Thus, any shock to consumption may significantly affect the GDP level. From the simulation, the mitigation may potentially reduce the consumption by 2.46% compared to the BAU level by 2030. This result is firstly attributable to the efficient production factor that reduces labor demand. This will significantly impact household income, especially households that absorb a lot of unskilled labor, such as agriculture. The decrease in labor absorption leads to a decrease in household income, which can be used for consumption activities. The labor trend will be explained further in the next part.

Besides, this result has been triggered by reduced production in several sectors, particularly those causing many emissions. As mentioned before, the model treats GHG emissions as “goods,” and the government’s GHG emission mitigation policy is considered emission certification. When a sector produces several emissions and exceeds the government’s limit, the latter will require that sector to pay more to accommodate their emission. In other words, it will increase the production cost for that sector.

Therefore, each production sector must invest in new technologies or reduce production to maintain its production cost. During the transformation period, each sector may also employ a combination of greener energy use and limitation of production. The proportion of that combination is decided in the model under the profit optimization principle. If the emitting sector reduces production to match its emission level, the number of goods/services consumed by the household will also automatically decrease since households consume both energy and non-energy goods.

As the structure between household and government is alike, a similar explanation applied to the lower government consumption under the CM scenario (−0.88% in 2025, −0.55% in 2030 compared to the BAU level). However, as the proportion of government consumption is small in Indonesia, the shock to this variable is not as high as it is on household consumption. From international trade, the model indicated a higher level of export and import by 2030 compared to the BAU level (0.85% for export, 0.76% for import).

We also attempted to discern the impact by sector (Fig. 8). Our simulation shows that agriculture would become the most impacted sector. Based on our model’s simulation, the agricultural sector would experience around 13.4% loss of GDP in 2030 compared to the BAU level by 2030. This sector is impacted the most because, under the GHG emission mitigation policies, the government wants to reduce land-use change and keep some conservation and carbon stock function areas. The impact of that policy will be to reduce the total land that could be used for economic activities. As we mentioned in the method part, in this model, the land is treated as capital. When there is any policy to limit land use, it will be treated as a shock for the land sector. Therefore, a shock in the agriculture sector results in a negative shock to the total GDP that cannot be offset by any sectoral GDP improvement from other sectors (e.g., energy and transport). This sectoral GDP shock also impacts Indonesia’s industrial and trade sectors since the biggest industry and trade in the country include food and beverage products that are mostly supported by the agriculture sector.

What happened to the agricultural sector also may affect the industrial sector. In Indonesia, the food and beverage industries give quite significant shares from the industrial sectors. As most of this industry inputs come from the agricultural sector, a shock from the agricultural sector may affect this sector’s output. However, the model only projects the sectoral GDP loss for this industry will only around 0.8% by 2030 compared to the BAU level. It is helped by some efficiency improvement that we introduced on the CM scenario for the industrial sector. The industrial sector also has a strong relationship with the trade sector. It explains some sectoral GDP loss in the trade sector (around 2% compared to the BAU scenario by 2030), although there are no direct emission mitigation scenarios for this sector.

Moreover, not all sectors will be negatively affected by the implementation of an emission mitigation policy because the introduction of mitigation technologies also leads to more investment, especially in energy, transport, and waste management. According to our simulation project, the sectoral GDP for energy, transport, and waste management will be

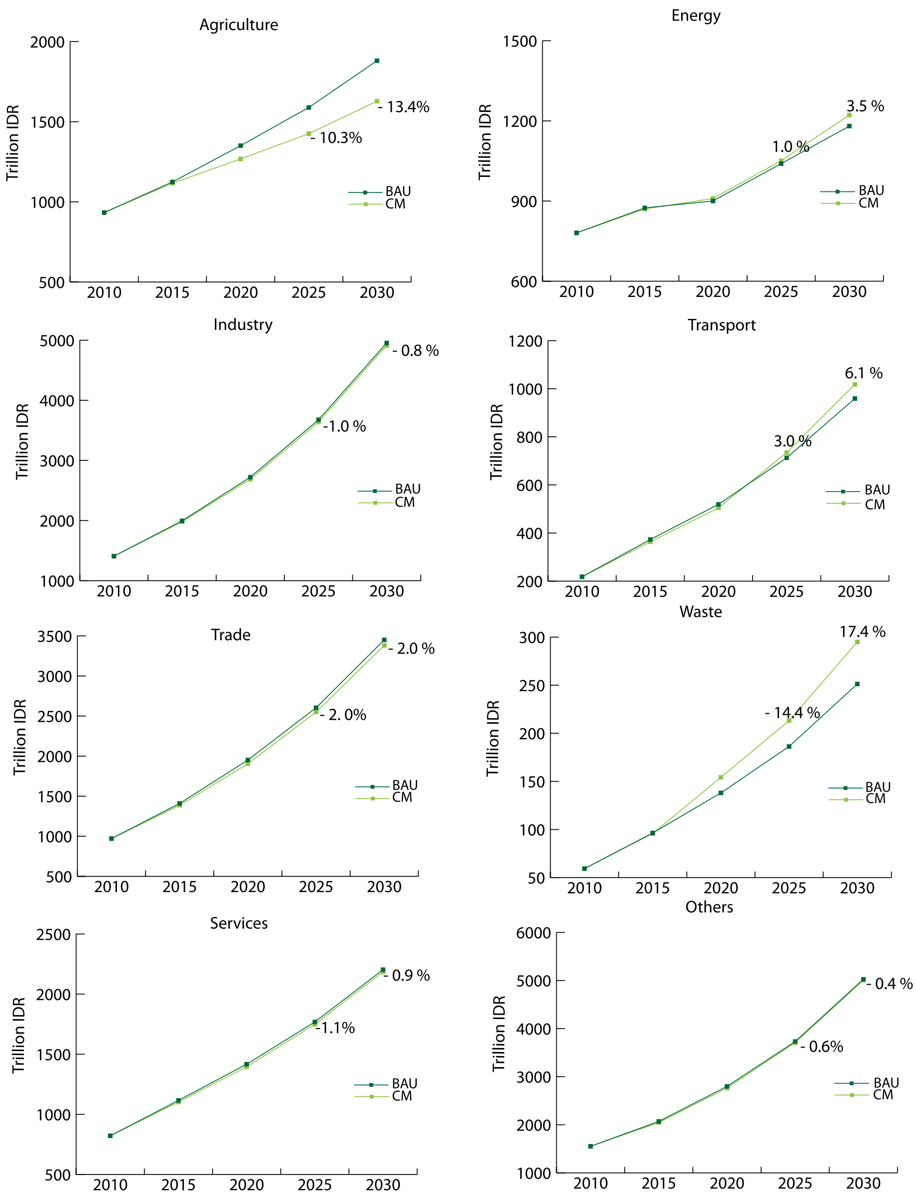

Fig. 8 Summary of sectoral GDP comparison under each scenario in 2010–2030

higher by around 3.5%, 6.1%, and 17.4%, respectively, by 2030 compared to the BAU level. This sectoral increase in GDP is caused by the introduction of high investment for energy efficiency in the industrial, commercial, and transportation sectors. We also consider more investment in the improvement of waste management. In the case of the transportation and energy sectors, the demand (consumption) of these sectors should normally remain high along with population growth.

