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Effectiveness of Reducing GHG Emissions with Fuel Conversion in Gas and Steam Power Plant PT PLN UPDK Belawan, North Sumatera

Randy Zulkarnain[1], Isra Suryati[*2,3], Naomi Febriyanti Siregar[2], Rahmi Utami[2], dan Suyanto[4]

[1]*PT PLN UPDL Padang, Lubuk Alung, Sumatera Barat, 255881, Indonesia*
[2]*Program Studi Teknik Lingkungan, Fakultas Teknik, Universitas Sumatera Utara, Medan, 20155, Indonesia*
[3]*Laboratorium Pemantauan Kualitas Udara dan Perubahan Iklim, Universitas Sumatera Utara, Medan, 20155, Indonesia*
[4]*PT PLN Nusantara Power UPDK Belawan, Medan, 24014, Indonesia*

[*]Corresponding Author: isratl@usu.ac.id

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ABSTRACT

Gas and Steam Power Plant (PLTGU) PT. PLN (Persero) Belawan Generation Control Implementation Unit (UPDK) is the main supplier of electricity needs in the Northern Sumatra System. In the initial period of operation, PLTGU PT. PLN UPDK Belawan uses diesel oil as fuel. The use of fuel originating from the bowels of the earth certainly produces greenhouse gas (GHG) emissions. Since 2015, this PLTGU has started using natural gas as fuel. Changes in fuel use will affect the GHG emission load resulting from the Belawan PLTGU. This research aims to analyze the GHG emission load from the two types of fuel and examine the differences in GHG emissions when the conversion of diesel fuel to natural gas occurs. The emission load calculation uses the IPCC method and guidelines from the Ministry of Energy and Mineral Resources with national emission factors, meanwhile, to carry out real difference tests using the WSR test from SPSS. The results of the emission load calculation show that there is a difference in the greenhouse gas emission load produced before using natural gas fuel and when using natural gas fuel of 20.85%. This shows that fuel conversion from diesel oil to natural gas can reduce the burden of household gas emissions.

Keywords: CCPP, Diesel Oil, Greenhouse Gas Emissions, Natural Gas

ABSTRAK

Pembangkit Listrik Tenaga Gas dan Uap (PLTGU) PT. PLN (Persero) Unit Pelaksana Pengendalian Pembangkitan (UPDK) Belawan merupakan pemasok utama kebutuhan listrik di Sistem Sumatera Bagian Utara. Pada masa awal pengoperasian, PLTGU PT. PLN UPDK Belawan menggunakan minyak solar sebagai bahan bakar. Penggunaan bahan bakar berasal dari perut bumi tentunya menghasilkan emisi gas rumah kaca (GRK). Sejak 2015, PLTGU ini mulai menggunakan bahan bakar gas alam. Perubahan penggunaan bahan bakar akan mempengaruhi beban emisi GRK yang dihasilkan dari PLTGU Belawan. Penelitian ini bertujuan untuk menganalisis beban emisi GRK dari kedua jenis bahan bakar tersebut dan menguji perbedaan emisi GRK ketika terjadi konversi bahan bakar minyak solar ke gas alam. Perhitungan beban emisi menggunakan metode IPCC dan panduan dari Kementerian ESDM dengan factor emisi nasional, sementara itu untuk melakukan uji beda nyata menggunakan uji WSR dari SPSS. Hasil perhitungan beban emisi menunjukkan adanya perbedaan beban emisi gas rumah kaca yang dihasilkan sebelum menggunakan bahan bakar gas alam dan saat menggunakan bahan bakar gas alam sebesar 20,85%. Hal ini menunjukkan konversi bahan bakar dari minyak solar ke gas bumi dapat menurunkan beban emisi gas rumah.

Keywords: Emisi Gas Rumah Kaca, Gas Alam, Minyak Solar, PLTGU

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1. Introduction

The issue of global warming (increasing the earth's surface temperature) is the main topic related to environmental problems. An increase in the temperature of the earth's surface will cause climate change which will have a major impact on human survival. This phenomenon, which is characterized by an increase in the earth's surface temperature, is caused by an increase in the content of greenhouse gases (CO_2, CH_4, and N_2O). Climate change is a global phenomenon caused by human activities due to the use of fossil fuel sources to support industrial activities and produce electricity [1]. Electricity is an energy that is very necessary for life. One of the plants that produces electricity is the steam and gas power plant (PLTGU).

