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Dynamic System Modeling of Concentrated Electrical Energy Provision with Reducing CO_2 Emissions in East Nusa Tenggara

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Abstract

Electric Power Generation (EPG) sourced from Fossil Energy (FE) has triggered an increase in CO_2 emissions in the atmosphere resulting in global warming which has a systemic impact on climate change. Whatever form of mechanism to reduce the increase in earth's temperature must be implemented. One way is to use a Solar Water Pump (SWP). This research aims to determine the use of EPG in East Nusa Tenggara (ENT) and find the amount of CO_2 emissions that can be reduced using SWP. This research uses dynamic modeling methods. The research results show that the production of electrical energy sourced from FE until 2030 is 2.270.656 MWh (87.77%), while the production of electrical energy sourced from RE is 316.441 MWh (12.23%). EPG sourced from FE in ENT results in CO_2 emissions at 22.603.641 tons. According to survey results, conversion of FEPWP to SWP can reduce CO_2 emissions at 424.942 tons.

Keywords

Dynamic System, Fossil Energy, Renewable Energy, CO_2 Emissions, Water Pumps

INTRODUCTION

Climate change and global warming are not new. Both phenomena have existed for tens of thousands of years, occurring naturally due to changes in the Earth's position. However, according to the Intergovernmental Panel on Climate Change (IPCC) report, in the last century, there has been an acceleration of global warming due to the increased production of greenhouse gases (GHG) in the atmosphere from the use of fossil fuels. The IPCC Special Report on Global Warming states that the Earth's temperature has increased by 1.5°C compared to pre-industrial times. If the amount of GHG in the atmosphere is too high, it will absorb more heat and cause the earth's temperature to rise above the normal level. The uncontrolled rise in the earth's temperature will make the earth even hotter, eventually causing natural damage and putting humans and other living things in a vulnerable condition. There are six types of GHGs that can cause global warming, namely: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFC_S), Perfluorocarbons (PFC_s), and Sulfur Hexafluoride (SF_6). GHG emissions globally are generated by various sectors, namely energy, land and forests, agriculture, industry, and waste. The energy sector accounts for nearly three-quarters of global emissions. The largest emissions in the energy sector come from power generation, transportation, and manufacturing [1].

Climate change has a significant impact on living things. Climate change affects the rainfall cycle and increases the incidence of prolonged droughts and extreme amounts of rainfall. When drought strikes, water supply becomes scarce. Meanwhile, in contrast, when rainfall of high intensity and frequency occurs for long periods, flooding occurs everywhere. Urban areas, especially on the coast, are projected to be the most vulnerable areas to flooding and infrastructure damage. Climate change, which affects rainfall cycles and precipitation and increases sea levels, exacerbates the situation. In addition to flooding during the rainy season, the National Development Planning Agency (Bappenas) projects that by 2034 almost all parts of Indonesia will experience a decrease in the amount of annual rainfall [2].

The increase in sea surface temperature also occurs in Indonesia, it happens along with the increase in air temperature. These temperature changes affect the intensity of storms and the height of sea waves. As a result, the percentage of ship accidents and obstruction of inter-island shipping increases. The number of days at sea for fishermen decreases. The increase in seawater temperature also causes the Arctic ice cap to melt rapidly. The average sea ice area shrinks by 130.000 km² per year. Coastal areas are unstable and vulnerable to tidal flooding. Heat waves, changes in temperature and precipitation result in reduced crop yields. If prolonged, this could threaten the world's food security. Trends in temperature and rainfall have reduced crop production and yields, especially wheat, corn, rice and soybeans. Food crop production will further decline. Public health is also affected by climate change, both directly and indirectly. Heat waves that worsen air quality can cause respiratory problems. On the other hand, increased ambient temperature and humidity levels can trigger stress in people engaged in work or physical activity. In the

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hottest months, productivity will be further compromised. Changes in rainfall and air humidity levels also contribute to promoting breeding, changing behavior and prolonging mosquito survival. The intensity of malaria transmission has increased. Likewise, the transmission of dengue fever, chikungunya, Zika and other mosquito-borne diseases, in addition to the increase in the number of mosquitoes, has expanded geographically. Meanwhile, indirectly, climate change is increasing the potential for crop failures and decreasing agricultural production, making it more difficult to fulfill community nutrition. Climate change also negatively affects the tourism and transportation sectors. The number of tourists who visit tourist sites that sell biodiversity and environmental charms such as beaches, glaciers, and others will be discouraged from visiting again if these assets experience extinction or damage. Extreme weather events such as floods and storms will hamper transportation operations, whether land, air or sea [3].