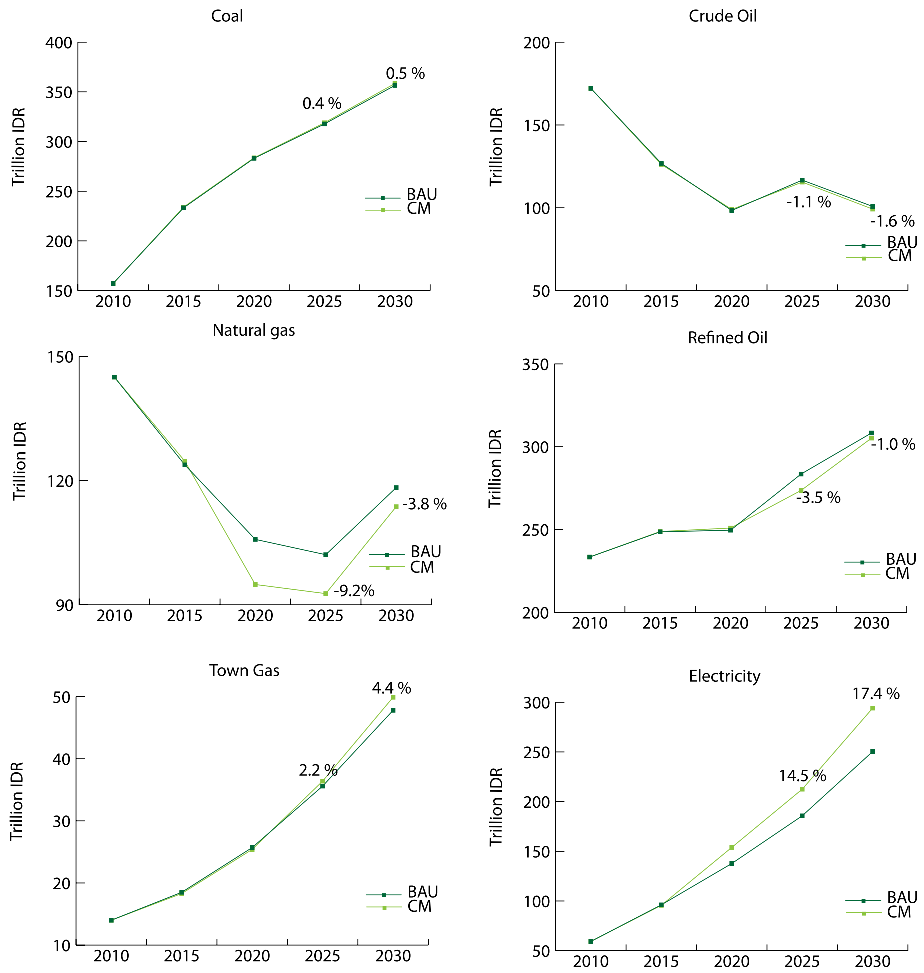

Fig. 9 Summary of sectoral GDP comparison with energy sector under each scenario in 2010–2030

In our study, as we disaggregate the energy sector, we also could see the result of this sector more detailed. If we view the sectoral GDP from the energy sector, we could see that the sectoral GDP from coal mining should still increase by 2030, while there is also a 0.4–0.5% increase of sectoral GDP under the CM scenario (Fig. 9). This result is driven by several factors. First, a significant increase in electricity demand is expected in the future. As the biggest installed power plant in the country is the coal power plant, the consumption of coal mining products, although they will be reduced under the CM scenario, will remain high. Second, Indonesia is expected to export some portions of coal as there will still be a demand for coal during the energy transition to greener energies.

This estimate is also based on the Indonesian government's plan to push domestic coal production for domestic use, especially in industries and power generation, in order to boost its exports. There is also an increasing share of electricity due to its higher consumption in all sectors of the economy. The significant improvements are due to the decline in Indonesia's reserves of higher calorific value coal. The investment to introduce more efficient technologies like CCT will also support the sectoral GDP from the coal sector (Mackenzie 2018). From the international trade perspective, as our simulation involves only mid-term simulation (by 2030), Sadamori (2018) estimated that the world coal price will still augment in the mid-term period, especially in Asia, although the increase is slowing down. This is because the transition from coal cannot be done instantly, at least in the mid-term period, as it has been massively used so far. Hence, coal exploration and coal trade will remain high till 2030. Considering all of those factors, as we can see from the simulation result, the sectoral GDP for coal under the CM scenario is higher compared to the BAU level. Still, it will not be too far from the BAU level due to some stock limitations and a reduction in supply and demand in the future.

The situation is slightly different if compared with crude oil and refined oil. The sectoral GDP from crude oil experiences a decreasing trend, along with the depletion of crude oil stock in Indonesia. For refined oil, the sectoral GDP is still expected to increase by 2030. As predicted, the oil demand will remain high for the mid-term period due to the rapid growth in the transportation sector, just like we assumed in the scenario. However, both oil sectors are experiencing GDP loss under the CM scenario because, under the CM scenario, all sectors need to reduce the oil consumption.

Since the domestic consumption of natural gas is also expected to increase to replace the dominance of oil and coal use during the energy transformation process, the model estimated an increase in the sectoral GDP of natural gas after 2025. However, the mitigation policy will force the industry to use energy more efficiently. Thus, sectoral GDP loss on natural gas under the CM scenario is approximately 3.8% compared to the BAU level by 2030.

Another interesting finding is that sectoral GDP from the energy sector will be supported by higher revenue from the secondary energies such as the electricity and town gas sectors. This increase results from more demand and utilization of gas and electricity in the household, industry, commercial sectors, and int the same time, more population. Besides, there are higher sectoral GDP from these sectors under the CM scenario. The high sectoral GDP in the electricity sector was motivated by high investment in the power generation sector, especially for the development of more renewable energy generators. Town gas is supported by the process of converting the use of oil into gas in households and industries. Due to the limited stock of natural gas, the import value for this sector is also expected to increase. Also, the investment for the town gas infrastructure in Indonesia is not as aggressive as for the power generation. Hence, the increase in income from this sector is much lower than from the electricity sector (only 4.4% by 2030 compared to BAU level).