Based on data centres and information technology for the Energy and Mineral Resources Ministry [2], energy sector GHG emissions in 2019, were 638,452 Gg CO_2eq. The largest category of emissions contributors respectively, include energy-producing industries (43.83%), transportation (24.64%), manufacturing and construction industry (21.46%), and other sectors (4.13%). In the category of energy-producing industry, there is a subcategory of electricity generation as the largest emitter. The Indonesian government continues to strive to reduce greenhouse gas (GHG) emissions under the targets stated in the Nationally Determined Contribution (NDC). Indonesia is committed to reducing GHG emissions by 29% by 2030, with a reduction target in the energy sector of 314-390 million tonnes CO_2eq [3].

To reduce GHG emissions, the latest regulations regarding efforts to protect and manage air quality in Indonesia are listed in Republic of Indonesia Government Regulation Number 22 of 2021 concerning Implementation of Environmental Protection and Management [4] in article 164 which is one of the efforts to plan for the protection and management of air quality carried out through air inventory. The air inventory in question is the emissions inventory. An emissions inventory is one way to find out reducing emissions in an area that requires complete and accurate data so that emissions reductions can be measured correctly. According to Ministerial Regulation Environment and Forestry No.1 of 2021 regarding assessment programs increasing company performance in environmental management (PROPER) [5], reducing air pollution is also included in the scope of the assessment. This is correct are all activities carried out by the company to reduce material emissions and air pollution to the environment and these efforts do not cause pollution to other media significantly one of the efforts that can be made is with an emissions inventory.

According to the Regulation of the Director General of PPKL Number P.18 2018 concerning Sector Benchmarking Gas Power Plant and Steam Gas Power Plant Industry [6], PLTGU is an activity that produces electric power using oil or gas as fuel which produces gas as a result of combustion which is used to drive a turbine which is on the same shaft as the generator so that generate electrical power while the remaining heat is generated next used for the water heating process in the Heat Recovery Steam Generator (HRSG) unit to produce steam which is used as a driving medium for steam turbines on a shaft with a generator to generate electric power. According to Adiputra (2018), Gas and Steam Power Plants (PLTGU) are categorized as thermal (heat) power plants and require sourced fuel from fossil fuels.

PLTGU PT. PLN UPDK Belawan operates using fuel diesel oil. In 2015, PLTGU added natural gas as an ingredient burn and started using this natural gas fuel for PLTGU operations. However, if natural gas fuel is inadequate for the operating process PLTGU for one month, then change the use of fuel from natural gas to diesel fuel. According to [7], fossil fuels (diesel oil) are a fuel that is not environmentally friendly. Therefore, the use of natural gas fuel in the energy sector is increasingly recommended by the government because natural gas is relatively more efficient used in generating engines and produces lower emissions [8]. Therefore, this PLTGU prioritizes natural gas fuel for operation compared to diesel fuel despite the supply of natural gas that can be provided by PT PLN UPDK Belawan is limited and adaptable with the combustion system in the generating engine. PLTGU PT. PLN UPDK Belawan has a quality monitoring tool, namely Continuous Emission Monitoring Systems (CEMS) but is no longer active.

This research aims to calculate the GHG emission load from the production process at PLTGU PT. PLN UPDK Belawan currently uses diesel fuel (2010 – 2014) and natural gas fuel (2015 – 2019). The results of this emission load calculation were tested for real differences in reducing GHG emissions to prove that fuel conversion will have a significant impact on reducing GHG emissions.

2. Method

2.1. Collecting Data Method

This research only uses secondary data in the form of fuel usage data for PLTGU PT.PLN UPDK Belawan from 2010-2019. Specification data for PLTGU PT.PLN UPDK Belawan chimneys are 4 (four) units. CO_2, CH_4, and N_2O greenhouse gas emission factors for stationary sources (chimneys) based on the Intergovernmental Panel on Climate Change (IPCC) 2006 and the Ministry of Energy and Mineral Resources 2018. Net Electricity Production (Electricity Production) data to see differences in emission loads generated when switching fuel types.

2.2. Data Analysis Method

The data analysis method in this research consists of 2 (two), namely the emission load calculation method and the real test difference method. The calculation of emission loads based on fuel use uses the tier 1 method using tier 1 emission factors based on the Intergovernmental Panel on Climate Change (IPCC), namely by multiplying activity data by the emission factor of each polluting gas. Apart from that, it is also based on the Guidelines for Calculating and Reporting Greenhouse Gas Inventories of the Directorate General of Electricity, Ministry of Energy and Mineral Resources (2018) Energy Sector - Electricity Sub-Sector using method 1 which is by national emission factors. The calculation formula is:

$$E_{CO_2} = DA \times FE \quad (1)$$

$$DA_{BBG} = F_{BBG} \times K \quad (2)$$

$$DA_{BBM} = F_{BBM} \times \rho \times NCV \times 10^{-6} \quad (3)$$

Noted:

E_{CO2} = Total emissions (ton CO_2)

