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Energy Transition Planning in Achieving the 2060 Net-Zero Emissions Target in the Electricity Sector of North Sumatra Province

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Abstract
Accessibility, adequacy, and environmental sustainability principles in providing a national electricity supply will become key demands in the coming years. The energy transition from fossil fuel sources to renewable energy is necessary to mitigate the impact of climate change, with projections towards the Net-Zero Emissions target by 2060 in Indonesia. The study aims to model energy transition scenarios, evaluate the optimal renewable energy mix, and determine emission reduction strategies in the electricity sector using LEAP-NEMO software. This study uses a forecasting-based simulation modeling method with a mathematical approach through LEAP software and NEMO optimization framework. Three scenarios were analyzed, namely Business As Usual (BAU), Net Zero Emissions Carbon Capture Storage (NZE CCS), and Net Zero Emissions Full Renewable Energy (NZE FRE).
The study results show that by 2060, the NZE FRE scenario can achieve a 100% renewable energy mix, compared to the BAU scenario (42.1%) and the NZE CCS scenario (70.8%). Solar, biomass, hydro, and geothermal energy are projected to be the main sources of electricity generation in the NZE FRE scenario, with solar energy as the largest contributor. The NZE FRE scenario is also proven to be the most effective in reducing greenhouse gas emissions by up to 265.9 million tons of CO_2, or 70.5% of avoidable greenhouse gas emissions, compared to the BAU scenario. Although the cost of the NZE FRE scenario is higher, it can provide lower external impacts and long-term benefits in environmental sustainability.

1 Introduction

The generation of electricity using fossil fuels has a serious impact on the sustainability of non-renewable resources as well as increasing greenhouse gas emissions which have a significant impact on global temperature rise. Based on the Ember Climate report, global emissions produced by power plants increased to 12,431 million tons of CO_2 (mt CO_2) in 2022 with Indonesia ranking ninth among the world's largest CO_2 emitters, recording 192.7 mt CO_2 in greenhouse gas emissions. It is projected that this emission value will continue to rise until 2030 (Ember Climate, 2024). In an effort to limit the rate of global temperature rise and reduce the adverse effects of climate change, in 2015 the Paris Agreement was agreed which requires countries to contribute and strive to reduce emissions to the maximum. The agreement was supported by 195 countries present at the time, including Indonesia, which had also ratified the Paris Agreement in 2016.

North Sumatra Province with a population of 15.47 million people or 5.51% of the total national population (Dukcapil Kemendagri, 2022) occupies the fourth position in the largest population in Indonesia. In 2023, the province recorded economic growth of 5.01% (BPS, 2024), ranking among the highest middle levels in Indonesia. North Sumatra is also the sixth province with the largest distribution of electricity, reaching 12,059 GWh in 2022 (MEMR, 2023). Based on the IEA report, greenhouse gas emissions in Indonesia are influenced by variables of population growth, energy consumption, and economic rate (IEA, 2022). Some of these variables make North Sumatra one of the provinces that plays a key role in decarbonization efforts towards the net-zero emissions target by 2060 in Indonesia.

The energy transition towards a greener electricity system has been a global concern, with a focus on shifting from a centralized model to a decentralized model that utilizes renewable energy sources. According to research by Christophe Defeuilley (2019), public policy and institutional change have an important role in shaping the future of the electricity sector. These factors are recognized as the main drivers of electricity system change, along with increasing public support, decreasing technology costs, and innovations in energy storage (Defeuilley, 2019).

Many studies have simulated energy transition planning in the electricity sector from fossil fuel sources to clean and renewable energy, such as a study conducted by Handayani et al. (2023) in Cambodia, Laos, and Myanmar which shows the potential for the application of renewable energy supported by energy storage technology to achieve net zero emissions target. The study uses the Low Emissions Analysis Platform (LEAP) as software to simulate a 100% renewable energy integration scenario in the electricity sectors of the three countries, which has proven feasible and sustainable despite requiring a large cost investment (Handayani, K. et al., 2023). Meanwhile, on a regional scale in the province of North Sumatra, the research from Sri Ulina et al. (2022) shows significant potential utilization in hydro, wind, and biomass energy, which is expected to make an important contribution to the decarbonization of the electricity system at the regional level until 2028 (Ulina, S. et al., 2022).

Another study conducted by V. Wambui et al. (2022) in Kenya highlighted the benefits of renewable energy development accompanied by the internalization factor of environmental externalities. The results of this study show that the development of renewable energy sources with energy storage can reduce CO_2 emissions, improve the reliability of the electric power system and provide great benefits in terms of cost-effectiveness, especially when environmental externalities are taken into account in the form of emission taxes (Wambui, V. et al. 2022). On the other hand, research by Zhongrui Ren et al. (2024) in China uses LEAP software combined with NEMO (Next Energy Modelling System for Optimization) to simulate a scenario of high renewable energy penetration and gradually increasing carbon prices, as well as a subsidy scenario for the renewable energy sector. The results show that the combination of carbon pricing and subsidy policies in the renewable energy sector plays an important role in achieving net zero emissions by 2050 (Ren, Z. et al., 2024).

Another study by Ahmed Hassan et al. (2023) explored the scenario of the renewable energy mix in Egypt in the 2020-2050 range and concluded that optimizing the increase in the portion of renewable energy in the national energy mix can significantly reduce greenhouse gas emissions and reduce energy production costs in the long term (Sayed, A. et al., 2023). Handayani, Filatova, et al. (2020) conducted a study using LEAP software combined with WEAP to simulate climate change mitigation efforts and long-term electricity system planning in the Java-Bali system by considering the impact of climate change on the demand and supply of electricity (Handayani, K. et al., 2020).

Research on the energy transition at another regional level, namely on the Sumatra electricity system by Abeth Novria Sonjaya et al. (2023) which mapped and harnessed the renewable energy potential in Sumatra Island for 2020-2050 using LEAP software highlighted that without significant intervention, CO_2 emissions in the region could almost double by 2028 (Sonjaya, A. et al., 2023). Meanwhile, another research study by Handayani, Anugrah, et al. (2022) on the ASEAN electricity system stated that the net-zero emission target can be achieved with the optimal use of renewable energy, especially PV technology which will contribute 61% to the energy capacity mix by 2050, although this scenario requires greater costs than other scenarios (Handayani, K. et al., 2022).