One of the key steps of energy management that concentrates on reducing CO_2 emissions is to utilize renewable energy sources. Solar energy is a renewable energy that produces electrical energy through Solar Power Plants (PLTS). To support the installation of PLTS projects, a study on the Levelized Cost of Electricity for PLTS has been conducted, especially in the Kupang City/District of East Nusa Tenggara. This study was conducted to determine the level of electricity purchase price by the government to investors in the business of providing electrical energy from PLTS. The results show that in On-Grid PLTS, the Harmonized Cost of Electricity is at the level of 0.19-0.21 US$/kWh (± Rp. 3,225/kWh). In Off-Grid PLTS, the Harmonized Electricity Cost is at the level of 0.29-0.31 US$/kWh (± Rp. 4.800/kWh). The Harmonized Electricity Purchase Cost of Off-Grid PLTS Systems needs to be determined by the Government through the Ministry of Energy and Mineral Resources-RI so that investors can invest where currently Off-Grid PLTS systems are urgently needed by rural communities that do not have access to electrical energy sources from PLN [4].

Analysis of Monocrystalline and Polycrystalline Solar Panels for the use of Solar Water Pumping System (PATS) has been conducted. The results of this study show that the comparison of PATS system efficiency using monocrystalline and polycrystalline solar panels is 6.87% and 6.73%. The average efficiency of the water pump is 33.85% and 32.34%. The global efficiencies were 2.30% and 2.17%. Thus, the more efficient use of solar panels in PATS systems is monocrystalline solar panels [5].

Research on PATS related to the Design of Portable Solar Water Pump 3.000 Liter Per Hour (PATSP 3.000 Lpj) which is expected to be applied to farmer groups used alternately has been conducted. The results showed that the estimation to get a water flow discharge of 3.000 LPJ, the pump head is at 1.5 m. Pump head affects the water flow rate. If the pump head (H) increases by 1 m, the water flow rate (Q) will decrease by 389.66 LPJ. The regression equation model is written Q = - 289.66 H + 3445.8: at R^2 = 79.08%. This means that 79.08% of Q is influenced by H, and 20.92% is influenced by other variables. The battery charging current (Ic) is affected by solar radiation (SR). If SR increases by 1 W/m2 then Ic will increase by 0.0044 Ampere. The regression equation model is written Ic = 0.0044 SR with R2 = 99.99% which means 99, 99% Ic is influenced by solar radiation and 0, 01% is the influence of other variables. Water discharge (Q) is influenced by water pump power (Pp). If the pump power increases by 1 Watt Pp, then Q will increase by 72.82 LPJ. The estimated regression equation model is Q = 72.819 Pp - 5609.9 and R2 = 80.73%, meaning that 80.73% of Q is influenced by Pp and 19.27% is influenced by other variables [6].