3.2 Labor

The mitigation actions may also affect the labor force in the economy. This result is important because Indonesia is a populous country that requires adequate employment to meet the growing national population. In general, the simulation results for employment align with the simulation results for the GDP sector (Fig. 10). The sectors that provide a high sectoral contribution to GDP tend to absorb more labor. Based on the simulation results, our model estimates that the agricultural sector will be the most affected in terms of employment, which will have enormous policy implications.

For Indonesia, agriculture always contributes significantly to absorb labor. However, along with economic growth and some economic structural shift, this contribution starts

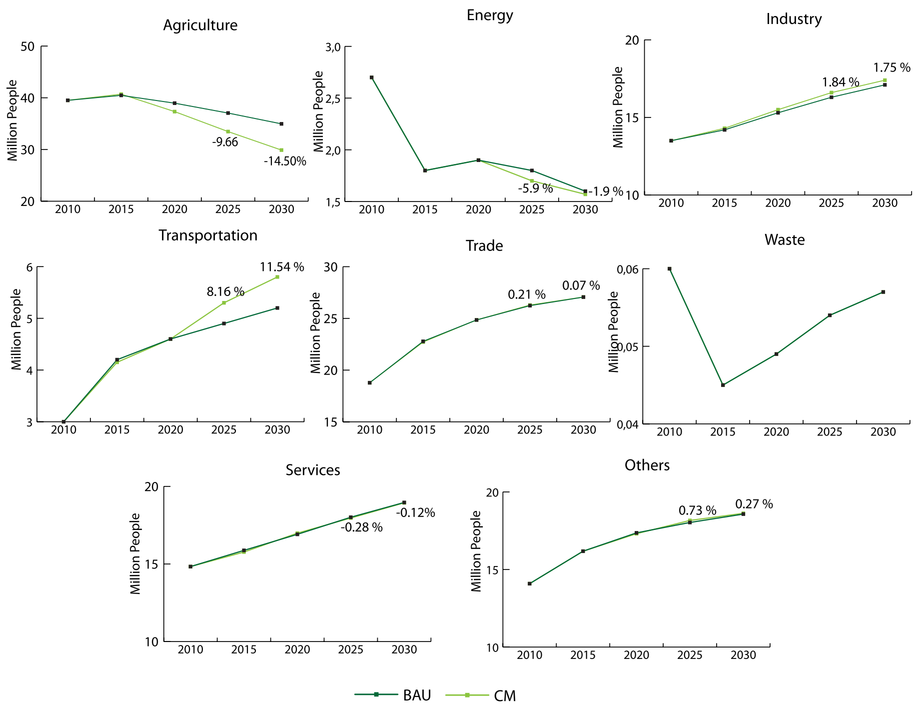

Fig. 10 Summary of labor condition under each scenario in 2010–2030

to decrease. Mitigation implementation will decrease the contribution further because the amount of cultivated land has reduced. At the same time, some mitigation technologies in this sector (such as the use of more efficient fertilizer and seeds) are also expected to require less labor. This result has already been anticipated in the Master Strategy of Agricultural Development (*Strategi Induk Pembangunan Pertanian*) 2015–2045, indicating that Indonesia expects to transition from an agricultural-based country to a sustainable agro-industry country (Kementerian Pertanian 2013).

When there is efficiency, there will usually be a decrease in demand for labor, including in the energy sector, which, in the CM scenario, will absorb less labor than in the BAU scenario. However, along with the increasing sectoral GDP in the energy sector (as seen in Fig. 8), the number of workers absorbed by this sector will gradually increase. Other potential sectors may absorb more labor, such as the industry, transportation, and trade sectors. It is based on the future estimation that the demand for those sectors will increase along with economic transformation and population growth.

3.3 Energy

3.3.1 Primary energy supply and final energy demand

Energy efficiency and the introduction of more renewable energy into the energy mix affect energy supply and demand. In general, mitigation will reduce energy supply and demand, especially for coal and oil.

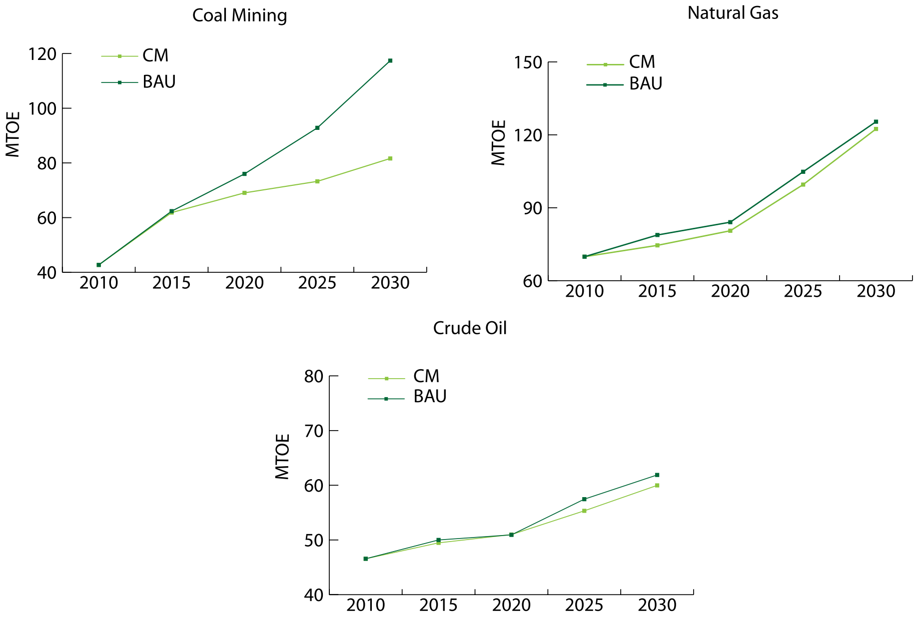

Fig. 11 Summary of primary energy supply condition under BAU and CM scenarios toward 2030

The simulation result for primary energy demand is conducted for crude-energy forms such as coal, natural gas, and crude oil. In line with the government's estimation concerning the primary energy supply, coal may dominate the energy supply. Besides, the energy supply from coal is still increasing, even under the CM scenario. Nevertheless, the growth is much lower than in the BAU level due to several factors. From an economic perspective, as one of the export goods, coal supply is still needed since the demand is expected to remain stable till 2030 relatively. However, due to the environmental concern, emission mitigation policy, price competitiveness, and depleted stock, the supply under the CM scenario is 5.69% lower than the BAU level (Fig. 11).