Based on the background of the problems raised and several previous research studies, North Sumatra Province with a projection of electricity consumption that will continue to increase in the future and has great potential in the development of renewable energy sources, has a strategic role in the clean energy transition efforts to achieve net zero emissions targeting Indonesia by 2060. This study aims to plan and analyze the energy transition in the electricity sector of North Sumatra province, identify renewable energy mixes that can meet electricity needs, and determine the best emission reduction scenario to achieve the net-zero emissions target by 2060.

2 Materials and Methods

This study uses an energy modeling method with forecasting-based simulation calculations with a mathematical approach using analytical programming (LEAP-NEMO model framework). LEAP software with the NEMO optimization framework is used as a modeling tool to estimate and evaluate energy transition scenarios in the electricity sector of North Sumatra Province. Below are some sub-discussions about the research methods conducted in this study.

A. Electricity System Modeling Design Method

The modeling uses the LEAP-NEMO framework which is designed by having several modules for the simulation process. The modules used include: an electricity demand projection module that aims to model how energy needs will evolve in the future, an electricity supply projection module that aims to model the electricity supply to meet a given demand, a cost module, and an emissions projection module that is used to calculate and compare GHG emissions generated from the electricity system in various scenarios.

The next process in designing electricity system modeling is to compile three scenarios used in the modeling simulation process. These three scenarios are designed based on reference to regulations, policies and recommendations related to the energy transition in the electricity sector to achieve NZE 2060 in Indonesia. The first scenario is the Business as Usual (BAU) scenario which assumes the continuation of portfolio flows based on the Electricity Supply Business Plan 2021-2030 (RUPTL) and the Regional Energy General Plan (RUED) in the current electricity sector without significant intervention with a target of implementing renewable energy of 23% by 2025 and at least 31% by 2050 (National Energy Policy, 2014). In the BAU scenario, the addition of coal-fired power plants and natural gas coal-fired power plants is unlimited and competes with all available generation technologies. In addition, the BAU scenario also serves as a comparative reference when assessing the implications of the other two scenarios.

The second scenario is the Net Zero Emissions Carbon Capture Storage (NZE CCS) scenario based on a progressive renewable energy utilization policy of at least 70% by 2060 (MEMR, 2024), whose implementation is limited by the potential resources available & technical potential. The NZE CCS scenario also applies carbon capture technology to coal, natural gas, and biomass power plants starting in 2035 which is also supported by the application of biomass cofiring starting in 2025 in coal-fired power plants to reduce greenhouse gas emissions. To optimize the results of electricity generation from renewable energy, this scenario also utilizes energy storage technologies, including hydro pump storage (HPS) and battery energy storage system (BESS).

Meanwhile, in the last scenario, namely the Net Zero Emission Full Renewable Energy (NZE FRE) scenario which simulates the integration of 100% of existing renewable energy potential into the electricity system of North Sumatra province. This scenario does not use carbon capture technology in the simulation process, the application of renewable energy is limited by the potential of available resources and their technical potential as well as the development of the utilization of energy storage technology which includes hydro pump storage (HPS) and battery energy storage system (BESS).

B. Simulation Modeling Method with LEAP-NEMO

This research uses LEAP software or stands for Low Emissions Analysis Platform. LEAP is a software developed by the Stockholm Environment Institute (SEI) that is widely used for energy policy analysis and climate change mitigation evaluation (Heaps, 2022). The modeling simulation with the hybrid model paradigm in this study combines top-down and bottom-up approaches in the process of analysis and forecasting of electricity system development. In the early stages, macroeconomic data, electricity sales activity, and load curves are used to estimate the final demand for electrical energy through a top-down approach, which can provide a big picture of energy demand based on macroeconomic indicators and historical data on electricity consumption. Figure 1 below shows the simulation framework of the LEAP-NEMO modeling for this research.

