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Research Paper

Power Sector Under Climate Scenario: A Study of Climate Policy Impact on Indonesia Electricity System

Hendra Kurniawan[1,4*], Iskhaq Iskandar[2], Muhammad Abu Bakar Sidik[3]

[1]*Environmental Management Program, Postgraduate School, Sriwijaya University, Palembang, 30622, Indonesia*
[2]*Department of Physics, Faculty of Mathematics and Natural Science, Sriwijaya University, Palembang, 30622, Indonesia*
[3]*Department of Electrical Engineering, Faculty of Engineering, Sriwijaya University, Palembang, 30622, Indonesia*
[4]*PT PLN (Persero), Jakarta, 12160, Indonesia*
***Corresponding author e-mail**: 20012622125024@student.unsri.ac.id

Abstract

In the sixth assessment report, the IPCC indicates that global temperature increased by 1.11 (±0.13) degrees Celsius in 2019 due to 6.5 gigatons of CO_2eq of greenhouse gas emissions into the atmosphere. The power sector is a major global greenhouse gas emitter, particularly in Indonesia. Indonesia's electricity sector emitted 149.90 million tons of CO_2eq greenhouse gas in 2020, which is expected to increase to 158.30 million tons of CO_2eq in 2021. Indonesia has committed to reducing greenhouse gas emissions according to the Paris Agreement. The Paris Agreement has been ratified into national law, accommodating Indonesia's roadmap to net zero by 2060. The emissions reduction target was published in 2022 through the enhanced Nationally Determined Contribution (NDC). This study aims to analyze the impact of climate policy in Indonesia's electricity sector to meet the net zero emissions target by 2060. Projection and calculation in this study were conducted using the Low Emissions Analysis Platform (LEAP). Data from 2020, including electricity demand, existing capacity, energy production, energy intensity, lifetime, and capacity factor, were used to support LEAP analysis. The data were obtained from the PLN statistical book, PLN sustainability report, Indonesia's statistical book, and climate change mitigation and adaptation reports in Indonesia. This study developed three climate scenarios, including business as usual (BAU), sustainable development (SD), and low-carbon development (LCD). These scenarios draw upon current climate policies that have various impacts on electricity generation in Indonesia. Based on LEAP analysis, by 2060, energy demand is expected to increase to 300.36 MTOE (BAU), 200.93 MTOE (SD), and 76.97 MTOE (LCD). Consequently, each climate scenario requires an increase in installed capacity to 821.82 GW (BAU), 727.06 GW (SD), and 334.58 GW (LCD). The renewable energy mix is projected to be 21% (BAU), 69% (SD), and 100% (LCD). Each scenario requires investment to develop capacity to meet energy demand. The investment cost is estimated to be 1,671.58 million USD (BAU), 1,537.64 million USD (SD), and 816.51 million USD (LCD). GHG emissions are projected to rise to 1,746.31 million tons of CO_2eq (BAU) and 264.39 million tons of CO_2eq (SD). However, the LCD scenario expects to achieve net zero emissions by 2060.

Keywords

Climate Policy, Global Warming, LEAP, Power Sector, Indonesia

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1. INTRODUCTION

The IPCC published a special report on global warming at 1.5 degrees Celsius, indicating the tendency of global temperature to rise to 1 degree Celsius against pre-industrial levels. An increase of 1.5 degrees Celsius is projected to be reached within 2030–2052 if temperatures continue to rise at the current rate without mitigating activity, which is undertaken as a preventive action (IPCC, 2022). According to NOAA's annual report in 2022, the average global land and ocean surface temperature increased by 0.78 degrees Celsius above the 20th-century average (NOAA, 2021). The Copernicus climate change services dataset reveals that 2021 is the fiftieth warmest year globally, with the highest GHG concentrations ever recorded (Copernicus, 2021). Global GHG emissions during 2010–2019 were recorded at 56 gigatons CO_2eq, or 9.1 gigatons CO_2eq per year, higher than the previous decade. Moreover, GHG emissions have increased by 1.3% per year during the same period (IPCC, 2022). The electricity sector produces the most significant GHG emissions (Steinberg et al., 2017), as a result of the utilization of fossil fuels (Misila et al., 2020). In 2019, the global energy sector emitted 33.2 gigatons of CO_2eq, representing a 16% increase over the previous decade. Due to the COVID-19 pandemic, GHG emissions decreased to 30.6 gigatons of CO_2eq in 2020, 8% less than in 2019. However, GHG emissions increased by 6% in 2021, obtaining 36.3 gigatons of CO_2eq, and will likely increase further due to increased energy demand (International Energy Agency, 2020; Danish Energy Agency, 2021). GHG emissions need to be considered in electricity system planning to support GHG emissions reduction (Khan, 2018). Transformation efforts and policies are needed to reduce GHG emissions in the development of the electricity sector (Hou et al., 2019). Furthermore, specific climate policies may lead to low-carbon development with lower GHG emissions (Emodi et al., 2017), and specific power plant technologies may help to meet emission targets while addressing energy demands (Malka et al., 2023) and maintaining several fossil fuels in operation (Cai et al., 2022).

In 2021, the IEA reported that the electricity sector emitted 44% of the total global GHG. Moreover, 73% of GHG emissions were generated from burning fossil fuels (International Energy Agency, 2023). In 2020, Indonesia's GHG emissions reached 1,050.41 million tons CO_2eq, and 56% of GHG emissions in Indonesia were generated by the energy sector, an increase of 21% compared to the previous year (Ministry of Environmental and Forestry, 2020).