Research on water level control systems both in reservoirs and in wells by testing 3 control systems, namely using Water Level Control (WLC) XHM203 Stainless Steel Fload Switch (FS3) sensors, WLC Arduino ultrasonic sensors and WLC copper sensors. Of the three water level control systems both in reservoirs and wells have advantages and disadvantages. The XHM203 WLC is limited to a relatively small capacity water pump with a maximum current of 10 A. While the digital-based ultrasonic sensor Arduino WLC is able to control the water level utilizing the distance of water to the ultrasonic sensor, but the weakness of this controller system requires a special battery power supply to provide energy to the Arduino circuit. WLC copper sensor is designed very simply. PATS DC testing using copper cable sensors for water control in reservoirs consists of 3 sensor points using 3x1.5 mm^2 NYM copper cable wrapped around ½" PVC pipe. The first sensor copper cable is placed at the bottom of the reservoir, from copper 1 to copper 2 is 44.5 cm and from copper 2 to copper 3 is 24.5 cm. The distance between these copper sensors can be adjusted depending on the needs. If it requires full water control of the reservoir, then copper sensor 3 is placed at the very top of the reservoir. The test results of the PATS WLC copper sensor show that it takes 60 minutes to fill the reservoir until the pump stops, with the volume of water lifted by the water pump from the well to the reservoir reaching 755 liters. The time to empty the reservoir is 60 minutes, then after the water passes through the lowest copper sensor, the pump starts again in the second filling. Filling the reservoir in the second stage takes 55 minutes to get the 755-liter water until the water pump stops. The difference between the first and second filling time is because the performance of the water pump is affected by solar radiation. The PATS DC test using a copper cable sensor for water control in a well is simulated using a water tank with a capacity of 800 liters. The copper cable sensor for water control in the well consists of 2 sensor points using NYM 2 x 1.5 mm^2 copper cable wrapped around ½" PVC pipe. The distance of copper sensor 1 from the bottom of the well to copper sensor 2 is 17.5 cm. this distance can be enlarged depending on

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needs. The test results show that for the first stage of emptying the well, it takes 12 minutes until the water pump turns off, indicating that the well is running out. Furthermore, filling the well is done again within 10 minutes. In the second test, emptying the well water took 10 minutes. This test was carried out 4 times, the fastest well water emptying time was 9 minutes and the longest well water emptying time was 12 minutes. The difference in well emptying results is influenced by solar radiation [7].

Energy modeling and forecasting in the rural household sector in Bangladesh shows that with the increase in GDP in Bangladesh the energy demand in rural areas is shifting to the path of electrical energy demand. The electrical energy consumption in Bangladesh from 370 TWh in 2010 is projected to increase about three times to 1.229 TWh in 2050. [8]. Long-term energy planning modeling with environmental condition metrics in Colombia has been carried out using three modeling scenarios, namely the business-as-usual (BAU) scenario which results in conditions of continuous increase in carbon dioxide emissions, the Middle-of-the-road scenario which is able to reduce carbon dioxide emissions by 30% in 2050, while the Climate stabilization scenario is able to reduce carbon emissions by 80% in 2050 with a premium that must be provided for the use of renewable energy resource technologies [9].

METHOD

DYNAMIC MODEL

The method used in this research is designed with a system approach method using a dynamic model. A dynamic model is a model that always changes over time [10]. The dynamic model is able to trace the time path of the model variables. Dynamic models are more difficult and expensive to make but have higher power in real-world analysis [11]. The study of dynamic system development aims to obtain a model of the dynamic relationship between influential variables. The model is an abstraction or simplification of the actual system [12]. The structure of a system model can be explained by determining the influence that will provide a cause-and-effect relationship between existing factors [13].

MODEL VALIDATION

Model validation consists of two tests: structural validation test and performance validation test. The structural validation test aims to gain confidence in the extent to which the similarity of the model structure approaches the real structure. This test is divided into two types, namely construction validation and structural stability. Construction validation is the confidence that the model construction is academically acceptable, while structural stability is the robustness of the structure in the time dimension. The performance validation test aims to gain confidence in the extent to which the performance of the model is compatible with the performance of the real system so that it qualifies as a scientific model by obeying the facts, namely by seeing whether the model output behavior matches the behavior of empirical data. Deviations from model output with empirical data can be determined by statistical tests, namely testing the absolute mean deviation (Absolute Means Error (AME)). The maximum acceptable deviation limit is less than ten percent (<10%). The formula for calculating the AME value is shown in equation (1) [13]. Where, S is the simulated value, A is the actual value, and N is the observation time interval.

$$AME\ (Absolute\ Means\ Error) = \frac{(Si - Ai)}{Ai} \times 100\% \tag{1}$$

EMISSION FACTOR ANALYSIS

Emission Factor Analysis (EFA) is carried out by calculating CO_2 emissions using the IPCC Tier as follows:

- Calculating the amount of electrical energy per year generated by power plants sourced from renewable energy. The equation used is [14]: Electric Energy / Year (MWh) = Installed capacity of the plant (MW) x 8760h.
- Calculating the CO_2 emission factor of a power plant, the equation used is [15]:

$$FE\left(\frac{tCO_2}{MWh}\right) = \frac{VolumeBBF}{E} \times EFBB \times KEBB \tag{2}$$

Where, E is the Energy produced, FE is the Emission Factor, BBF is the Fossil Fuel, $EFBB$ is the Fuel Emission Factor, and $KEBB$ is the Fuel Energy Content. If one of the parameters for calculating the emission factor is unknown, the CO_2 emission factor determined by UNDP can be used empirically. For Electric Power Plants in Indonesia, [16] has calculated in detail the CO_2 emission factor shown in Table 1.