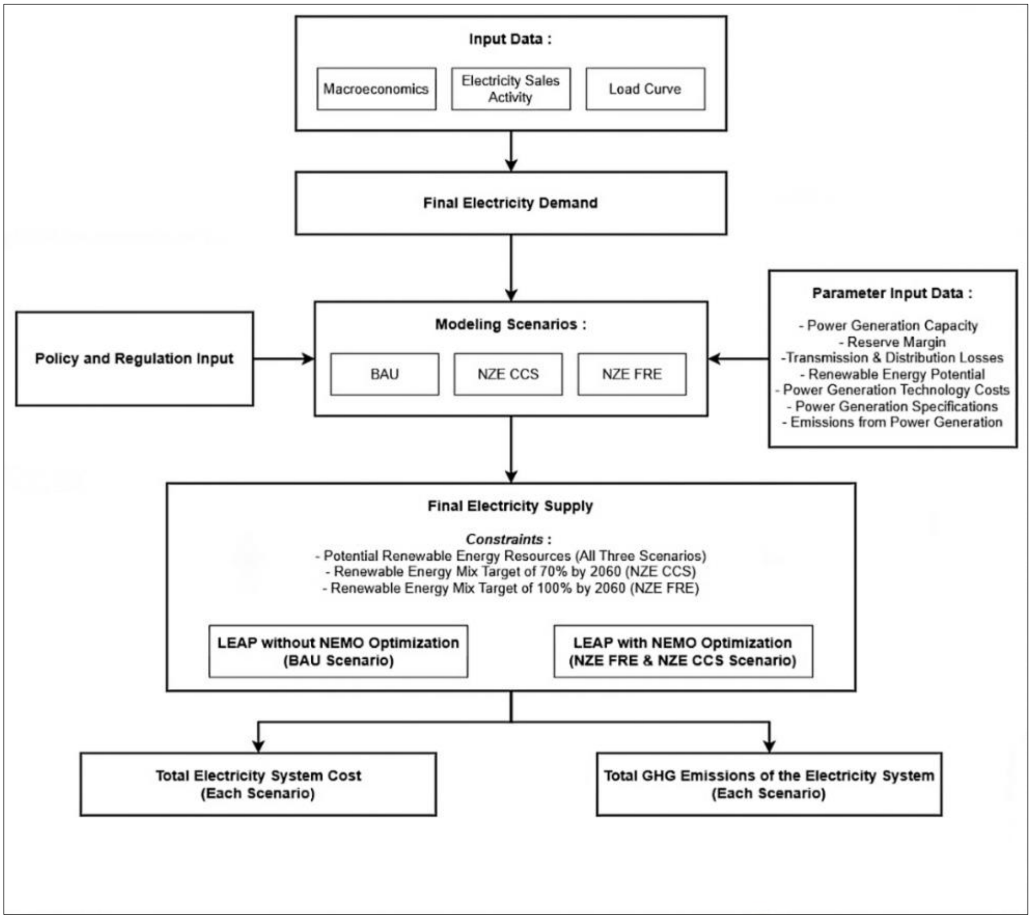

Figure 1. LEAP-NEMO Modeling Simulation Framework

This simulation framework includes policy and regulatory inputs in each modeling scenario. Parameters such as the technical specifications of the power plant, reserve margins, transmission and distribution losses, renewable energy potential, and others are used as databases for the simulation of the final electricity supply. A bottom-up approach is applied to simulate specific policies and technologies in the provisioning module towards basic energy consumption.

The process of providing electricity in each scenario must meet several limitations. The simulation was carried out under two conditions: without NEMO optimization for the BAU scenario and with NEMO optimization for the NZE CCS and NZE FRE scenarios. In a scenario without optimization, LEAP adds new power plants capacity to meet annual needs and regulates electricity distribution based on priority in accordance with policies and regulations. Meanwhile, in a scenario with NEMO optimization, LEAP manages the expansion of generation technology capacity, capacity addition time, and electricity distribution to achieve the lowest cost of electricity system expansion. The simulation results show electricity generation, energy mix per scenario, and expansion of plant technology capacity from 2023 to 2060. The final stage of this hybrid model provides an output in the form of total system cost, external cost of GHG emissions, and total GHG emissions for each scenario.

C. Simulation Data

The electricity demand modeling conducted in the LEAP software estimates electricity demand based on the multiplication of electricity intensity values and total electricity consumption activities. The total electricity consumption activity can be reflected by the accumulation of the number of electricity customers or the accumulation of economic activity levels (GRDP). Meanwhile, energy intensity is the ratio of energy consumption value per electricity customer or per value of economic activity (GRDP). In this study, the ratio of growth in the number of customers, economic growth, growth in electricity consumption, and energy intensity growth value were used to simulate forecasting in the modeling year period (2023 – 2060) using growth trends based on historical data over the last 10 years (2013 – 2022), in this case this study follows the same projected growth of electricity demand as in the RUPTL 2021-2030. Table 1 below is a tabulation of the simulated data of electricity demand used in this study.

Table 1. Tabulation of Electricity Demand Simulation Data

Data Caption	Data Value
Customer Growth Projection	4.00 %
Business as Usual Growth Rate Projection	4.72 %
Energy Intensity (Base Year)	0.00298 GWh/ Customer
Energy Intensity Growth Projection	0.70 %
Energy Elasticity	1.00 %
Electrification Ratio Projection (2023-2060)	100 %

Furthermore, Table 2 below is data on the potential of renewable energy sources in North Sumatra Province (Draft National Electricity General Plan 2023-2060, 2023)(North Sumatra Provincial Regional Energy General Plan for 2022-2050, 2022). The potential of this renewable energy will be one of the limitations used in the transformation process of electricity generation.

Table 2. Renewable Energy Potential Resources

Energy Source	Potential (MW)
Biomass	3,939
Biogas	116
Municipal Solid Waste (MSW)	31
Hydro	5,012
Solar	11,852
Wind	356
Geothermal	2,026
Total Potential Resource	23,332

Table 3 below is data on the existing power generation capacity that has been operating in the province of North Sumatra in 2022 (Electricity Statistics in 2022, 2023). This data is the input value in the capacity of 2022 or the base year of the LEAP software.

Table 3. Existing Power Plants Capacity 2022

Types of Power Plant	Capacity (MW)
Coal	1,350
Natural Gas	1,057.96
Diesel	135.96
Hydro	1,002.45
Mini Hydro	154.53
Geothermal	504.15
Wind	0
Solar PV	0.45
Municipal Solid Waste (MSW)	0
Biomass	145.57
Biogas	21.51
Total Capacity	4,372.58

Some technical parameter data is required as input data in the LEAP software. There are 16 types of technologies used in this study, but the use and utilization of these types of technologies will differ according to the characteristics of each scenario, such as the absence of Battery Energy Storage System (BESS) technology in the Business As Usual scenario because the scenario is a simulation and not an optimization scenario in the LEAP software. Table 4 below shows the data on the technical parameters of the power plant technology used in this study (MEMR, 2024) (IESR, 2023) (Handayani and Anugrah, 2021).

Table 4. Technical Parameter Data of Power Plant Technology

Types of Technology	Lifetime (Years)	Process Efficiency (%)	Maximum Availability (%)	Capacity Credit (%)
Coal	30	42	73	100
Natural gas	25	56	85	100
Diesel	25	45	95	100
Biomass	25	31	81	100
Biogas	25	32	85	100
MSW	25	28	90	100
Hydro	50	100	41	52
Mini Hydro	50	100	76	58
HPS	60	80	80	25
Solar PV	30	100	22	22
Wind	30	100	35	35
Geothermal	30	15	80	100
BESS	25	30	17	22
CCS Coal	30	34	80	100
NG CCS	25	48	80	100
BECCS	25	30	90	100

The projected cost of expanding the electricity system in this study has several cost variables that play a role in influencing power generation technology until 2050. Costs considered include capital cost, fixed o&m cost, variable o&m cost, and fuel cost. Table 5 below is the cost parameters of each power generation technology (MEMR, 2024) (IESR, 2023) (Handayani and Anugrah, 2021).