There is a similar trend in crude oil and natural gas. Nonetheless, the reduction is not as high as in coal mining. For crude oil, the reduction is small because its stock is already low. Regarding natural gas, although the supply is lower under the CM scenario than under the BAU level, the reduction is not as high as with coal because natural gas supply will be needed to support the energy transformation in the industry sector and power generation. This result also denotes that it is likely that Indonesia should still import natural gas and crude oil to maintain the supply of fossil fuel. To understand this result further, we must consider the trend in energy demand.

A similar trend can be found in energy demand. The highest energy demand will come from the industrial sector, followed by the transportation sector. The energy demand from industry is highest because, along with economic growth, industries must produce more output, which requires more energy. Furthermore, population growth will lead to an increase in energy demand in all sectors. However, the increases are lower under the CM scenario than under the BAU level. The lower energy demand is mainly due to our energy efficiency setting on the simulation. More efficiency leads to lower energy use in all sectors without affecting normal activity.

A slightly different trend can be found in the household sector. Under the CM scenario, the energy demand reduction for the household sector involves no significant decline compared to the BAU level. This is because there was a conversion of oil to gas is introduced for household cooking. Despite some reduction in oil use, there is still a very high demand for town gas. We also set an energy efficiency in the household sector; however, as the number of households will keep increasing along with population growth, the electricity demand from the household may also increase, affected with high total energy demand. Also, the technology improvement in the household sector is not as advance as it is in other sectors. Those factors make the total energy demand in the household sector is projected not to decrease significantly (Fig. 12).

Moreover, energy demand can also be considered in terms of the energy source. The demand for oil refineries' products is expected to remain high till 2030, followed by the need for coal mining products and natural gas. However, with the implementation of mitigation technologies, the demand for coal, natural gas, gas (town gas), and oil refineries will reduce. This will be one of the implications of energy efficiency across all sectors.

Moreover, despite the assumption of energy efficiency for electricity use in industry, business, and household, the electricity demand in the CM scenario only slightly compares to the BAU one, mostly because there is no significant electricity demand reduction from the household sector. Moreover, the demand for natural gas and town gas is expected to increase to support the energy shifting in the household sector (replacing oil with gas) and power generation (Fig. 13).

3.3.2 Power generation

Power generation plays a crucial role in mitigating emissions from the energy sector because the electricity demand will rapidly increase in the future. Therefore, energy sources for electricity generation are the concern of policymakers to reduce emissions. Based on the simulation results from existing data, the model indicates that both in BAU and CM scenarios, Indonesia's power generation is still dominated by non-renewable energies (Fig. 14). However, the pattern will change.

Under the BAU scenario, the coal power plant should dominate the power plant generation. Under the CM scenario, the domination will be taken over by natural gas. Although coal use for power plants will become more stagnant, the proportion of coal use will remain high till 2030. As there is a target to utilize more renewable energy in the power generation mix, the number of renewable power plants, mostly hydro pp and geothermal pp, also increases. Although Indonesia has a huge potential for biomass production, the share of biomass-waste power plants is still insignificant because biomass and waste power plants' installation is small compared to others in the power plant mix (Fig. 14). This result makes sense as the use of natural gas is always targeted to be increased significantly during the energy transition process to the greener energies. Indonesia's government also projected to use more gas while at the same time preparing and developing more renewable-energies-based power plants along with its infrastructure(Kennedy 2018; Dewan Energi Nasional 2020). However, the proportion of coal use in the power generation mix is projected to still high.

The high use of coal, especially for power generation, is caused by several factors. The main reason is that the installed capacity of coal power plants is already remarkably high in Indonesia, and these installed power plants cannot be eliminated. A way to reduce the massive use of coal is to utilize technology, such as the development of CCT, a commercially established technology for coal power plants. It uses supercritical boilers and ultra-supercritical boilers. Both technologies operate at temperatures and pressures that are above

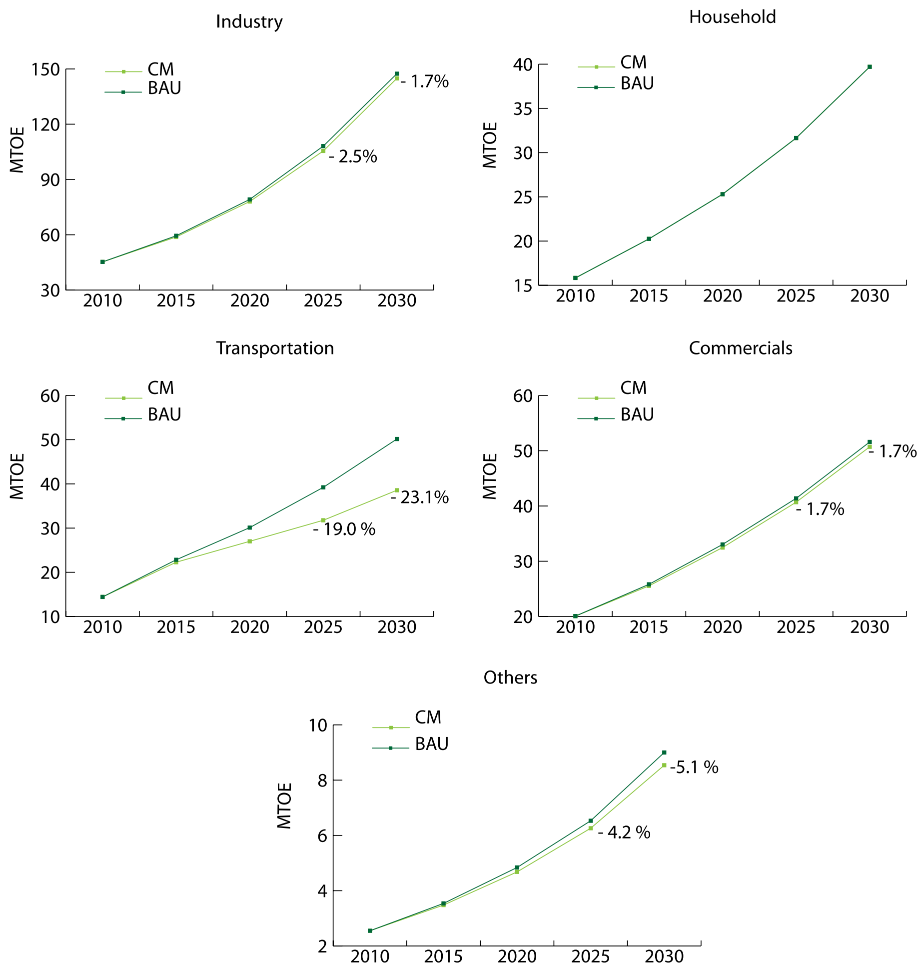

Fig. 12 Summary of final energy demand by energy sources under BAU and CM scenarios toward 2030

the critical point of water. The efficiency of the supercritical boiler can reach about 44% and the ultra-supercritical about 50%, while the older type of coal power plant operates at approximately 30% efficiency (Afework et al. 2018). The establishment of both types of power plants is focused on Java. Furthermore, there is the circulating fluidized bed (CFB) boiler technology that focuses on reaching Sumatra and eastern Indonesia. The CFB can improve power generation efficiency by approximately 40% (Hotta 2012).