Indonesia is committed to reducing GHG emissions in accordance with the Paris Agreement, which was ratified in Indonesian regulations number 16 in 2016 (Government of the Republic Indonesia, 2016). The Paris Agreement requires each country to set GHG emissions reduction targets and report regularly to the UNFCCC. Indonesia set a GHG emissions reduction target of 29% for unconditional mitigation or 38% for conditional mitigation through Indonesia's first NDC (Ministry of Environmental and Forestry, 2016). The GHG emissions reduction target changed in the 2021 NDC update, with an unconditional mitigation target increase to 29% or 41% conditional mitigation (Ministry of Environmental and Forestry, 2021). The thirteenth emission gap report, released in 2022, predicts that 2030 emissions will exceed the Paris Agreement policy to limit global warming below 2 degrees Celsius. Current policies project a temperature rise of 2.8 degrees Celsius by the end of the century. Implementing the current commitments will only reduce the temperature rise to 2.4–2.6 degrees Celsius for conditional and unconditional mitigation. The NDC demands to be revised to include a more rigorous target and cut 45% of emissions to prevent future rising temperatures (UNEP, 2022). In 2023, 153 countries have submitted their NDC updates to support emissions target reduction (UNFC, 2023). Indonesia has set an additional ambitious target of reducing GHG emissions to support global emission reductions by 2030 through the enhanced NDC. The enhanced NDC aims to unconditionally reduce GHG emissions by 31.89% and 43.20% conditionally by 2030. The enhanced NDC will also provide a short-term target of emission reduction by 2030 and achieve net zero by 2060 (Ministry of Environmental and Forestry, 2022), which could be challenging for Indonesia without international support (Suroso et al., 2022). In addition to assisting in the reduction of GHG emissions, the NDC has a positive impact on encouraging sectors to shift to renewable energy (Chang and Lo, 2021). Additionally, the NDC represents pathways to decarbonization and a shift toward energy transition (Siriwardana and Nong, 2021). Shifting to an energy transition requires at least fifty percent renewable energy penetration (Reyseliani et al., 2022), even though energy transition programs require long-term policy planning. It may impact increasing investment (Jeong et al., 2021) and increase the need for system flexibility (Chen et al., 2020).

Several previous studies have been conducted to analyze the impact of climate policy on the electricity sector globally, including the impact on electricity supply (Fant et al., 2020), energy demand (Zheng et al., 2020), energy security (Xie and Xie, 2023), renewable energy penetration (Laha and Chakraborty, 2020), and the possibility of achieving net zero (Ren et al., 2024). In Indonesia, some research has been conducted by optimization of the GAINS method in projecting GHG emissions against climate policy 2021–2050 (Cahyono et al., 2021), employing renewable energy to meet energy demands (Erdiwansyah et al., 2021), and creating decarbonization scenarios for the electricity system in the Sumatra region (Sani et al., 2021) and East Kalimantan (Kresnawan and Safitri, 2018). Limited studies have addressed climate policy in the electricity sector within the scope of Indonesia. Therefore, this research aims to analyze the influence of the climate policy scenario on Indonesia's electricity sector during the 2021–2060 period. This study intends to describe the impact of climate policy implementation on energy demand, installed capacity, renewable energy mix, cost of investment, and GHG emissions in Indonesia's power generation.

2. EXPERIMENTAL SECTION

This study employs fundamental information derived from the PLN Statistics Book from 2010 to 2020, as well as the Indonesian Statistics Book year 2020, the PLN Sustainability Report year 2020, and the climate change mitigation and adaptation reports in Indonesia, which are analyzed using the Low Emissions Analysis Platform (LEAP) software with restrictions based on the specified scenario.

2.1 Scenario Development

The scenarios in this study were developed using Indonesia's current climate strategy. We established three scenarios: business as usual (BAU), sustainable development (SD), and low-carbon development (LCD).

2.1.1 Business As Usual (BAU)

This scenario develops based on growth in energy demand without considering the expansion of new renewable energy technologies. Energy conservation policy and specific targets are not considered under this scenario. The priorities for future power plant expansion will use current technologies, including coal-fired, hydropower, combined cycle, gas turbine, geothermal, and diesel.

2.1.2 Sustainable Developmen (SD)

This scenario is developed by employing sustainability policies. It intends to provide clean energy in compliance with the SDG and Indonesia's power development plans (PDP) to encourage GHG emissions reductions to meet the NDC target. Numerous power plant technologies will be gradually phased out by 2060. The development and operation of diesel power plants are limited until 2030. Furthermore, the development and operation of coal-fired power plants, combined cycles, and gas turbines are limited until 2060. Various renewable energy technologies, including hydropower, geothermal, solar, and wind, are expected to emerge. Energy conservation begins in 2021, intending to reduce energy intensity by 1% annually through 2060.

2.1.3 Low Carbon Development (LCD)

The low carbon development (LCD) scenario draws upon Indonesia's Long Term Strategy - Low Carbon and Climate Resilience (LTS-LCCR) and national policies that aim to achieve net zero emissions by 2060, following the NDC target. The utilization of fossil technology will steadily decline until 2060, and the development of new fossil technologies will be rigorously limited. Diesel power plants are limited to operation until 2030. The operation of combined cycle and gas turbines is limited until 2050. Moreover, coal-fired power plants are limited until 2060. Renewable energy technologies are rapidly expanding to meet future energy demands. Hydropower, geothermal, solar, and wind are among the renewable energy technologies expected to develop until 2060. Energy conservation will carried out in stages. The first stage, from 2021 to 2030, aims to reduce 1% of energy intensity per year. The second stage, from 2031 to 2045, reduces energy intensity by 3.5% anually. Furthermore, the third stage begins in 2046 and continues until 2060 to reduce energy intensity by 4.5% per year.

2.2 LEAP Modeling Framewroks & Methodology

This study employs the Low Emissions Analysis Platform (LEAP) for data analysis. LEAP, a scenario-based modeling tool developed by the Stockholm Environment Institute (SEI), is not limited to the energy sector but can also be effectively used in non-energy sectors for policy modeling (Heaps, 2022). Its versatility is evident in its use in energy policy modeling with various scenarios, supply-demand modeling for sustainable power development in Ecuador 2018–2040 (Bolonio and Mazadiego, 2018), projecting GHG emissions in Colombia's energy sector (Nieves et al., 2019), modeling the transition to renewable energy in South Asian countries (Rana and Gróf, 2021), policy analysis of Pakistan's demand forecast 2015–2050 (Mirjat et al., 2018), and analyzing the achievement of renewable energy targets and GHG emissions reduction in Thailand (Misila et al., 2020).

LEAP methodology in this study is shown in Figure 1. LEAP frameworks in this study consist of 4 main modules. The input module consists of end-user data, including energy demand, growth, existing capacity, energy production, energy intensity, lifetime power plant, energy efficiency, capacity factor, etc. This study used the emissions factor IPCC Tier-1 to calculate GHG emissions. The economic factor is calculated based on the capital cost for each technology applied in the transformation module. The demand analysis model consists of demand projections for each end-user with constraints according to specific scenarios. This study analyzes seven economic sectors as energy end-users: residential, industrial, public street lighting, transportation, social services, business, and government buildings (PLN, 2021). Energy demand analysis is carried out in the demand module using the base year data 2020. Growth projections for each end-user sector are based on the PLN statistic book for 2010–2019. Residential size is derived from Indonesian statistical reports (Indonesia Central Bureau of Statistics, 2021). The transformation module contains input for generation data, which consists of exogenous capacity, endogenous capacity, merit order, etc. This study employed the following technologies: coal-fired, combined cycle, gas turbine, diesel, wind, photovoltaic, hydropower, and geothermal. The capacity requirements are analyzed in the transformation module, with restrictions determined by each climate policy scenario. The output module describes the results of analyzing the input, demand, and transformation modules. The output module in this study consists of energy demand, installed capacity, energy mix, investment cost, and GHG emissions.