Table 5. Power Plants Technology Cost Parameter

Types of Technology	Capital Cost (Million USD/MW)		Fixed O&M Cost (USD/MW)	Variable O&M Cost (USD/MWh)	Fuel Cost (USD/MWh)
	2023	2050			
Coal	1.73	1.63	56.6	1.25	9.53
Natural gas	1.08	0.95	23.5	2.6	23.90
Diesel	0.91	0.89	8	7.3	41.50
Biomass	2.28	1.82	47.6	3.4	8.34
Biogas	2.45	1.84	14.85	0.13	30.71
MSW	5.97	4.94	243.7	27.5	5.88
Hydro	2.2	1.96	37.7	0.74	0
Mini Hydro	2.5	2.23	53	0.57	0
HPS	1.2	1.2	8	0.94	0
Solar PV	1.2	0.6	14.4	0	0
Wind	1.65	0.95	60	0	0
Geothermal	4.4	3.96	50	0.27	0

BESS	1.33	0.64	7.6	2.3	0
CCS Coal	3.46	2.77	98.4	4.2	9.53
NG CCS	1.84	1.72	32.5	4.36	23.90
BECCS	5.45	5.09	64	8	8.34

As shown in the table, capital costs are projected to decrease by 2050. This is influenced by each technology's learning rate, where the more research and development are achieved in energy technologies, the lower the investment costs will be (MEMR, 2024).

This study also considers other variables in projecting the electricity supply system modules, such as planning reserve margin data and the projected electricity losses in the transmission and distribution system in North Sumatra Province. Table 6 below presents the tabulation of these data requirements. (MEMR, 2023) (PLN, 2021) (MEMR, 2019).

Table 6. Planning Reserve Margin and Transmission – Distribution Losses

Input Parameters	Data
Planning Reserve Margin	35 %
Transmission-Distribution Losses Projection	8.3 – 6.1 %

The Planning Reserve Margin in the LEAP software is used to determine how much additional capacity (as a percentage) is required above the peak load to maintain system security. Meanwhile, in the transmission and distribution losses data, the value will decrease until 2038 with a percentage value of 6.1%.

3 Results and Discussion

A. Results of the Electricity Demand Projection

Based on the input process of several simulation data in the LEAP software, the results of the projection of electricity demand in North Sumatra province are obtained as shown in Figure 2 below.

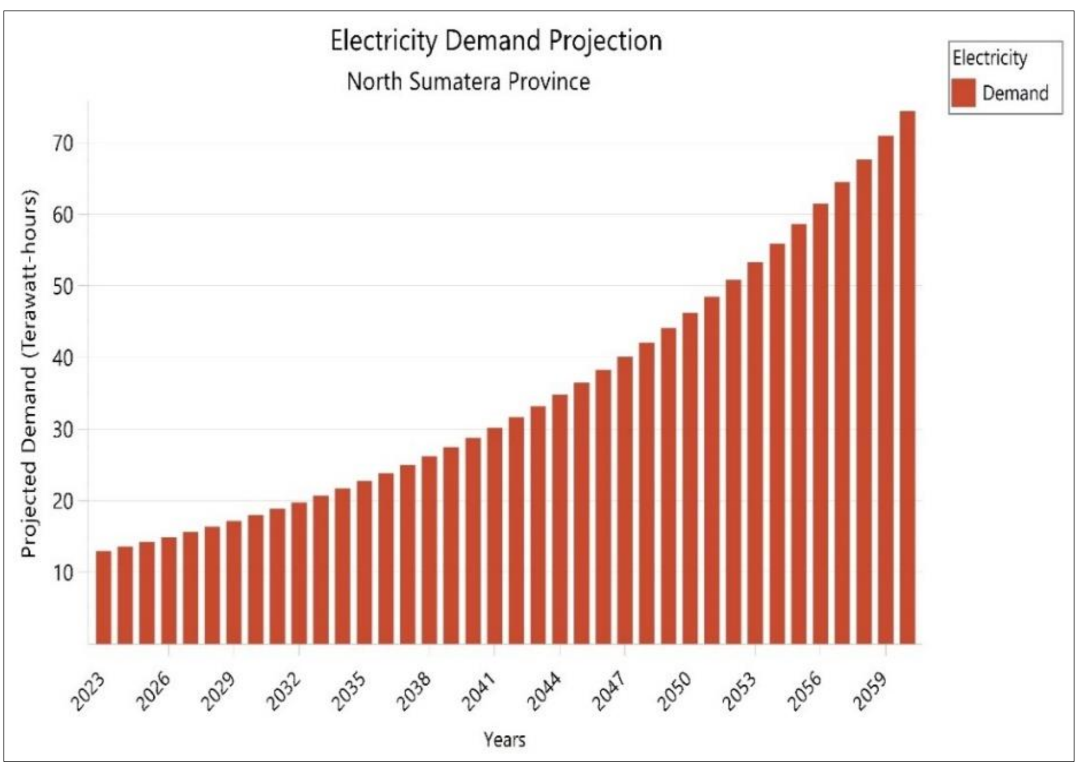

Figure 2. Projected Total Electricity Demand in North Sumatra Province

In 2023, electricity demand is projected to reach 13.0 TWh. This electricity demand is expected to continue increasing, reaching 18.0 TWh by 2030, with the growth trend continuing over the next 10 years. By 2040, the demand is projected to reach 28.8 TWh, an increase of 10.8 TWh over the next 10 years. Then, by mid-century 2050, electricity demand is expected to surge to 46.2 TWh. In the final period of the study, by 2060, electricity demand in North Sumatra Province will reach 74.4 TWh, more than five times higher compared to the starting year of the study period. Therefore, the total cumulative electricity demand for North Sumatra Province during the energy transition planning projection period (2023-2060) will be 1,341.2 TWh.

B. Results of the Electricity Supply Projection

1) BAU Scenario Projection

Based on the simulation results, electricity production in North Sumatra province until 2060 will still be dominated by the energy mix produced from fossil fuels, namely coal and natural gas. It is recorded that in 2025 energy production from coal-fired power plants will reach 4.5 TWh, and will increase to 4.6 TWh in 2030, 6.8 TWh in 2040, then this energy production is projected to continue to increase consistently until it reaches 23.3 TWh in 2060.

Energy produced by natural gas power plants also recorded a consistent increase. In 2025 the energy produced is expected to reach 3.3 TWh, and in 2040 it is projected to reach 5.1 TWh which will also continue to increase to 22.0 TWh by 2060. Furthermore, the energy generated in other fossil fuel power plants, namely diesel power plant, will reach 0.4 TWh in 2025 which is projected to continue to decline until it reaches 0 TWh in 2050. This diesel power plant is widely used in isolated electricity system on the island of Nias.