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TABEL 1

CO_2 EMISSION FACTOR

Type	Fuel	FE CO_2 (Kg/KWh)
PLTU	Coal	1.14
	Natural Gas	0.678
	HSD	1.053
PLTG	MFO	0.876
	Natural Gas	1.002
	HSD	1.091
PLTGU	Natural Gas	0.505
	HSD	0.709
PLTD	HSD	0.786
	MFO/IDO	0.728
PLTP		0.2
PLTA		0

Calculating CO_2 emissions. The equation used is [15]:

$$CO_2\ emission\ (tCO_2) = Electric\ Energy\ per\ year\ (MWh) \times FE\ \left(\frac{tCO_2}{MWh}\right) \quad (3)$$

$$CO_2\ emission\ (kg) = Energy\ generated\ (KWh) \times FE\ \left(\frac{kg}{KWh}\right) \quad (4)$$

RESULTS AND DISCUSSION

Electricity in NTT is provided through power plants including: PLTU, PLTMG, PLTD, PLTM, PLTMH, PLTP, PLTP and PLTHybrid. The Stock Flow Diagram of modeling the existing electricity supply is shown in Figure 1. The total capable power of the Electric Power Plant (PTL) in NTT is 552.17 MW. The highest capable power is PLTD of 245.77 MW followed by PLTMG of 179.41 MW and PLTU of 78.10 MW [17].

The results of modeling the supply of electrical energy in NTT under existing conditions show that the total electrical energy production of PTL-NTT until 2030 is estimated to be 2.587.097 MWh. The production of electrical energy sourced from Fossil Energy (EF) until 2030 amounted to 2.270.656 MWh (87.77%), while the production of electrical energy sourced from Renewable Energy (RE) amounted to 316,441 MWh (12.23%). PTL sourced from EF in NTT results in CO_2 emissions estimated at 22.603.641 tons in 2030. The modeling simulation of NTT's electrical energy production is presented in Figure 2, the NTT PTL-EF CO_2 Emissions Simulation is presented in Figure 3 and the total amount of NTT PTL-EF CO_2 emissions is presented in Figure 4.

The use of RE in NTT can reduce CO_2 emissions by 2.038.844 tons (9.02%) until 2030. Simulation of the reduction in CO_2 emissions in the existing conditions of NTT is presented in Figure 5.

The results of the Survey of Solar Water Pump (PATS) Needs for the people of East Nusa Tenggara show that 77% use water pumps. The type of water pump used 58.7% use AC water pumps and 41.3% use DC water pumps. The source of energy for the water pump 94.6% uses a source from PLN. Respondents' willingness to convert Fossil Energy Powered Water Pump (PATEF) to Solar Powered Water Pump (PATS) was 69.2% where 14.9% stated that they were willing to bear the entire initial cost of installing PATS, 54.3% were willing if the conversion cost of installing PATS was 50% subsidized by the government and the other 30.9% were not willing. The results of the PATEF to PATS conversion survey are presented in Figure 6.

The population of NTT in 2017 amounted to 5.287.302 people [18]. Meanwhile, the average population growth rate until 2021 is 1.43% [19]. The population of NTT until 2022 amounted to 5.466.300 [20]. The conversion of PATEF to PATS by 69.2% of the number of water pump users in NTT according to the survey results will be able to reduce CO_2 emissions by 424.942 tons until 2030. The stock-flow diagram of the PATEF to PATS conversion scenario modeling is presented in Figure 7. The CO_2 emission reduction simulation of the PATEF to PATS conversion scenario is presented in Figure 8.