Thus, there should be energy diversification. PLN (the state-owned electricity company) plans to take the fuel-switching step from oil and coal to gas as the initial step to reduce the massive use of coal. It aims to divert the use of fuel oil to gas in gas-fired power plants (PLTG), gas-steam power plants (PLTGU), and gas engine power plants (PLTMG), as well as the use of biofuel mixtures in diesel power plants (PLTD). The fuel switching step will also directly reduce GHG emissions because gas emission factors are lower than fuel emission factors. This step is also taken to reduce coal and oil use as the stock is already depleted (PLN 2015, 2018). Nevertheless, considering that gas stocks are also

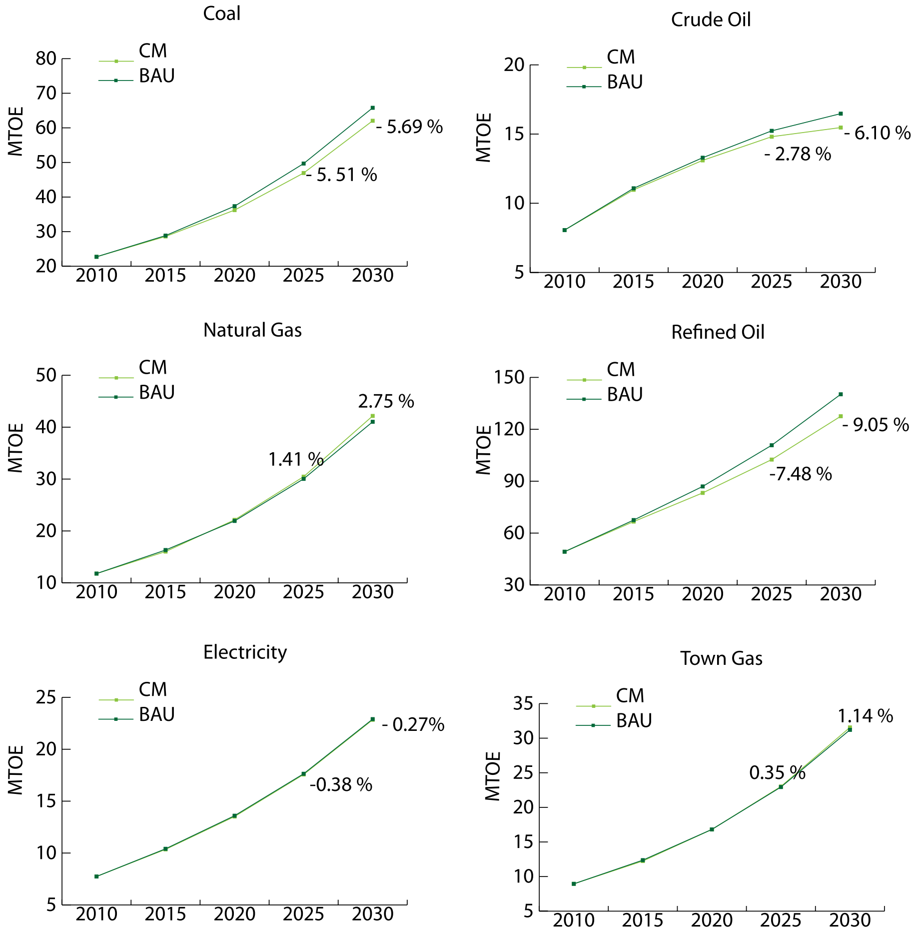

Fig. 13 Summary of final energy demand by sector under BAU and CM Scenario toward 2030

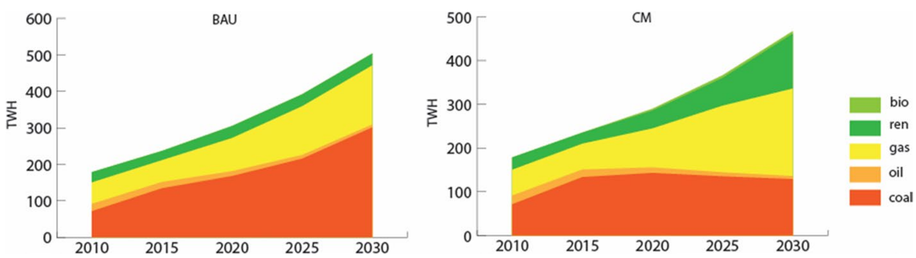

Fig. 14 Summary of power generation under BAU and CM scenarios toward 2030. All renewable energies excluded biomass and waste sources, bio: biomass and waste sources

limited, along with the fuel-switching step, PLN and the government are also working to increase the use of renewable energy (*ren*), especially hydropower and geothermal, which can be developed in Indonesia. This is another reason the high utilization of renewable power plants in 2030 is expected to increase significantly.

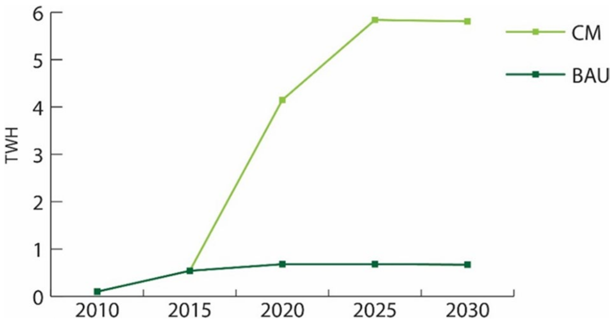

Fig. 15 Simulation result of biomass-waste (bio) power generation under BAU and CM scenarios toward 2030

Although smaller compared to other renewable energies, the power generated using biomass and waste is also expected to increase. However, the growth is not as high as other renewable energies (e.g., hydropower, geothermal, etc.) (Fig. 15). This result comes because when we are doing the simulation, the available data shows that the installed capacity and the expansion plan of these power plants are still very limited. Based on the data, our model project that by 2030, under the CM scenario, Indonesia may generate at least 5.8 TWh of electricity from biomass and waste.

4 Discussion and policy implications

Compared to previous studies, when only partial emission policies were introduced (Malahayati and Masui 2018b, 2019), all mitigation actions in all sectors provided a smaller GDP reduction. It is supported by further investment. However, with the current economic growth, the mitigation actions still cause a shock to household consumption, and as household consumption dominates the GDP, GDP loss is still significantly affected. Among all the sectors affected by the mitigation policy, the agriculture sector is expected to be the most affected. The sectoral GDP and labor of agriculture are considerably reduced in the CM scenario. Notably, such a decline could indicate that the Indonesian government should prepare for structural change in the economy. Transport and energy sectors could be alternatives that could accommodate this change and absorb the labor from the agriculture sector. However, considering that agricultural labor, in general, is unskilled labor, the government must improve the skills for agricultural labor so that they can easily move to other sectors that are more capital intensive and that require skilled labor rather than unskilled labor.