In addition to the energy produced from fossil fuel power plants, renewable energy power plants will also be one of the resources that will be utilized. In this scenario, the energy from renewable energy power plants will be dominated by hydro, geothermal and biomass power plants. In 2060 hydropower plants are projected to generate 12.4 TWh of electricity, while geothermal power plants are 7.8 TWh and biomass power plants are projected to contribute 5.5 TWh by 2060. Figure 3 below shows the projected results of electricity generation in the BAU scenario until 2060.

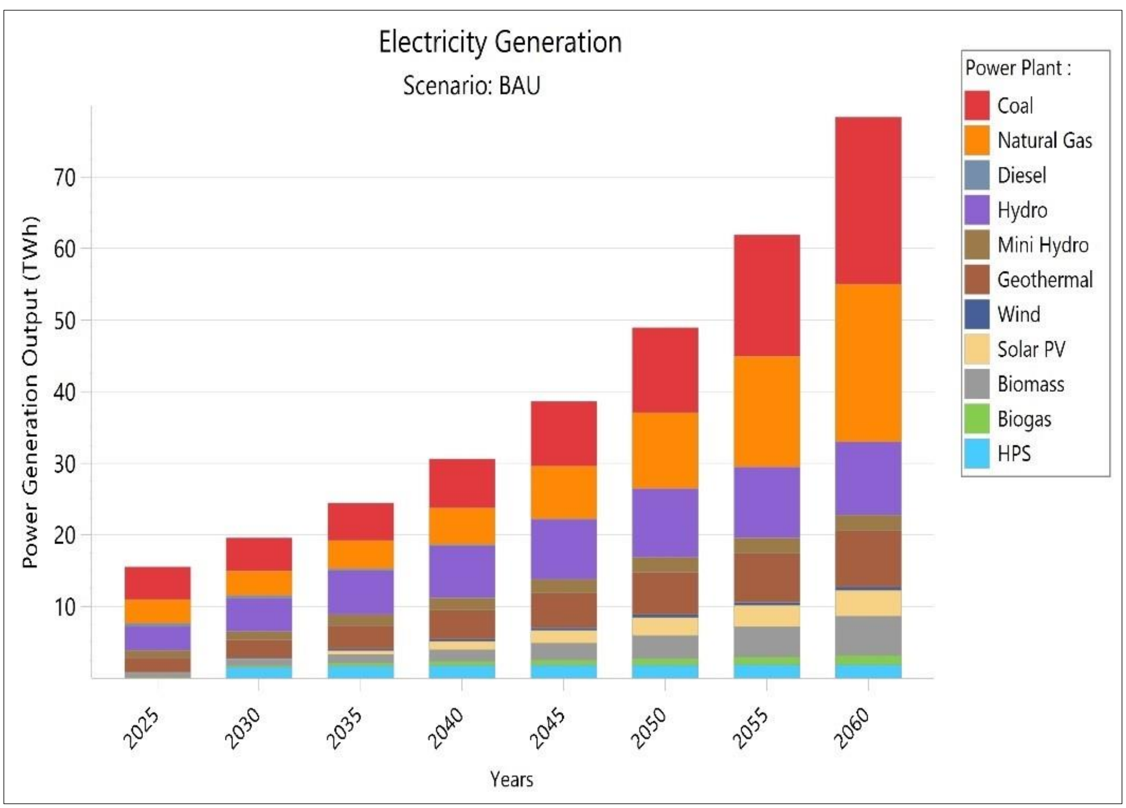

Figure 3. Electricity Generation in the BAU Scenario

2) NZE CCS Scenario Projection

Based on the International Energy Agency (IEA) report, as an effort towards a clean energy transition in Indonesia, carbon capture and storage (CCS) technology can be one way to reduce the impact of emissions produced on the power generation sector (IEA, 2022). Figure 4 below shows the projected results of an electricity generation in this scenario.