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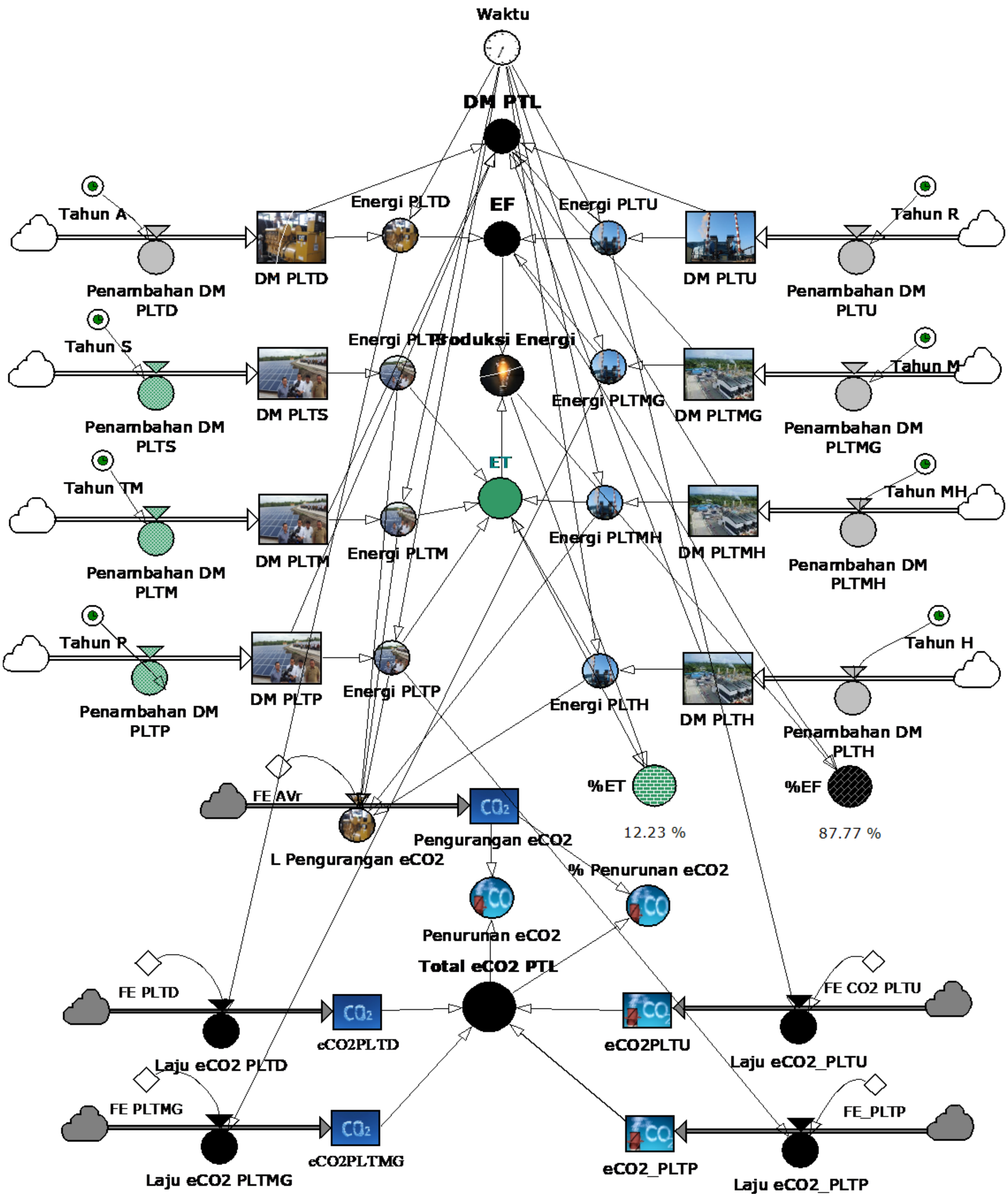