2.2.1 Demand Projection

Electricity demand projections in this study were calculated using demand growth in each economic sector. Total energy demand is affected by total activity and energy intensity (Equation 1).

$$TD_{a,s,t} = (TA_{a,s,t} \times DG_{a,s,t}) \times EI_{a,s,t} \quad (1)$$

Where TD is electicity demand, DG is demand growth while TA is total activity and EI is energy intensity for activity a on scenario s in year t.

2.2.2 GHG Emissions Calculation

The calculation of GHG emissions in this study is described in units of CO_2eq. CO_2eq is used to measure GHG emissions of various types of GHG based on the global warming potential (GWP) of each GHG converting equivalent to carbon dioxide gas (IPCC, 2022). GHG emissions in this

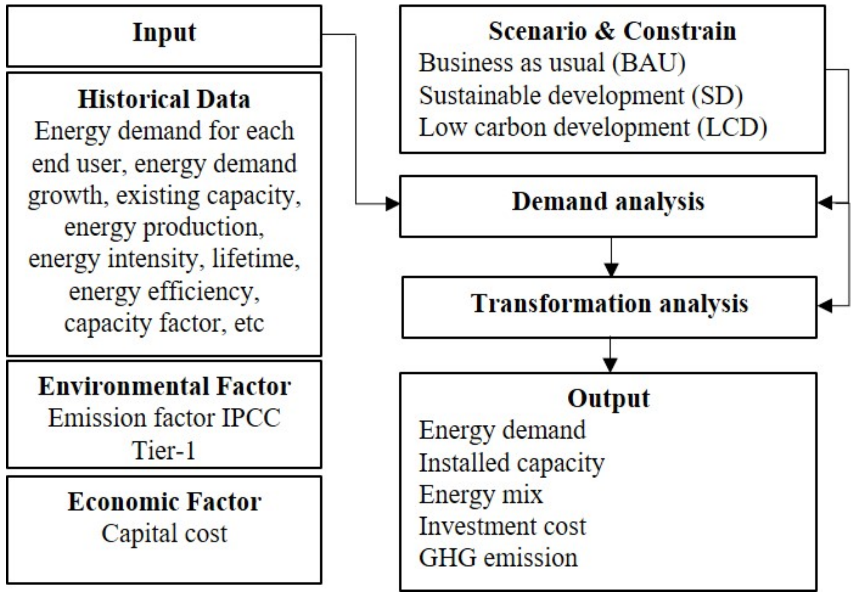

Figure 1. LEAP Methodology

study were calculated by using IPCC Tier-1 (Equation 2) with specific emissions factors for each generating technology (IPCC, 2014)

$$ET_{p,f} = EP_{p,f} \times EF_{p,f} \quad (2)$$

Where ET is GHG emissions, EP is energy production, meanwhile EF is IPCC emissions factor on technology p using fuels f.

2.2.3 Cost Calculation

Cost calculation in this study is described as an annualized investment value within 2021-2060 time span (Equation 3). Capital cost uses the capital cost data set for each technology in Indonesia power sector (DEA, 2021).

$$IC_t = AC_{p,t} \times (CP_{p,t} \times CRF) \quad (3)$$

Where IC is investmen cost in year, AC is additional capacity and CP is capital cost on technology p in year t. Capital cost is annualized using capital recovery (CRF) method (Equation 4)

$$CRF = \frac{R}{1-(1+R)^{-LF}} \quad (4)$$

Where R is discount rate dan LF is lifetime power plant.

3. RESULT AND DISCUSSION

3.1 The Role of Energy Conservation on Energy Demand

The implementation of energy-conservation initiatives bring about a significant reduction in energy demand by 2060. Notably, the LCD scenario showcases the most promising results with the lowest energy demand, followed by the SD scenario. Conversely, the BAU scenario, which lacks such initiatives, exhibits the highest energy demand by 2060 (Figure 2).

Under the BAU scenario, energy demand is projected to surge by a staggering 42% in 2030. This means that energy demand is expected to reach 35.46 MTOE in 2030, and a staggering 300.36 MTOE in 2060. The annual growth in energy demand is expected to be a daunting 97.316 MTOE per year. This alarming trend is a direct consequence of the absence of any energy conservation policy, leading to an over-reliance on non-renewable sources of energy. In contrast, implementing energy conservation initiatives starting in 2021, as seen in the other scenarios, could significantly curb this growth.

Under the SD scenario, energy demand is expected to increase by 36% in 2030. In 2030, energy demand is projected to be 32.07 MTOE and increase to 200.93 MTOE in 2060. Energy demand grows 73.30 MTOE per year. Implementing 1% energy conservation starting in 2021 impacts energy demand growth, which is relatively lower than the energy demand growth in the BAU scenario. Furthermore, the energy demand in the SD scenario is 33% lower than in the BAU scenario.

Under the LCD scenario, energy demand will increase by 35% in 2030. Energy demand will rise from 31.26 MTOE in 2030 to 76.97 MTOE in 2060. The energy demand growth is expected to be 44.76 MTOE per year. Energy demand in the LCD scenario might be considerably decreased compared to the BAU and SD scenarios by gradually implementing energy conservation initiatives starting in 2021. Moreover, the energy demand in the LCD scenario is 62% lower than