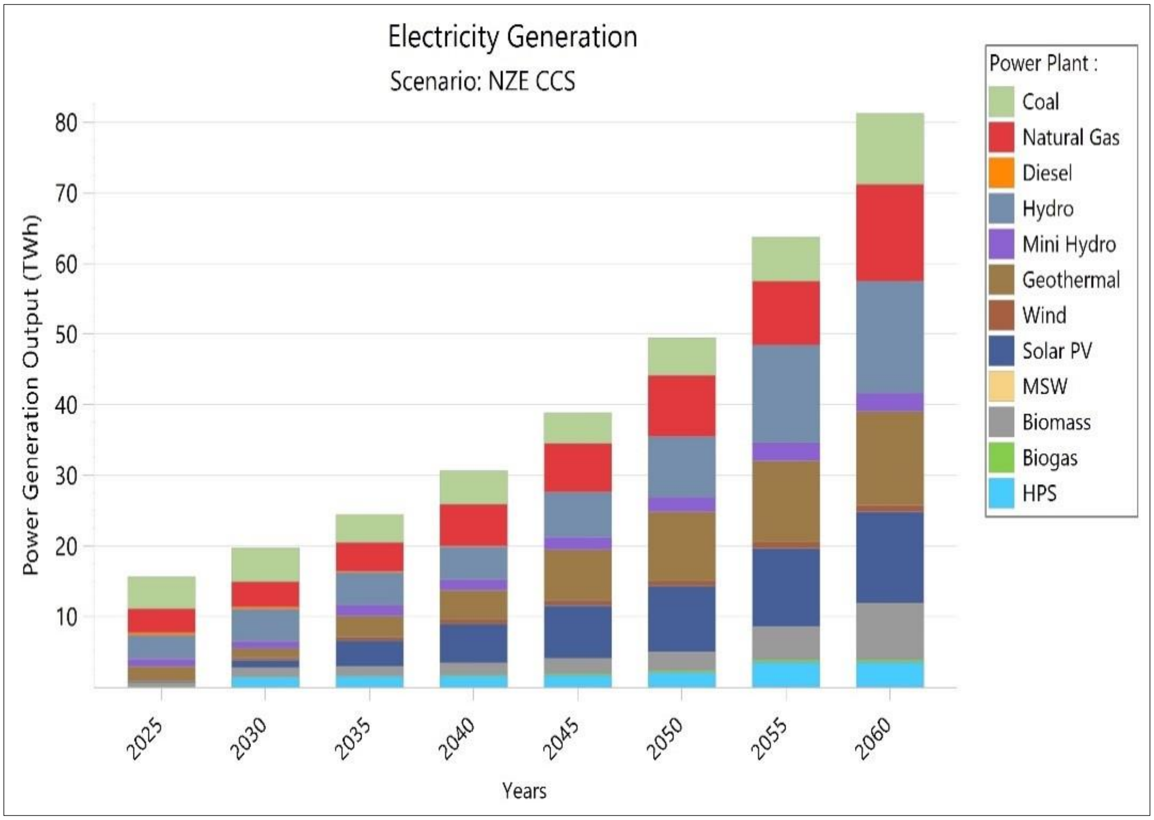

Figure 4. Electricity Generation in the NZE CCS Scenario

In the electricity generation projection, coal and natural gas power plants will continue to be utilized until 2060, with the integration of CCS technology. In 2025, electricity production from coal power plants is expected to reach 4.5 TWh, increasing to 4.8 TWh by 2030, then decreasing to 4.0 TWh by 2035 due to the high cost of CCS integration and to provide space for the growth of renewable energy power plants. By 2060, electricity production from coal power plants is projected to reach 10.0 TWh, lower than in the BAU scenario. Natural gas power plants will generate 3.3 TWh in 2025, declining by 2035 for reasons similar to coal. However, after 2035, natural gas production will rise and surpass coal due to lower total costs. Electricity generation from natural gas will reach 13.7 TWh by 2060, also lower than in the BAU scenario.

For renewable energy power plants, electricity production will be dominated by hydropower, geothermal, and solar power. Hydropower generation will continue to increase, reaching 18.5 TWh by 2060. Geothermal power generation will also increase to 13.3 TWh, followed by solar power, which will reach 12.9 TWh. This scenario successfully simulates a renewable energy mix target of 70.8% by the end of the study period. The NZE CCS scenario integrates 4.8 GW of Battery Energy Storage System (BESS) by 2060.

3) NZE FRE Scenario Projection

The NZE FRE scenario projects that the renewable energy mix in the electricity system of North Sumatra province will be 100% by 2060 by utilizing all the potential renewable energy resources available. Figure 5 below is a projection of the electricity generation in the NZE FRE scenario.

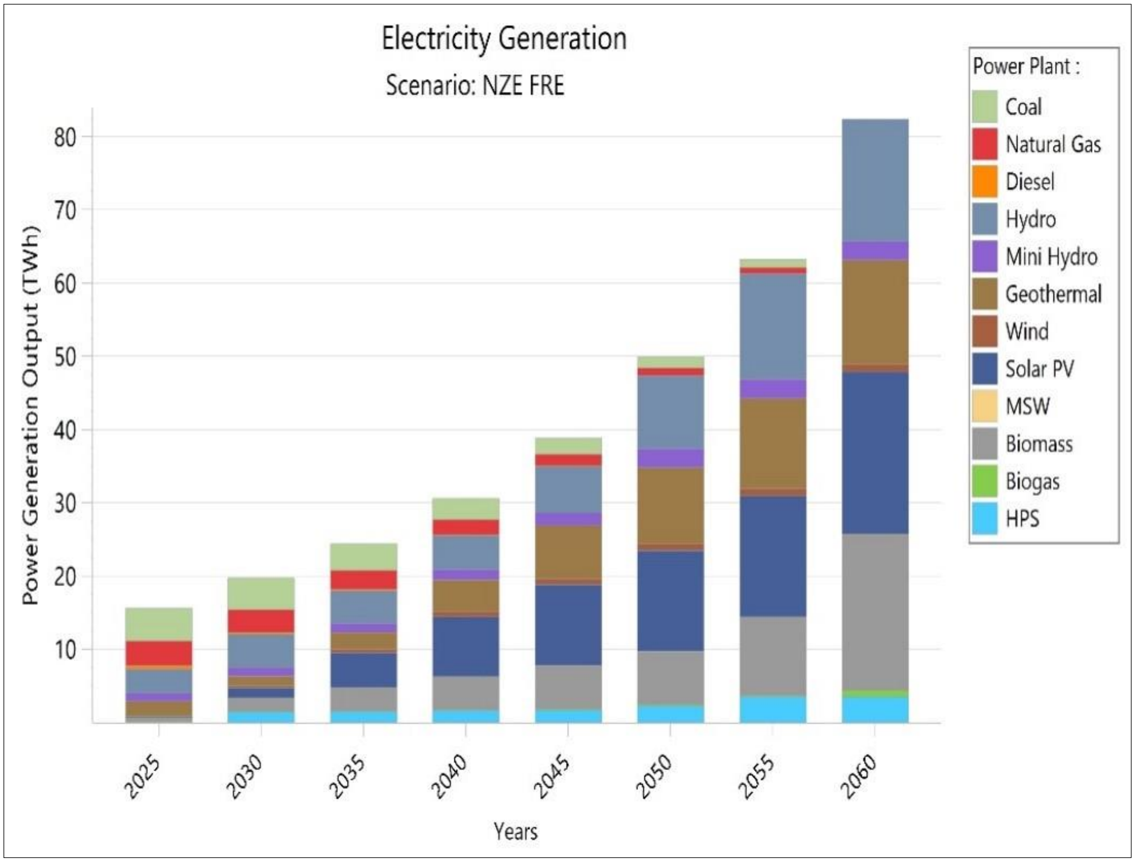

Figure 5. Electricity Generation in the NZE FRE Scenario

Coal-fired power plants are projected to generate 4.5 TWh of energy in 2025. However, their production will gradually decrease to 0 TWh by 2060 as part of the phase-out process and replacement with renewable energy capacity. A similar decline is expected for natural gas power plants, which are projected to produce 3.3 TWh in 2025 and will decline to 2.1 TWh by 2040, eventually reaching 0 TWh by 2060. Meanwhile, diesel power plants will phase out earlier, in 2050, resulting in a reduction to 0 TWh by that year. In this NZE FRE scenario, battery energy storage system (BESS) technology is integrated, just as in the NZE CCS scenario, to support stability, reliability, and balance in the supply and demand of fluctuating renewable energy (ASEAN Centre for Energy, 2024). The NZE FRE scenario requires a battery storage capacity (BESS) of 5.1 GW by 2060.