Coal is expected to play an essential role in Indonesia, although mitigation actions in the energy sector will lead to a decline in its demand. The government may accommodate this domestic demand reduction by exporting more coal because its demand, as well as price, should remain high despite slower growth. In the future, Indonesia may not be the only country implementing mitigation policies. As other countries may do the same, this situation may lead to a price drop in high-carbon energy sources such as coal. In that case, coal will not be profitable enough as an export commodity. Even a developing country like Indonesia must design a more aggressive scenario for new and renewable energy development.

The development of new and renewable energies still lags in Indonesia, but their utilization has improved, especially for power generation. Unfortunately, the utilization of renewable energies tends to be less competitive than that of fossil fuel. In the case of power generation, this study predicted that the use of renewable energies for power generation would significantly increase when the government limits coal use. Hydro, geothermal, and solar power plants are also expected to contribute to electricity generation considerably. However, the power plant's energy transformation will be dominated by natural gas before the domination of renewable power plants. As Indonesia also has huge biomass and waste potential, the biomass and waste power plant are separated. Nevertheless, our model predicts slow growth for the biomass and waste power plant under both the BAU and CM scenarios because the number of installed power plants for biomass and waste is still very low, and the model cannot consider a significant increase in these power plants by 2030.

Based on our simulation, our research suggests the government pays attention to the use of this fuel. As our result indicates that the development of renewable energies in Indonesia will take time, in parallel with the infrastructure development for renewable energies, it is also crucial to boost coal and gas energy efficiency. For example, regarding coal use, especially for power generation, it is recommended to introduce more technology like super-critical (SC) and ultra-super-critical (USC) in steam power plants throughout Indonesia, at least to increase the efficiency of the powerplant.

Moreover, the government also needs to notice that gas will be an important energy source during the energy transition process. In Indonesia, the government still faces many operational constraints (e.g., refinery management and infrastructure provision for gas distribution). With more efficient use of coal and gas, the amount of emission produced can be lower and facilitate the energy transformation process, considering that Indonesia still has a lot of "homework" in developing and penetrating new renewable energy.

Another message from our findings is that the government in developing countries, especially the Indonesian government, needs to plan their mitigation emission policies. Considering the economic growth, infrastructure readiness, and the ambitious target, the government needs to anticipate that it may slightly be slowing down the economy compared to the BAU target, at least in the mid-term period. Because the longer the government delays the development of all the supporting infrastructure for emission control, the more production and consumption of people will have to be "sacrificed" to achieve the emission reduction target. As an illustration, if the government does not immediately rejuvenate unproductive commercial plantations such as palm oil, the government will continue to issue a moratorium on palm oil or even closed some activities to reduce the rate of deforestation and emissions from the land sector. Then Indonesia must rely on the available plantation with low or even diminishing productivity. Such a thing could be prevented if the government anticipates it by providing support for the replanting and certification program for commercial plantations. If that happened, the revenue from this sector may stagnate or even experience a decline. That logic applies to other sectors. Also, long delays in providing the mitigation technologies will make the government need to provide more budget for the mitigation in the future and more challenging it is to achieve the emission target. It is also in line with the previous study by Wijaya et al. (2017) that suggests Indonesia should have a clear policy and investment plan for emission mitigation actions. So, we feel it is very important for the Indonesian government to formulate the right investment and policies as soon as possible to achieve the emission reduction target and minimize the economic impact that may arise.

This model can still be improved in the future, especially in terms of mitigation technologies. With further discussions with experts, the efficiency improvement and the cost structure can be established more accurately. Assessing a longer analysis period is important for the government, especially the Indonesian government, to understand the future benefits of mitigation policies.

It is also very important to expand the simulation year, especially for Indonesia, which recently committed to extend its mitigation commitment to a longer period, known as long-term scenario (LTS). Under the LTS, it will also be useful and give the Indonesian government more motivation if another co-benefit analysis (e.g., the impact on air pollutant reduction, health, etc.) can be considered. For further model update, more comprehensive and updated data will be needed. However, it is hoped that this study can enrich the literature and research regarding emission mitigation in developing countries, especially Indonesia.

5 Conclusion

This model attempts to measure the potential impact of comprehensive emission mitigation policies on Indonesia using the CGE model. There are two scenarios: the Business as Usual or BAU scenario and the mitigation or CM scenario. In the CM scenario, all the emission mitigation in energy and activities is introduced. Mitigation from the LUCF is indirectly introduced into this model using the land use information obtained from the previous chapter (CGE with LUCF). In the CM scenario, the forest area is larger, and the cropland for the economic activities is more limited than at the BAU level. Energy is also treated in more detail, especially in the power sector.

The introduction of mitigation scenarios is expected to create approximately 1.66% GDP loss compared to the BAU level by 2030, owing to lower household consumption and investment. Despite an increase in investment, improvement cannot cover the loss in household consumption, which occupies the biggest proportion of Indonesia's total demand. The introduction of mitigation policies will reduce the sectoral GDP from agriculture, energy, and industry. It is also predicted that the sectoral GDP from other sectors will not be directly affected by the mitigation policies will increase or, at least, experience a smaller loss as the sectors are directly affected by the mitigation.

The model estimated a significant decrease in agricultural labor in the CM scenario because less land can be cultivated in the mitigation scenario. These predictions indicate that the Indonesian government should prepare for structural change by employing people in other sectors. In the energy sector, the mitigation action reduced the domestic energy demand for almost all energy sources. This model also establishes that renewable energy utilization will increase significantly for power generation, especially after 2025. However, fossil fuel use remains high, especially the use of natural gas that will replace the dominance of coal as the energy source for power generation. Furthermore, power generation from biomass and waste is expected to improve under mitigation conditions. This improvement is still insignificant compared to other renewable energy sources (hydro, geothermal, and solar power plants).

As one of the initial studies on the impact of comprehensive emission mitigation policy's introduction on the economy and environment, this research still has several limitations. As the CGE model is extremely sensitive to the parameter settings and the assumption environment on the exogenous parameter, the result may change with different input and policy introduction settings. Thus, the model can be developed with the cooperation and coordination of other stakeholders. Nonetheless, this study can figure out the potential impact of the comprehensive emission mitigation policies implementation in the country. In the future, this study can be expanded to capture longer period simulations and to consider co-benefits of the GHG emission policies (e.g., poverty reduction and health improvement). Thus, further studies regarding this subject matter will benefit developing countries, especially Indonesia.