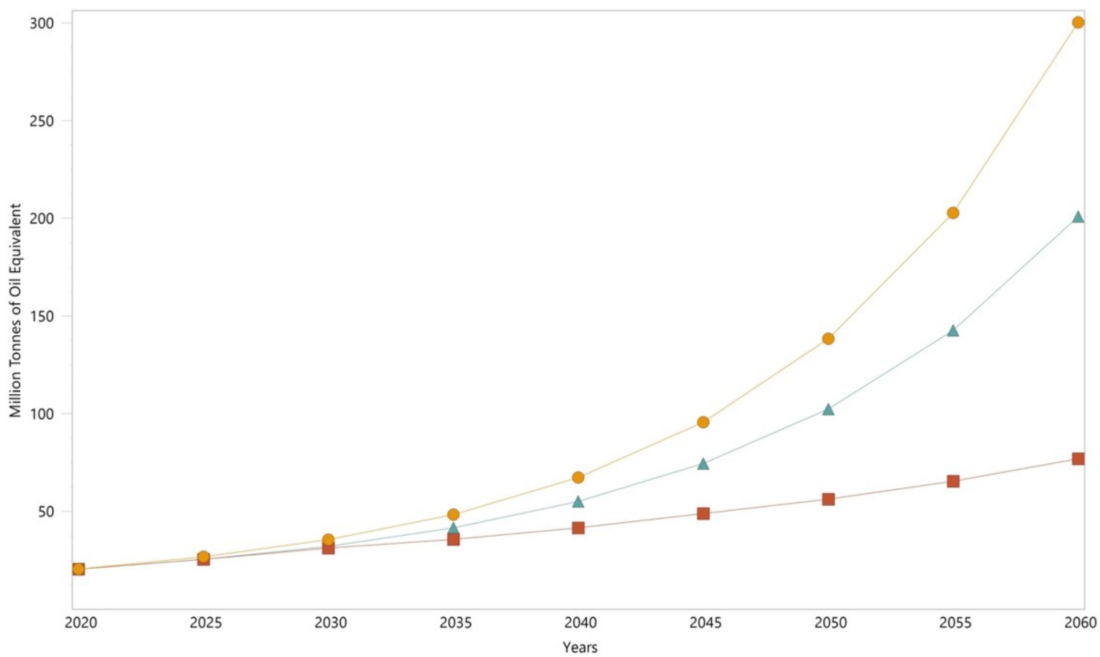

Figure 2. Energy Demand Projection under BAU, SD and LCD Scenario

in the SD scenario and 74% lower than in the BAU scenario.

The energy demand for each economic sector is consistent across scenarios (Figure 3). The industrial sector is experiencing a significant increase in energy demand. In 2030, it will consume 43% of total energy demand and rise by 71% by 2060. The other sectors' percentage shares of energy demand are decreasing, with the public lighting sector having the lowest energy demand until 2060.

3.2 Installed Capacity

In order to provide energy demand under the BAU scenario, installed capacity has increased to 108.95GW in 2030 and a staggering to 838.50 GW in 2060. Compared to other technologies, coal-fired capacity remains dominant (Figure 4(a)), with a capacity share of 59.46 GW in 2030 and 363.48 GW in 2060. A number of other technologies have also increased within the period. Gas turbine installed capacity will increase from 6.31 GW in 2030 to 51.94 GW in 2060, followed by combined-cycle capacity projected to rise from 18.24 GW in 2030 to 107.57 GW in 2060. Hydropower capacity is expected to increase from 14.45 GW in 2030 to 227.70 GW in 2060. The increasing installed capacity under the BAU scenario is a result of careful consideration of the compatibility of future-generation technology with present technology while also acknowledging the importance of new technology that may initially be considered a cost center in developing energy supply.

Under the SD scenario , the installed capacity is expected to increase from 98.99 GW in 2030 to a promising 681.59 GW in 2060. In 2030, coal-fired installed capacity remains dominant, with a capacity share of 23.87 GW. However, it steadily decreases to 0.89 GW in 2059 as the last operation of coal-fired power plant. The installed diesel capacity has also seen a decrease, with only 0.45 GW of diesel in operation in 2029. On the other hand, gas turbines and combined-cycles capacity continue to be added to the installed capacity, as they are considered to have lower GHG emissions than coal-fired and diesel power plants. Gas turbine capacity increased from 9.19 GW in 2030 to 55.55 GW in 2060, followed by increased combined-cycle capacity from 22.30 GW in 2030 to 107.63 GW in 2060. Renewable energy has increased under the SD scenario due to intervening policies to provide clean energy Therefore, hydropower capacity has seen massive development (Figure 4(b)) with a capacity increase from 23.72 GW in 2030 to an impressive 274.06 GW in 2060, becoming the largest percent share installed capacity in 2060, followed by the geothermal capacity that rose from 9.16 GW in 2030 to 96.41 GW in 2060. Photovoltaic will increase from 23.72 GW in 2030 to 131.09 GW in 2060, and wind capacity will also increase from 1.33 GW in 2030 to 16.85 GW.

Installed capacity has increased from 107.08 GW in 2030 to 279.47 GW in 2060 under LCD scenario. Increasing installed capacity in the LCD scenario remains lower than in the BAU and SD scenarios. The number of fossil fuels will start to decrease by 2060. As the last remaining coal-fired power plant, coal-fired installed capacity decreased from 23.87 GW in 2030 to 0.80 GW in 2059. Diesel capacity decreased to 0.45 GW in 2029 as the last diesel in operation. Gas turbine capacity decreased from 2.88 GW in 2030 to 0.14