Figure 1. Stock Flow Diagram Modeling of Electric Energy Supply in NTT

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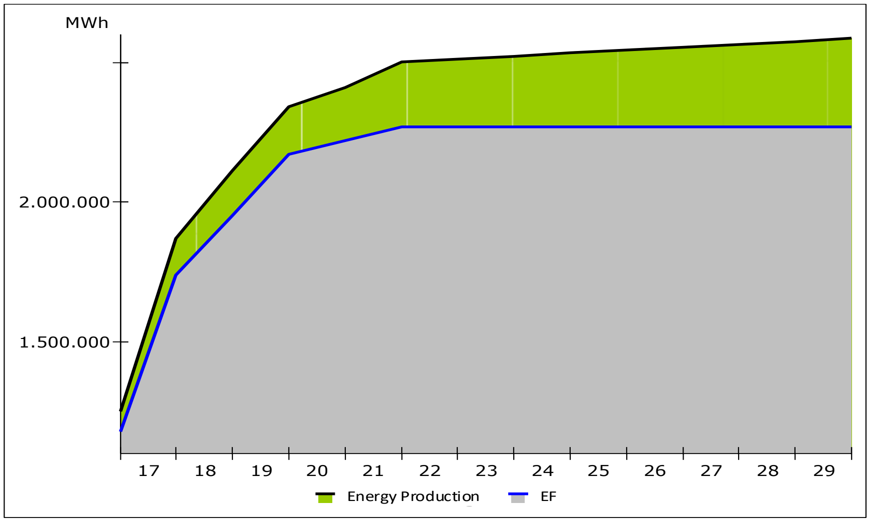