Appendix 1

Table 3 Input–output table: sector classification

Sec	Code	Sector	Sec	Code	Sector	Sec	Code	Sector
1	PAD	Paddy	20	OIL	Oil refinery and LNG	Value added	LAB	Labor
2	COR	Corn	21	CHE	Chemical industry	Value added	CAP	Capital
3	CAS	Cassava	22	FER	Fertilizer and Pesticide	Final demand	h_c	Household consumption
4	OAG	Other agriculture	23	NON	Non-metal industry	Final demand	h_i	Household investment
5	RUB	Rubber	24	CEM	Cement	Final demand	g_c	Government consumption
6	PAL	Palm oil	25	IRO	Iron and steel industry	Final demand	g_i	Government investment
7	OPL	Other plantation	26	MET	Metal-based Industry	Final demand	stc	Stock change
8	LIV	Livestock	27	OIN	Other industry	Final demand	exp	Export
9	WOO	Wood	28	ELE*	Electricity	Final demand	imp	Import
10	OFO	Other forest	29	GAS	The results of natural and artificial gas, supplying steam/hot water, cold air, and ice products			
11	MAR	Marine and fisheries	30	WAT	Water supply			
12	COA	Coal and lignite mining	31	WAS	Waste			
13	CRU	Crude oil	32	BUI	Building			
14	NAT	Natural gas and geothermal	33	TRA	Transportation			
15	MIN	Mining	34	TRD	Trade, hotels, and restaurants			
16	FOO	Food, beverages, and tobacco	35	AMU	Amusement and telecommunication			
17	APP	Apparel	36	FIN	Financial services			
18	WIN	Wood industries	37	GOV	Public services			
			38	OTH	Other sectors			

Full database of Indonesia IO Table can be accessed in (Badan Pusat Statistik 2015) (see reference)

*The electricity sector is disaggregated into electricity from coal, oil, gas, renewables non-biofuel, and renewable biofuels

**Sector 1–10: LND (land) sectors

Appendix 2 Model reliability check (calibration setting)

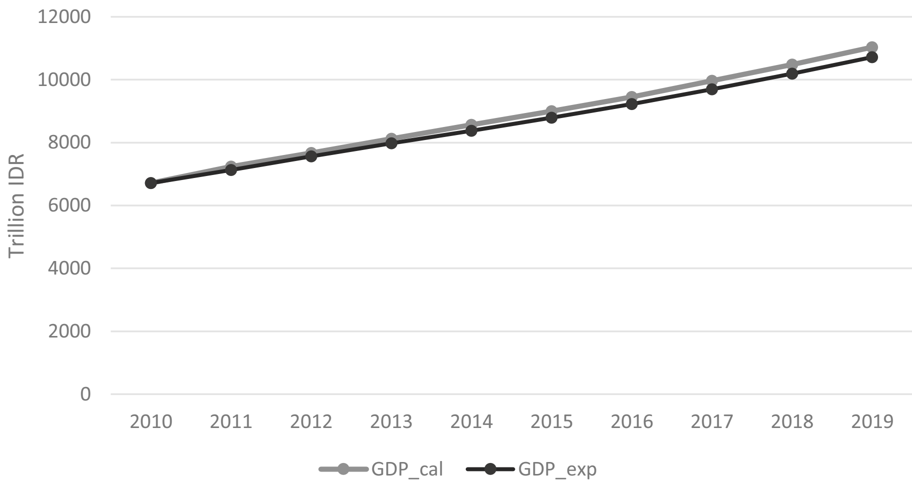

Fig. 16 Model reliability check between the GDP from the model simulation (GDP_cal) and the expected GDP based on the real GDP growth (GDP_exp) between 2010 and 2019

As mentioned before, there are several limitations to the CGE model: (1) its output is highly dependent on the inputs and parameter setting. (2) The data foundation for the CGE model construction (either IO table or social accounting matrix (SAM)) is often considered outdated. Although it is still considered reliable to describe a country's economic structure in general, it is common that some people have some doubts, especially for those who rarely utilized this kind of dataset. The problem might be more serious in developing countries, including Indonesia, where the data update is often very slow considering technical, financial, and human resources limitations. However, we could minimize the errors by doing some model reliability checks.

One benefit of doing the dynamic CGE modelling is we could calibrate our model parameter to find the closest result with the recent statistics. This is why in any study that involves a CGE model, some time-series statistics are needed as an anchor. The most used data is GDP and its growth. To ensure our model's reliability, we tested it and compared the calculated GDP (BAU GDP based on the model recursive-dynamic process) and the expected GDP (based on Indonesia's actual GDP and its growth from 2010 to 2019).[3]

Based on our test, the deviation between the simulation and the expected GDP is lower than 5% (1.5–3%). Thus, mathematically speaking, our dynamic model is still reliable enough to describe the current economic situation (Fig. 16).

Another note regarding the parameter adjustment is that the CGE model is a market-based economic model. The most important and strictest assumption in any CGE model is there must be an equilibrium in both supply and demand. Thus, we cannot set too many strict parameter restrictions on the model because it will make the model fail to reach its "mathematical optimal solution" or, simply put, show a feasible result.

[3] The test is only for GDP 2010 to 2019 as the data for 2020 is still provisional value. Also, the value for GDP in 2020 is totally fluctuates due to the COVID-19, which we not considered in this study and mitigation calculation.

Although the modeller cannot perfectly project each variable, it will try to minimize the deviation, find the result closest to the present data, and ensure all the computing processes do not lead to further error and misleading results.

Recursive dynamic process

The dynamic CGE model in this study utilizes the "recursive dynamic" process to simulate 2030 by following the optimization principles. In the process of utility maximization, the general mathematical equation can be written as:

$$MaxU = \sum_t udf_t u\left(C_t\right)$$

$$s.tY_t = f(K_t, L_t)$$

$$Y_t = C_t + I_t$$

$$K_{t+1} = (1 + \delta)K_t + I_t$$

where
U Social utility
C Final consumption
I Investment (saving)
K Capital stock
Y Production
L Labor
udf Utility discount factor
δ Depreciation rate
$u(\bullet)$ Utility function.
$f(\bullet)$ Production function.

The equation above stated that to maximize the total discounted utility (U), income (Y) is distributed for present consumption (C), or saving (I/investment/future consumption). In other words, the update of capital and efficiency improvement are the keys. This capital stock is updated using investment (fixed capital formation) and depreciation. The information on the investment is available in the IO table and there is no other way except to follow this database. The efficiency is set exogenously by considering the technologies we would like to introduce. Efficiency improvement for new capital, including energy efficiency and consumption pattern, is updated using the scenario (in this study, we have the BAU and CM scenario). The depreciation follows a common rate (around 5–10% of depreciation per year). Then, the model will be looping the target year by following equation sets, optimization principles, and the parameter setting. As it is a dynamic recursive, the model will count sequentially (in this case, year by year) (Fig. 17).