Hydropower is projected to generate 4.4 TWh in 2025 and continue increasing to 19.2 TWh by 2060. Energy from solar power will start at 0.1 TWh in 2025 and grow significantly to reach 22.2 TWh by 2060. Biomass generation is expected to contribute 0.5 TWh in 2025, gradually increasing to 21.2 TWh by 2060, while geothermal energy will also make a significant contribution, with projections reaching 14.2 TWh by 2060. In addition to hydropower, solar, biomass, and geothermal energy, other energy sources will also play a role in the energy transition, including wind, biogas, hydro pump storage (HPS), and municipal solid waste (MSW). By 2060, wind energy generation is expected to reach 1.1 TWh, with biogas energy projected to reach 0.9 TWh, a modest amount due to the limited biogas potential in North Sumatra Province. HPS technology will be integrated with hydropower, adding 3.5 TWh by 2060, and MSW will contribute 0.1 TWh by 2060.

C. Projected CO_2 Emissions of Electricity System

Projected power system emissions are needed as an indicator to measure the impact of greenhouse gas emissions from several scenarios in this study because of the influence of the expansion of the electricity system to meet the needs of electricity, as well as the extent to which the implications will have an impact on the environment in the next few years. Figure 6 below is the result of the projected greenhouse gas emissions from the three scenarios.

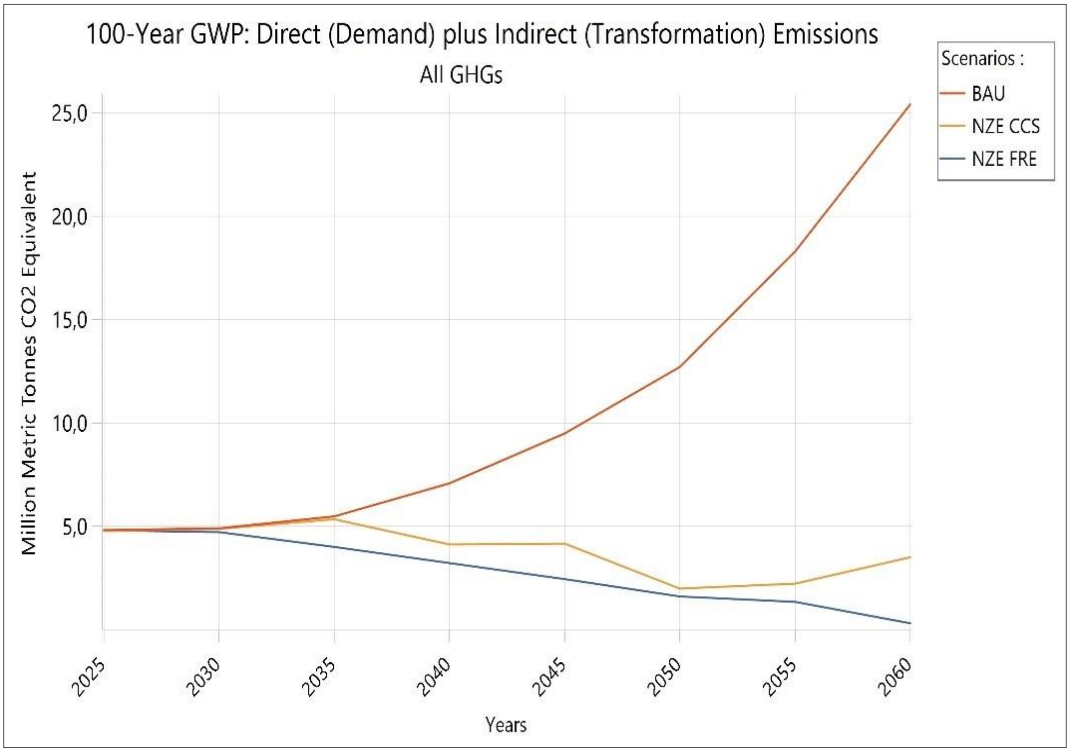

Figure 6. Projection of Greenhouse Gas Emissions for the Three Scenarios

The BAU scenario will be the scenario with the highest carbon emission levels during the study period. The projected CO_2 emissions in absolute terms for this scenario will continue to grow from 4.9 Million tons CO_2 in 2030, reaching an increase to 25.4 Million tons CO_2 by 2060. In the NZE CCS scenario, the projected CO_2 emissions in absolute value are 4.9 Million tons CO_2 in 2030 and are expected to decrease to 3.5 Million tons CO_2 by 2060. Furthermore, in the NZE CCS scenario, the implementation of carbon capture technology is projected to reduce greenhouse gas emissions from fossil fuel-based power plants by 40% starting in 2036. This reduction projection is based on several real-world projects already implemented in various countries (Schlissel et al., 2021). By 2050, assuming an increase in the learning rate for carbon capture technology, the carbon capture rate is expected to reach 80%, which is in line with the ideal conditions studied by the IPCC (IPCC, 2018).

Meanwhile, in the NZE FRE scenario, the projected reduction in GHG emissions shows a very significant decrease compared to the other two scenarios. In this scenario, the projected GHG emissions in absolute terms will decrease from 4.7 Million tons CO_2 in 2030 to 0.3 Million tons CO_2 by 2060, driven by aggressive renewable energy penetration and accompanied by a reduction in the capacity of fossil fuel-based power plants that will phase out by 2060. Table 7 below shows the cumulative total greenhouse gas emissions for the three scenarios.

Table 7. Projections of Total Emissions from Three Scenarios in Cumulative Value

Scenario Type	Total Emissions (Million tons CO_2)	Emission Reduction Compared to BAU	
		Million tons CO_2	Percentage Reduction (%)
BAU	377,4	-	-
NZE CCS	146,1	231,3	61 %
NZE FRE	111,5	265,9	70,5 %

D. Projected Results of Electricity System Costs

Figure 7 below is the result of the projected total cost of expanding the construction of the North Sumatra province electricity system in cumulative values with a discount rate of 12% during the research period (IESR, 2023) (Handayani and Anugrah, 2021).