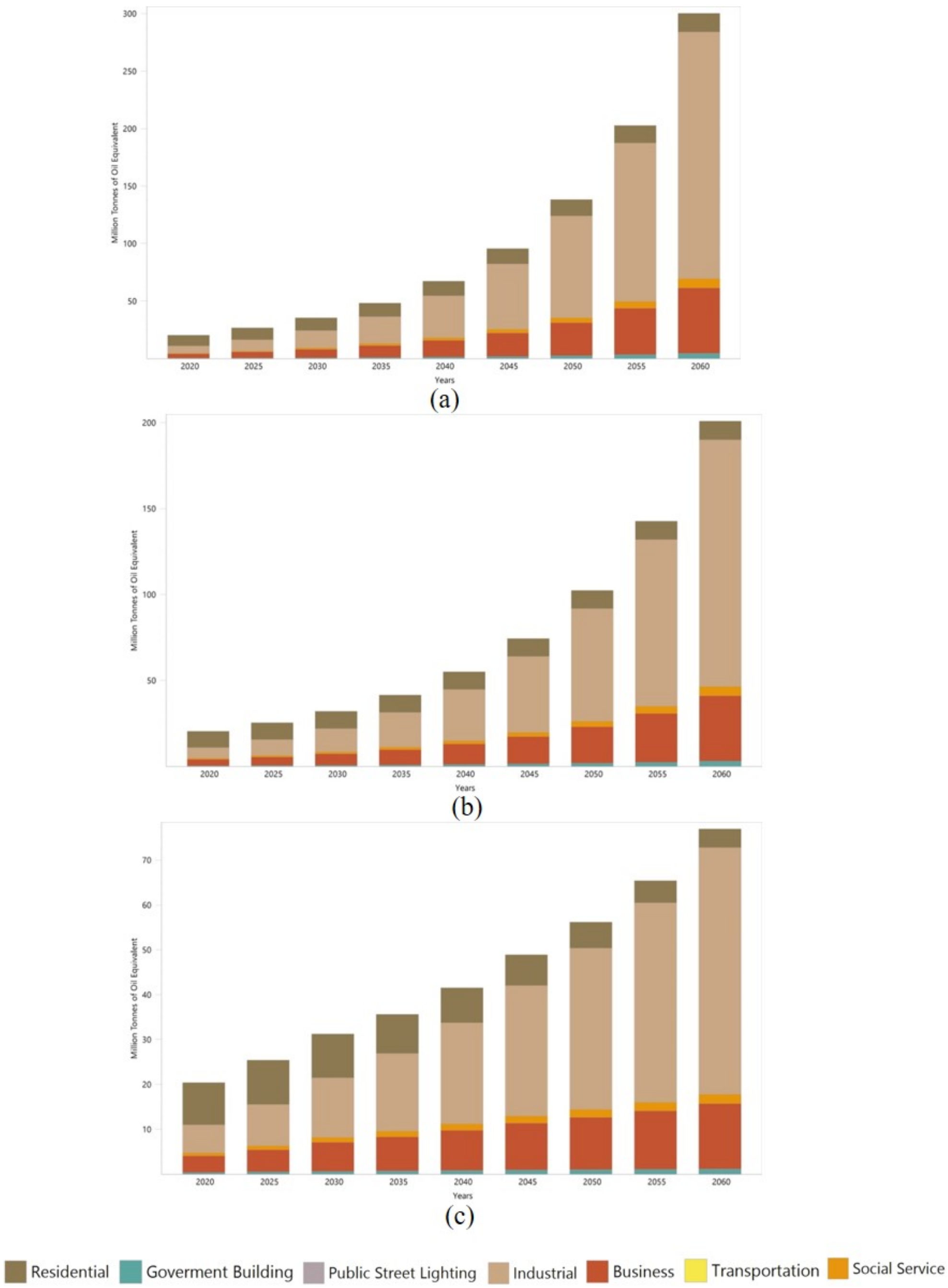

Figure 3. Energy Demand for each Economic Sector under BAU Scenario (a), SD Scenario (b) and LCD Scenario (c)

GW in 2049, as the last gas turbine in operation, followed by a decrease in the combined-cycle capacity from 9.57 GW in 2030 to 0.48 GW in 2049. Certain renewable energy technologies have undergone enormous growth until 2060 under the LCD scenario (Figure 4(c)). Hydropower capacity increased from 42.26 GW in 2030 to 144.25 GW in 2060. Photovoltaic capacity increased from 14.12 GW in 2030 to 70.26 GW in 2060. Winds capacity is also scaled from 1.87 GW in 2030 to 8.82 GW in 2060, followed by geothermal capacity from 12.51 GW in 2030 to 56.14 GW in 2060. The clean energy development policy, involving the early retirement of coal-fired, gas turbine, combined cycle, and de-dieselization programs and efforts toward net zero, affects the added renewable energy capacity. Therefore, renewable energy will provide 100% of total capacity in 2060.

3.3 Energy Mix

The BAU scenario involves a limited focus on advancing renewable energy sources and instead relies heavily on coal-