A more detailed process of capital stock calculation during each recursive process is described in more detail in Fig. 18.

Notes:
U Social utility
C Final consumption

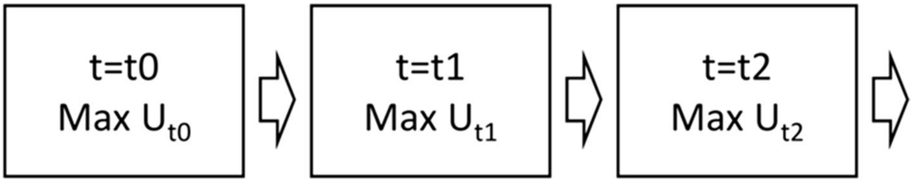

Fig. 17 Illustration of a recursive dynamic process in doing utility optimization process

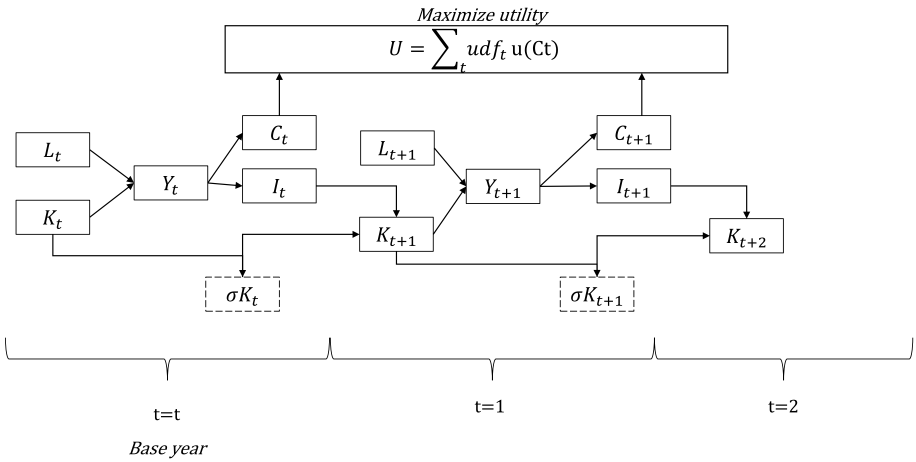

Fig. 18 Illustration of the recursive dynamic process in calculating the capital stock and maximize the utility

I Investment (saving)
K Capital stock
Y Production
L Labor
udf Utility discount factor
δ Depreciation rate.
f(•) Production function.
u(•) Utility function.

Appendix 3 Sensitivity analysis of parameter changes

As mentioned in Appendix 2, the result of the CGE model depends on data inputs and parameter settings. As the model is designed as a dynamic recursive model, the variable is calculated for each year until it reaches the target year. In this case, the capital stock change needs to be considered. In this model, capital stock is updated using investment and depreciation. The total investment is updated by using the future scenario and the GDP growth rate assumption; the higher a country's GDP growth, the bigger its ability to generate and accumulate its capital stock. Therefore, the CGE simulation results will also be closely related to this capacity. It makes sensitivity analysis necessary to see to what extent, changes in capital will affect the results. This study set an average GDP

Table 4 Sensitivity analysis result for different economic growth post-2020

Scenarios	Macroeconomic indicator 2030							Energy Sector		
	GDP	CH	CG	I_H*	I_A*	EXP	IMP	P_E(MTOE)	F_E (MTOE)	ELE (TWh)
BAU	18,913.9	12,812.3	1212.8	5219.4	0.0	6409.3	6740.0	399.7	317.6	504.0
CM										
This study										
5%	18,702.7	12,497.1	1206.2	5212.5	115.0	6463.5	6791.5	358.8	301.6	466.9
Difference with BAU (%)	−1%	−2%	−1%	0%		1%	1%	−10%	−5%	−7%
Pessimist										
4%	17,345.0	12,296.6	1156.0	4116.8	88.2	5705.8	6018.4	323.4	268.4	423.8
Difference with BAU (%)	−8%	−4%	−5%	−21%		−11%	−11%	−19%	−16%	−16%
Optimist										
6%	19,701.5	12,589.0	1240.1	6087.5	125.7	7188.7	7529.4	384.5	326.5	499.4
Difference with BAU (%)	4%	−2%	2%	17%		12%	12%	−4%	3%	−1%
Very optimist										
7%	20,933.8	12,551.0	1277.8	7281.0	175.7	7949.4	8301.1	409.1	351.7	534.5
Difference with BAU (%)	11%	−2%	5%	39%		24%	23%	2%	11%	6%

GDP gross domestic product, *CH* household consumption, *CG* government consumption, *I_H* fixed capital formation/investment of household, *I_A* additional investment (comes by the introduction of mitigation), *EXP* export, *IMP* import, *P_E* primary energy, *F_E* final energy, *ELE* electricity generation, *MTOE* megatons of oil equivalent, *TWh* terrawatt hours

Highlighted value shows the positive value

*In this study, total investment (INV) is the total of I_H + I_A growth rate of around 5%, a "middle of the road" scenario, considering the average economic growth since 2010.

However, the Indonesian government also has various economic targets. For example, the Indonesian Ministry of National Development Planning (National Development Agency/Bappenas) often puts up optimistic and very optimistic economic growth projections, namely around 6–7% post-2020. The projections can also be seen in several Bappenas publications, such as the Low Carbon Development Initiatives (LCDI) (Bappenas 2019). However, considering the COVID-19 pandemic since mid-2020 and the time-consuming economic recovery process, many also predict Indonesia's economic growth will be lower than in previous years. On this basis, we conducted sensitivity analyses and conducted additional simulations with different economic growth perspectives. We added a pessimistic scenario with an economic growth of 4% post-2020 and an optimistic and very optimistic scenario targeted by Bappenas, namely 6% and 7% economic growth, respectively (Table 4).

The simulation results show a consistent result that the economic shock from emission mitigation can be minimized or even have a positive impact if Indonesia maintains high economic growth, as shown in the optimistic and very optimistic economic scenario. This result is because Indonesia can accumulate capital to continue maintaining the production process and incorporate various existing technologies. In this regard, this makes mitigation actions "cheaper." This is logically acceptable if the growth targets can be achieved. Moreover, it is highly expected of the government and the people of Indonesia. However, considering the economic trends so far, especially with the economic slowdown since 2020 (IMF 2020), it is wise to anticipate the middle-of-the-road scenario which is around 5% as described in this study.

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