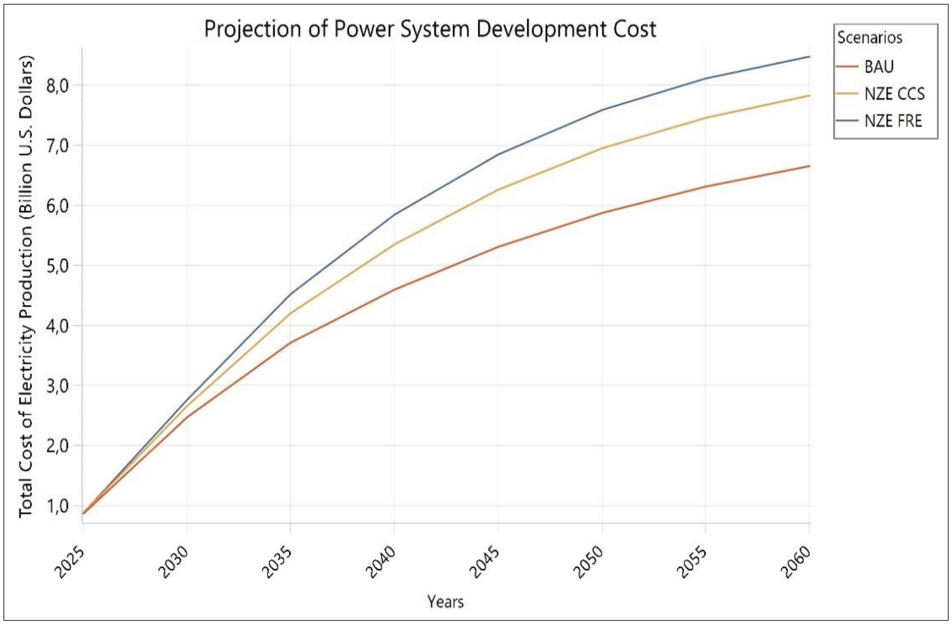

Figure 7. Projection of Total Electricity System Costs

The BAU scenario will be the scenario with the lowest total projected costs compared to the other two scenarios. The BAU scenario will require a total cumulative cost of 6.7 billion USD for the expansion of the electricity system during the period from 2023 to 2060. The NZE CCS scenario becomes the second-highest cost scenario due to the non-competitiveness of the carbon capture technology integrated into fossil fuel-based power plants. The NZE CCS scenario is projected to require a total cumulative cost of 7.8 billion USD over the 2023-2060 period. Meanwhile, the NZE FRE scenario becomes the scenario with the highest projected costs, with a total cost of 8.5 billion USD required during the 2023-2060 period.

Furthermore, in the context of energy transition planning, efforts are also needed to identify external costs generated by the use of fossil energy, such as health impacts due to air pollution and environmental damage. These external costs are often not reflected in the projected total costs of energy transition planning (Wambui, V. et al., 2022). Figure 8 below is the projected external costs generated in the three scenarios.

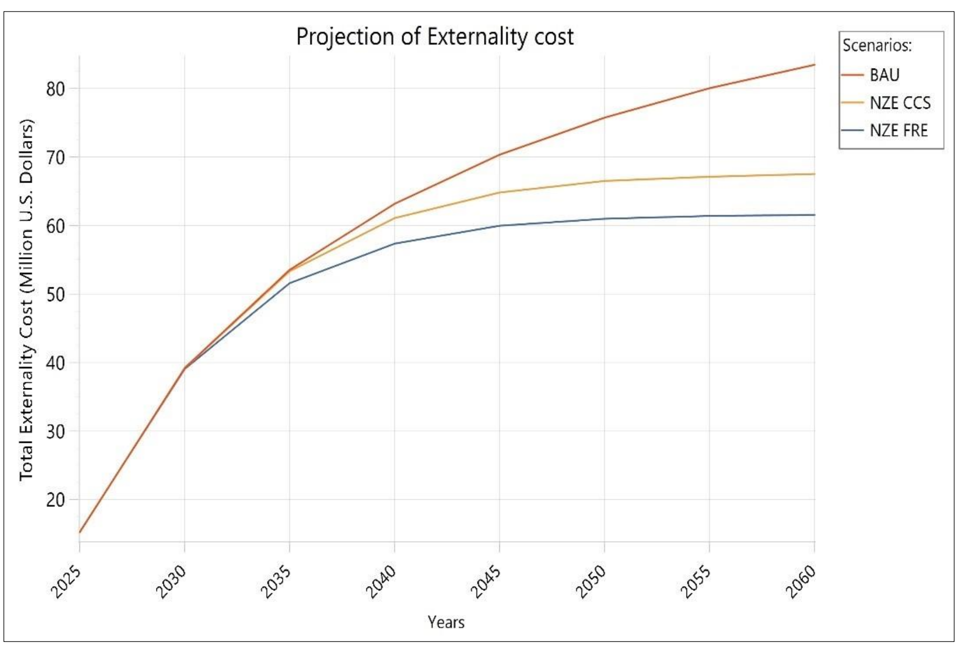

Figure 8. External Cost Projections on the Electricity System

This study uses a carbon tax rate of Rp 30,000 per ton of CO_2 equivalent based on reference to Government Regulation of the Republic of Indonesia number 7 of 2021 on the harmonization of tax regulations and the Presidential Regulation of the Republic of Indonesia number 98 of 2021 on the implementation of carbon economic value. Based on the results of projections, the BAU scenario is projected to have a total cumulative external costs of 83.5 million USD during the 2023-2060 period. In the NZE CCS scenario, the total cumulative external costs would be lower, at 67.6 million USD. Meanwhile, in the NZE FRE scenario, the cumulative total external cost over the 2023-2060 period is 61.4 million USD and will be the scenario with the lowest total external cost when compared to the other two scenarios.

4 Conclusion

This study provides recommendations for the NZE FRE scenario as the best scenario for energy transition planning as a climate change mitigation effort to achieve the NZE 2060 target. This scenario has been shown to reduce GHG emissions by 70.5% over the study period when compared to the projected GHG emissions of the BAU scenario, as well as the projected GHG emissions of almost zero by 2060. Although the total cumulative cost of developing an electricity system in the NZE FRE scenario is the largest among the other two scenarios, the projected external costs of this scenario are the lowest. In addition, environmental sustainability and climate change aspects due to GHG emissions that will be borne in the future are one of the biggest reasons for choosing the NZE FRE scenario to be the best. Further research could include the influence of future climate change variables that could affect all components of the electricity system, such as how rising temperatures and weather may affect electricity demand and the efficiency of power generation technology.

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