Figure 2. Modeling Simulation of NTT Electric Energy Production

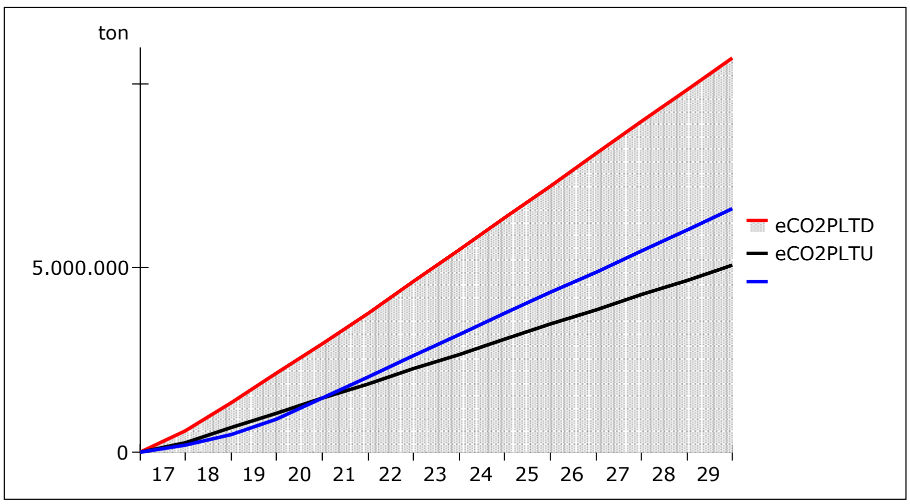

Figure 3. Simulation of NTT PTL-EF CO_2 Emissions

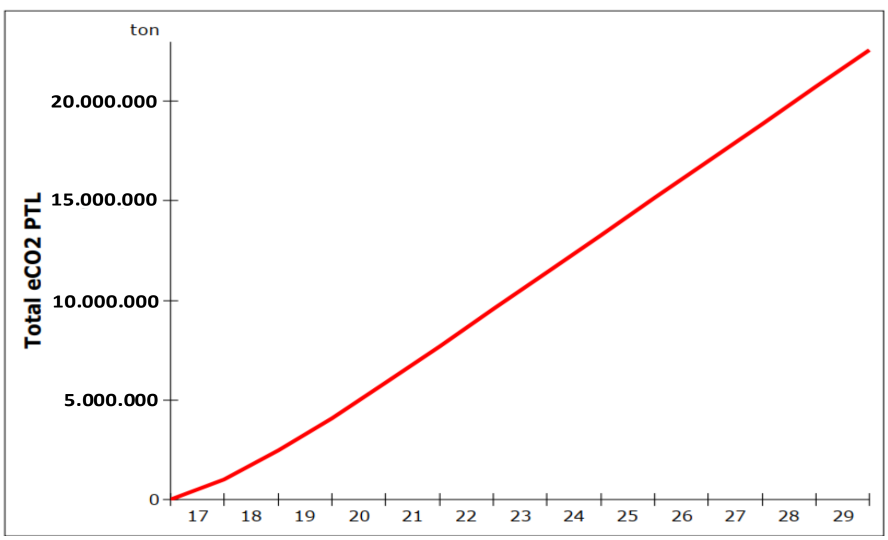

Figure 4 Simulation of Total CO_2 Emissions of PTL-EF NTT

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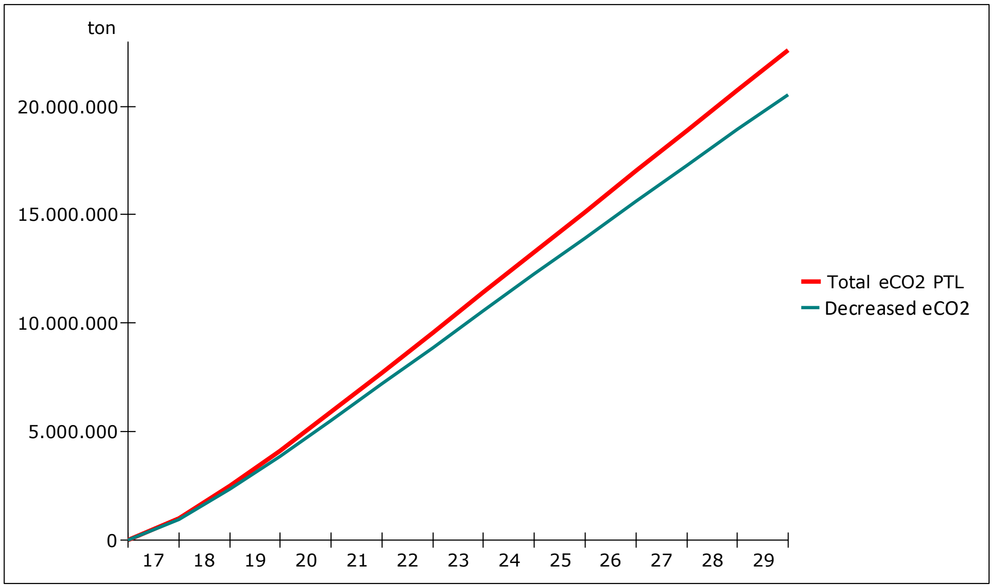

Figure 5. Simulation of CO_2 Emission Reduction in the existing condition of PTL-NTT