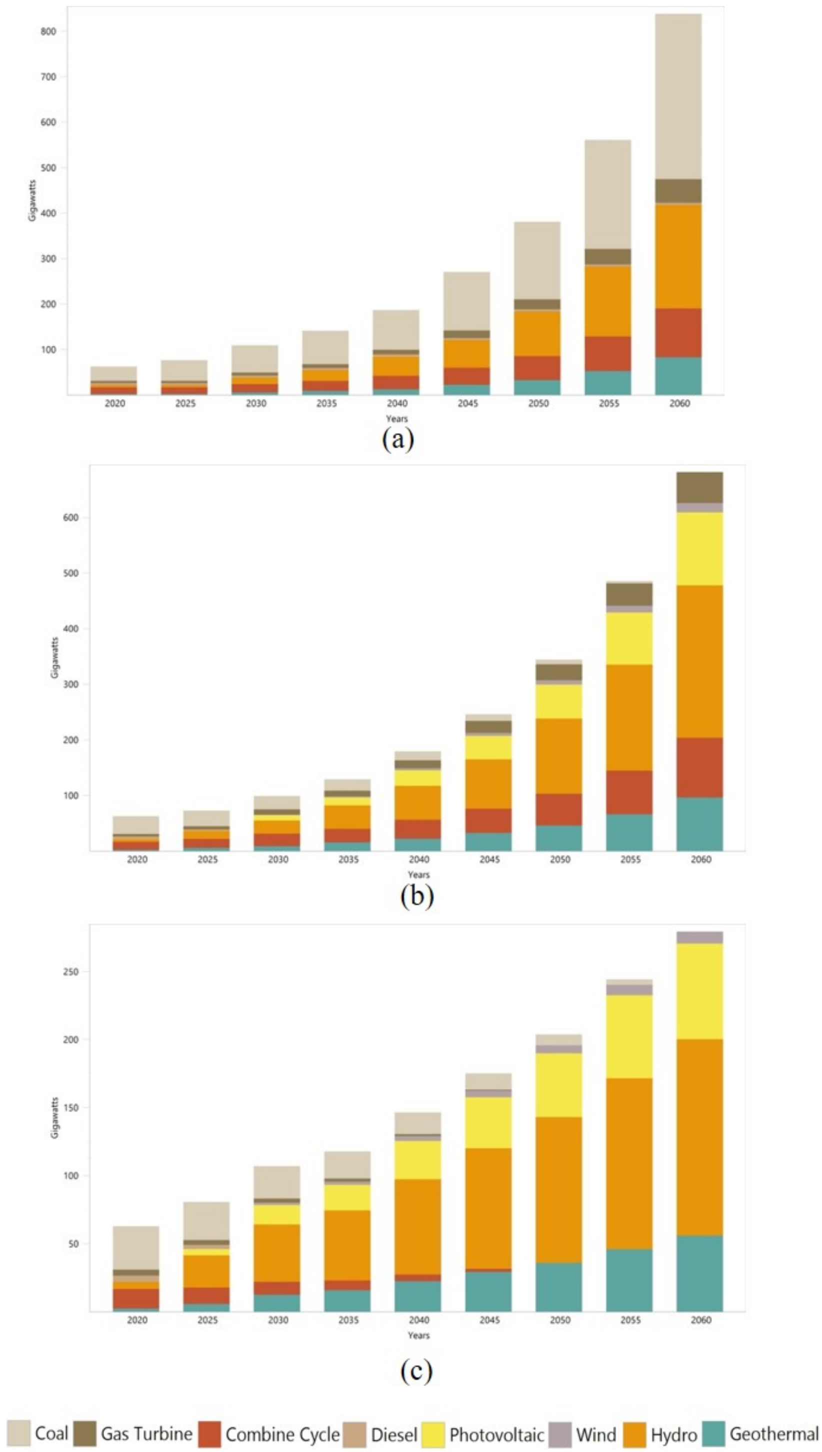

Figure 4. Installed Capacity under BAU Scenario (a), SD Scenario (b) and LCD Scenario (C)

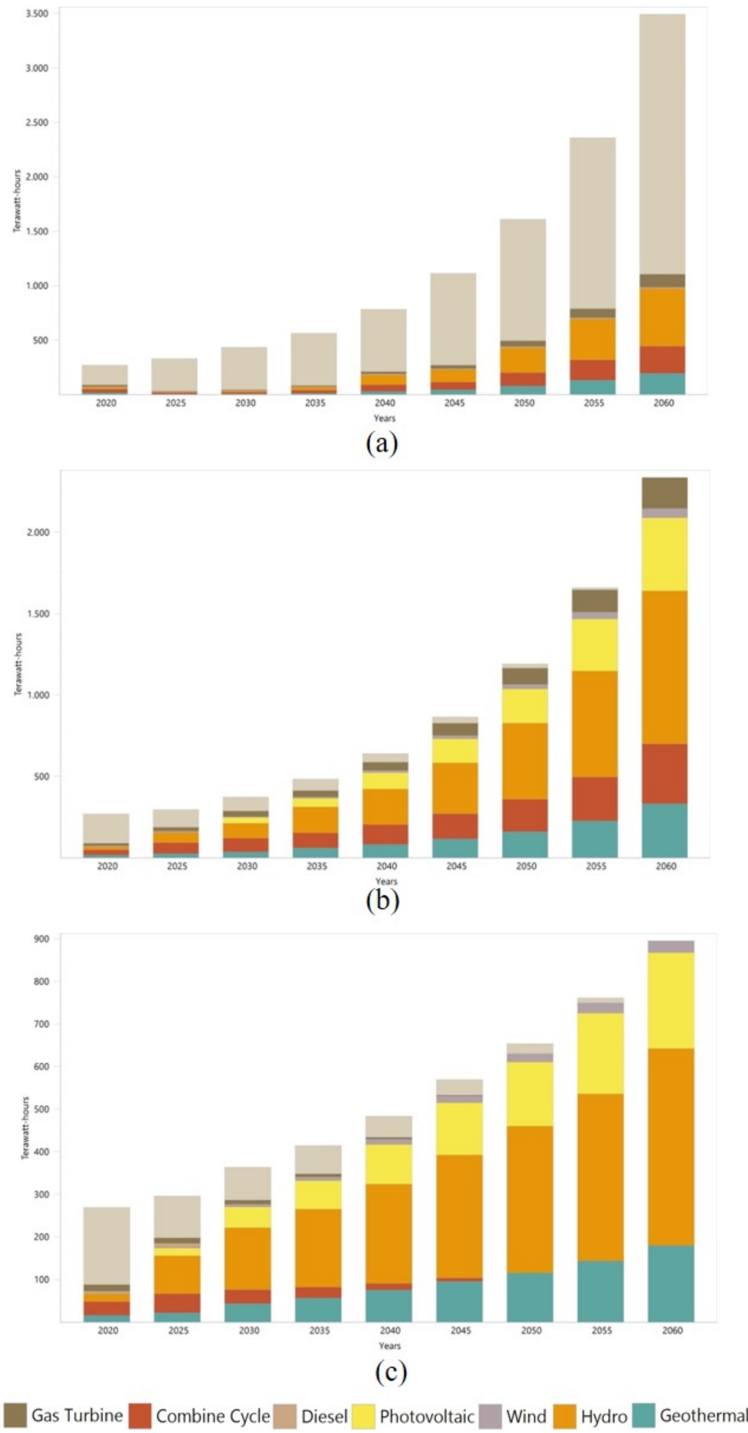

Figure 5. Energy Mix under BAU Scenario (a), SD Scenario (b) and LCD Scenario (c)

fired power plants for most energy production. Restriction in the BAU scenario significantly impacts the limited inclusion of renewable energy in the overall energy mix (Figure 5(a)). Renewable energy mix in 2030 is projected at 4% and continue to grow to 21% by 2060. The energy mix from coal-fired power decreased from 90% in 2030 to 68% in 2060. However, the energy mix from combined-cycle and gas turbine power plants increased to 10% during the same period.

The expansion of clean energy and the implementation of the de-dieselization program under the SD scenario significantly influence the proportion of renewable energy in the energy mix (Figure 5(b)). The proportion of renewable energy in the energy mix scaled from 45% in 2030 to 76%

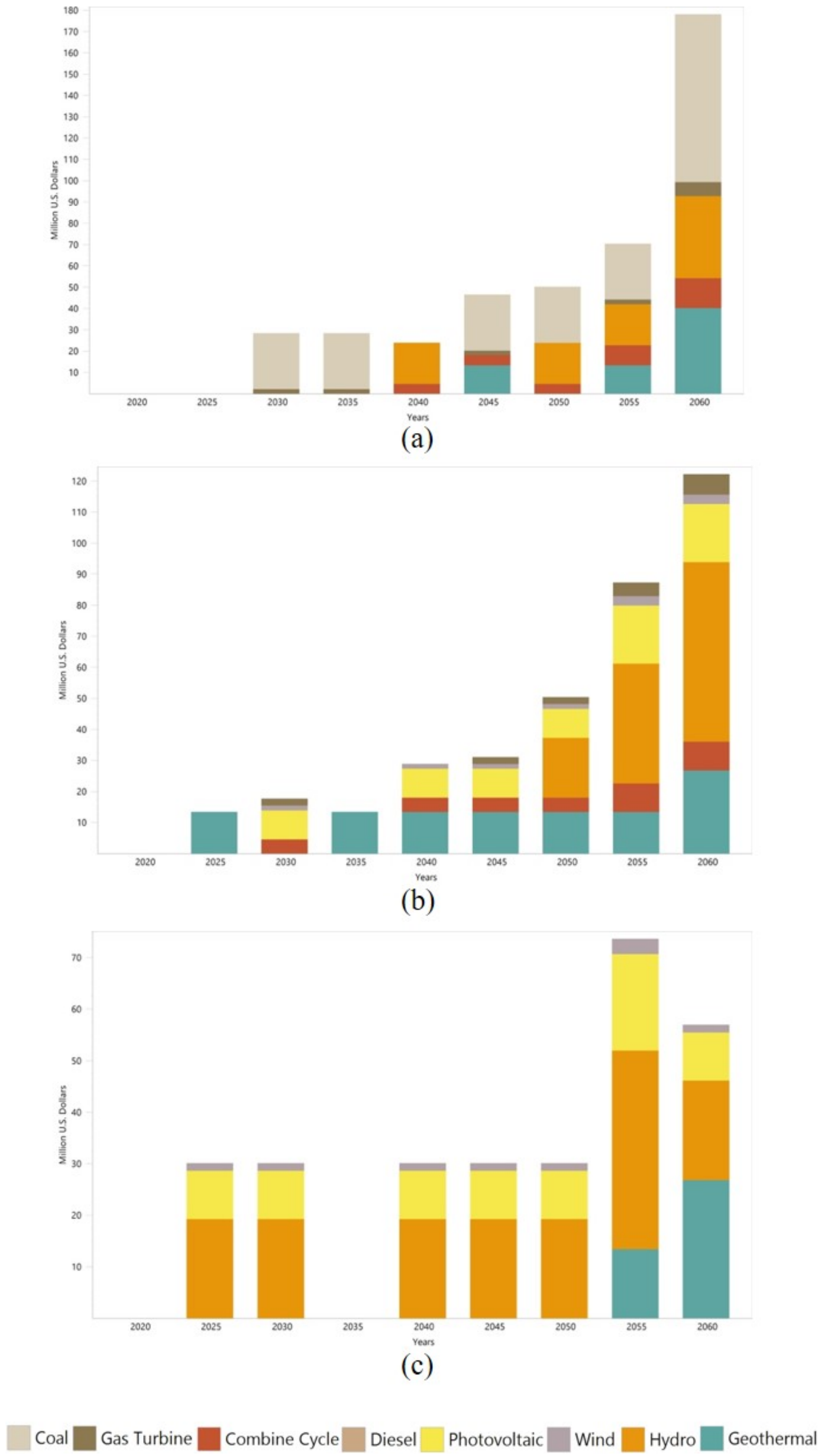

Figure 6. Investment Cost under BAU Scenario (a), SD Scenario (b) and LCD Scenario (c)

in 2060. Given a total share of 40% in 2060, hydropower plants are expected to have surpassed coal-fired plants as the dominant energy source, painting a promising picture for the future of renewable energy.

Renewable energy development and limited energy supply from fossil fuels significantly impact the energy mix under the LCD scenario (Figure 5(c)). The percent share of the renewable energy mix increased by 67% in 2030 and is projected to reach 100% by 2060. Hydropower plants contributed 40% of the renewable energy mix in 2030 and will increase to 52% in 2060. However, the coal-fired power plant mix decreased from 21% in 2030 to zero in 2060. The policy