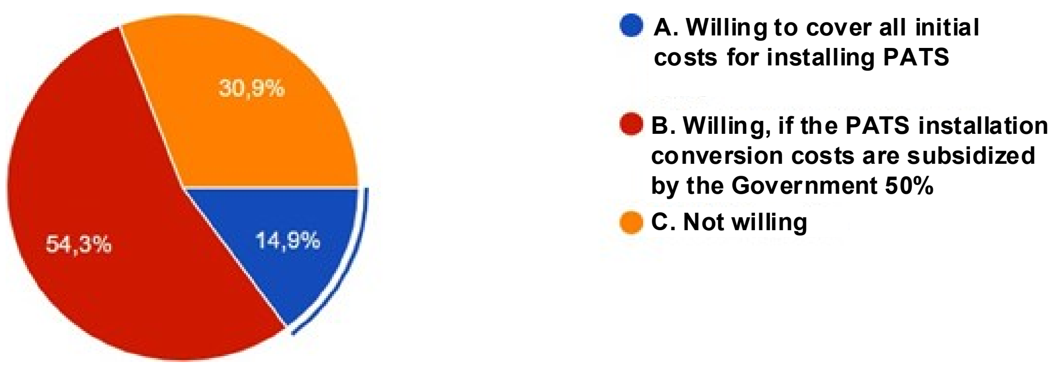

Figure 6. Results of the PATEF to PATS Conversion Survey

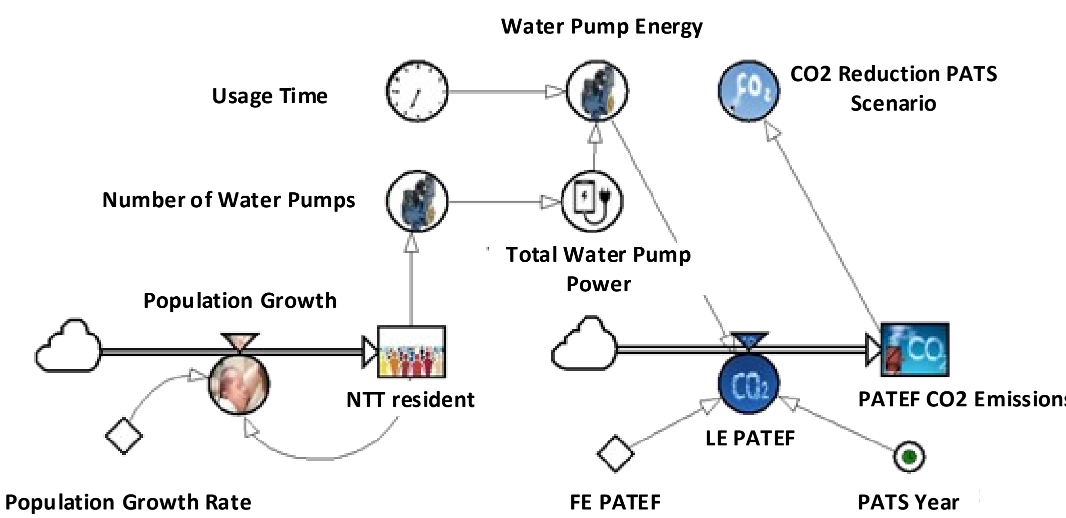

Figure 7. Stock-flow Diagram Modeling of PATEF to PATS Conversion Scenario

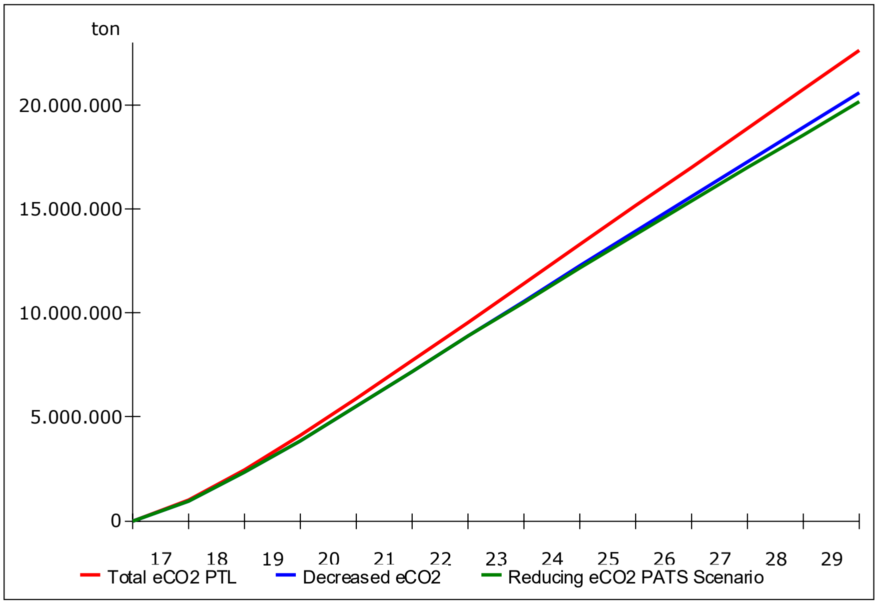

Figure 8. Simulation of CO_2 Emission Reduction of PATEF-PATS Conversion Scenario

CONCLUSION

The results showed that NTT's electrical energy production from EF sources until 2030 amounted to 2.270.656 MWh (87.77%), while electrical energy production from renewable energy (RE) amounted to 316.441 MWh (12.23%). PTL sourced from EF in NTT resulted in CO_2 emissions of 22.603.641 tons. The use of RE in NTT can reduce CO_2 emissions by 2.038.844 tons (9.02%) until 2030. The conversion of PATEF to PATS in NTT can reduce CO_2 emissions by 424.942 tons.

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