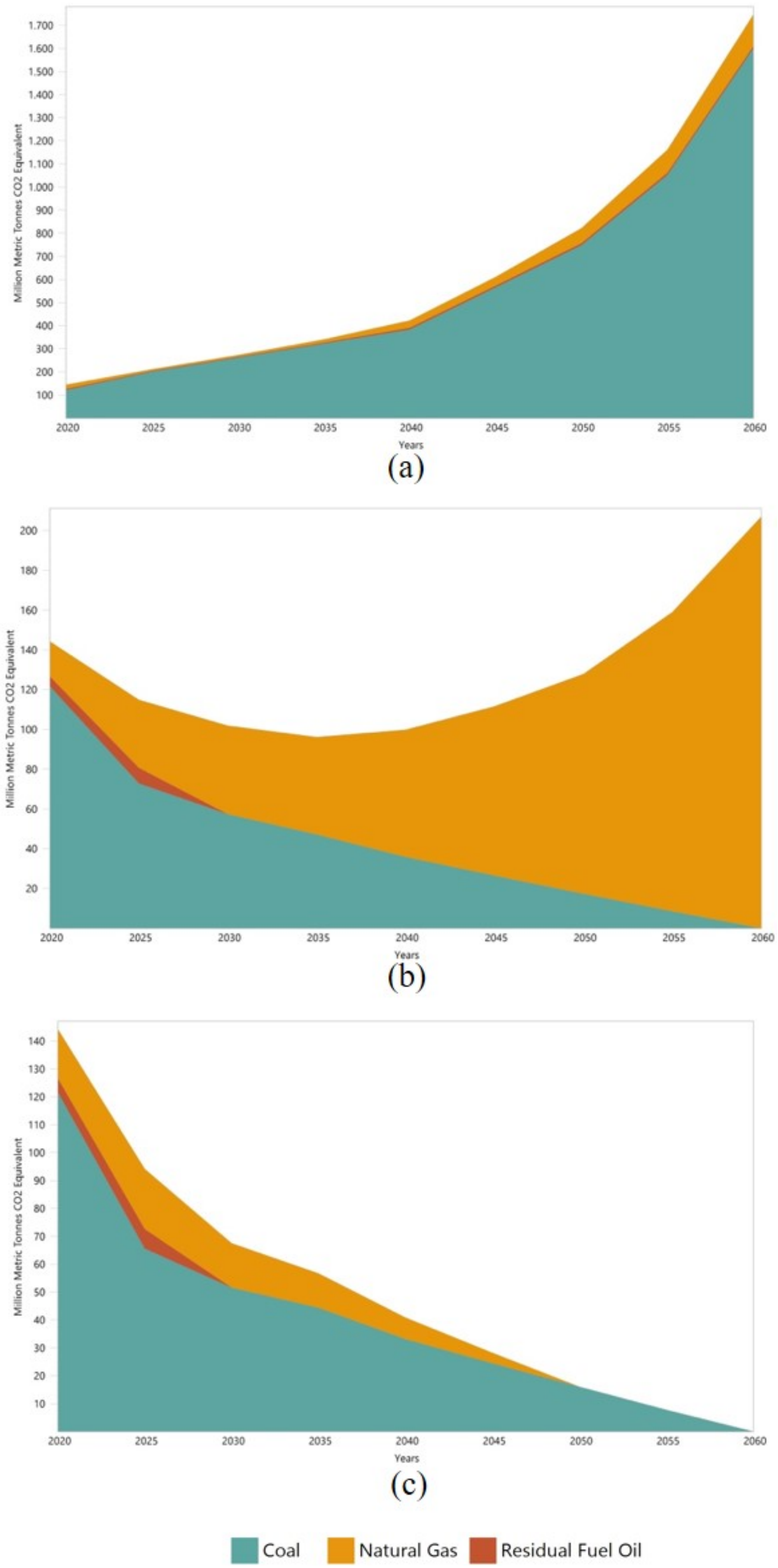

Figure 7. GHG Emissions under BAU Scenario (a), SD Scenario (b) and LCD Scenario (c)

of early retirement of gas turbines, combined cycle, coal-fired power plants, and de-dieselization impacts the growth of the renewable energy mix under the LCD scenario.

3.4 Investment Cost

demand in 2030. This amount will increase significantly to 1,671.58 million USD by 2060. Developing coal-fired power plants requires the highest investment, with a total of 52.51 million USD until 2030 and increasing to 682.66 million USD by 2060. Developing coal-fired power plants remains dominant until 2060 (Figure 6(a)), with a 41% share of the investment requirement.

Investment costs for developing the SD scenario are estimated to be 107.57 million USD in 2030 and increase to 1,537.64 million USD by 2060. The development of hydropower plants requires the highest feasible capital for investment. Hydropower plant development needs 38.57 million USD to finance installed capacity expansion in 2030 and increase to 597.86 million USD by 2060. Hydropower plant expansion remains dominant (Figure 6(b)), with a 39% share of the total investment needed in 2060.

Financing for the LCD scenario development is expected to rise from 149.92 million USD in 2030 to 816.51 million USD by 2060. The LCD scenario requires significantly less expenditure than the BAU and SD scenarios. All investment costs apply to developing renewable energy technologies, particularly hydropower plants. Hydropower plant development required the highest investment in 2030, with 77.14 million USD, and it will continue to rise to 366.43 million USD until 2060. Hydropower development remains dominant (Figure 6(c)), with a total investment share of 45% until 2060.

3.5 GHG Emissions

GHG emissions increase from 272.79 million tons CO_2eq in 2030 to 1,746.31 million tons CO_2eq in 2060 under the BAU scenario. Increasing the installed capacity of coal-fired, combined cycles, gas turbines, and diesel power plants until 2060 is mainly responsible for the rise in GHG emissions (Figure 7(a)). Coal-fired contributes the highest GHG emissions, expected to rise from 261.74 million metric tons CO_2eq in 2030 to 1,599.99 million metric tons CO_2eq in 2060. GHG emissions from natural gas used in combined cycle and gas turbine power plants are expected to increase from 7.82 million tons CO_2eq in 2030 to 137.36 million tons CO_2eq in 2060. Diesel power plants produce the most minor emissions; it is expected to rise from 3.23 million tons CO_2eq in 2030 to 8.95 million tons CO_2eq in 2060.

The SD scenario emphasizes a higher priority on developing renewable energy sources while maintaining the operation of several fossil fuel power plants. The increase in GHG emissions appears insignificant, indicating that a small amount of GHG emissions will continue to increase until 2060 (Figure 7(b)). Developing an SD scenario emits 101.92 million tons of CO_2eq of GHG emissions in 2030, and it is expected to rise to 207 million tons of CO_2eq in 2060. It is seven times lower than the BAU scenario during the same period. Coal-fired power plants still emit GHG emissions until they retire in 2059, with GHG emissions slowly decreasing from 57.35 million tons of CO_2eq in 2030 to 1.72 million tons of CO_2eq. GHG emissions produced by diesel power plants will also decrease until 2029, reaching 1.51 million tons CO_2eq. GHG emissions from the combined cycle and gas turbine are expected to rise from 44.57 million tons CO_2eq in 2030 to 207 million tons CO_2eq in 2060. These technologies remained the sole sources of GHG emissions until 2060.

In 2030, GHG emissions under the LCD scenario are expected to be 67.48 million tons CO_2eq and a further decrease to 1.58 million tons CO_2eq by 2059. Compared to the BAU and SD scenario, the LCD scenario generally emits significantly lower GHG emissions within the same period (Figure 7(c)). Coal-fired power plants still emit 51.62 million tons of CO_2eq in 2030 and will continue to decrease to 1.58 million tons of CO_2eq in 2059. Furthermore, 15.86 million tons of CO_2eq of GHG emissions were still emitted by combined-cycle and gas turbine power plants in 2030 and continue to decrease to 0.77 million tons of CO_2eq in 2049. Diesel power plants's GHG emissions will slowly decrease to 1.43 million tons CO_2eq in 2029. The role of energy conservation has a positive impact on lowering GHG emissions (Akdag and Yildirim, 2020). Meanwhile, implementing climate policy and strategies that enhance the use of renewable energy sources to produce electricity can reduce future GHG emissions.

4. CONCLUSIONS

Each climate scenario has distinct impacts on energy demand, installed capacity, energy mix, investment cost, and GHG emissions. Implementing energy conservation strategies in the SD and LCD scenarios significantly impacts lower energy demand than the BAU scenario. Therefore, capacity must be added to meet energy demand in each scenario. The low energy demand under the LCD scenario requires less installed capacity. Constraints in each climate scenario impact various renewable energy mixes. Specific climate policies such as early retirement fossil power plants, de-dieselization programs, and green energy initiatives determine the increase in renewable energy mix under SD and LCD scenarios. However, the absence of a specific target for renewable energy development affects the low renewable energy percentage under the BAU scenario. Renewable energy mix has a direct impact on GHG emissions. The scenario with a higher percentage of renewable energy intends to produce less GHG. However, the low renewable energy mix scenario contributes to increased GHG emissions, particularly in the BAU scenario. Each scenario requires a particular investment to expand the install capacity related to the renewable energy mix. The lowest energy demand with a higher renewable energy percentage requires less investment cost due to the small scale of installed capacity being added into the system.

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