DA = Activity data (TJ)

FE = Emission Factor (ton/TJ)

DA_{BBG} = CNG using activity data (TJ)

F_{BBG} = CNG consumption in a year (MMBTU)

K = Conversion factor (0,001055 TJ/MMBTU)

DA_{BBM} = Fuel Using activity data (TJ)

F_{BBM} = Fuel consumption in a year (kilo litter)

NCV =Net caloric value of fuel (TJ/Gg)

ρ = Specific gravity fuel (kg/m^3)

The emission factor values for each type of fuel can be seen in Table 2.1

Table 2.1 Generator Fuel Emission Factors

Fuel Type	CO_2 (Kg/TJ)	CH_4 (Kg/TJ)	N_2O (Kg/TJ)
High-Speed Diesel	74.100	3	0.6
Natural Gas	56.100	1	0.1

Source: [9]

Each type of greenhouse gas emission has a different impact on global warming, depending on the energy absorption capacity of the gas and the length of time the gas is in the atmosphere. Global warming potential (GWP) was developed to allow comparison of the impact of each type of gas on global warming. Specifically, GWP shows how much energy is absorbed by 1 ton of greenhouse gas emissions over a certain period for each ton of carbon dioxide (CO_2) emissions, as shown in Table 2.2 [10].

Table 2.2 GHG Global Warming Potential Index

Parameter	GWP
CO_2	1
CH_4	21
N_2O	310

Source: [10]

The higher the GWP, the greater the role of the gas in global warming over a certain period. GWP values can be used to convert non-CO_2 emission data into CO_2 emission equivalent (CO_2eq) data. Therefore, when CH_4 and N_2O emissions are added to CO_2 emissions, we obtain CO_2eq [10].

The second method used is to validate the existence of real differences in the use of different types of fuel in the operation of PLTGU PT. PLN UPDK Belawan is to carry out statistical inference (decision) analysis using SPSS software. To find out the selected statistical analysis method, a normality test was first carried out on the PT PLTGU chimney emission load data. PLN UPDK Belawan based on the type of fuel used. Next, the type of non-parametric method test is determined by the characteristics of stationary source activity emission load data based on the use of fuel type.

Hypotheses are first prepared before the WSR test is carried out so that the results of the test can be interpreted. In the WSR test, the null/basic hypothesis (H0) indicates that there is no difference between the two paired sample groups. Meanwhile, the alternative hypothesis (H1) indicates that there are differences between the two paired sample groups. Next, the significance level is determined as the critical value of the WSR test. If the statistical test result is smaller than the significance rate value, then the null hypothesis is rejected [11]. The significance rate for the WSR test is 0.05. Thus, the arrangement of hypotheses for this research is:

H0 = The use of natural gas does not affect the amount of emission load produced by the stationary source PLTGU PT. PLN UPDK Belawan (no significant difference in the emission load value due to the use of natural gas).

H1 = The use of natural gas affects the amount of emission load produced by the stationary source PLTGU PT. PLN UPDK Belawan (there is a significant difference in the emission load value due to the use of natural gas).

After the hypothesis is prepared, it is continued with the Wilcoxon Signed Rank test using IBM SPSS 29.0 software.

3. Results and Discussion

3.1. GHG Emission Load Before Using Natural Gas

Data on the fuel used before the use of PT PLTGU natural gas. PLN UPDK Belawan for 5 years, namely 2010 – 2014, can be seen in Table 3.1 and an example of calculating the GHG emission load before using natural gas as fuel can be seen below:

Load Emission of CO_2 in 2010:

$$DA = F_{BBM} \times \rho \times NCV \times 10^{-6} \quad (4)$$

$$DA = 889.854\ kL \times 837{,}5 \frac{Kg}{kL} \times 43 \frac{TJ}{Gg} \times 10^{-6} \quad (5)$$

$$DA = 32.045{,}87\ TJ \quad (6)$$

$$E_{CO_2} = DA \times FE_{CO_2} \quad (7)$$

$$E_{CO_2} = 32.045{,}87\ TJ \times 74.100 \frac{Kg}{TJ} \quad (8)$$

$$E_{CO_2} = 2.373.598.967 \text{ kg} \frac{CO_2}{tahun} = 2.374.598{,}97 \text{ ton} \frac{CO_2e}{tahun} \quad (9)$$

The same calculation steps are applied to the emission load calculation for the N_2O and CH_4 parameters and multiply the results of the emission load calculation by the respective GWP. The calculation of all these parameters also applies to each chimney at PLTGU PT PLN UPDK Belawan. So, the total emission load from the PT PLN UPDK Belawan PLTGU chimney for 5 years before the use of natural gas can be seen in Figure 3.1.

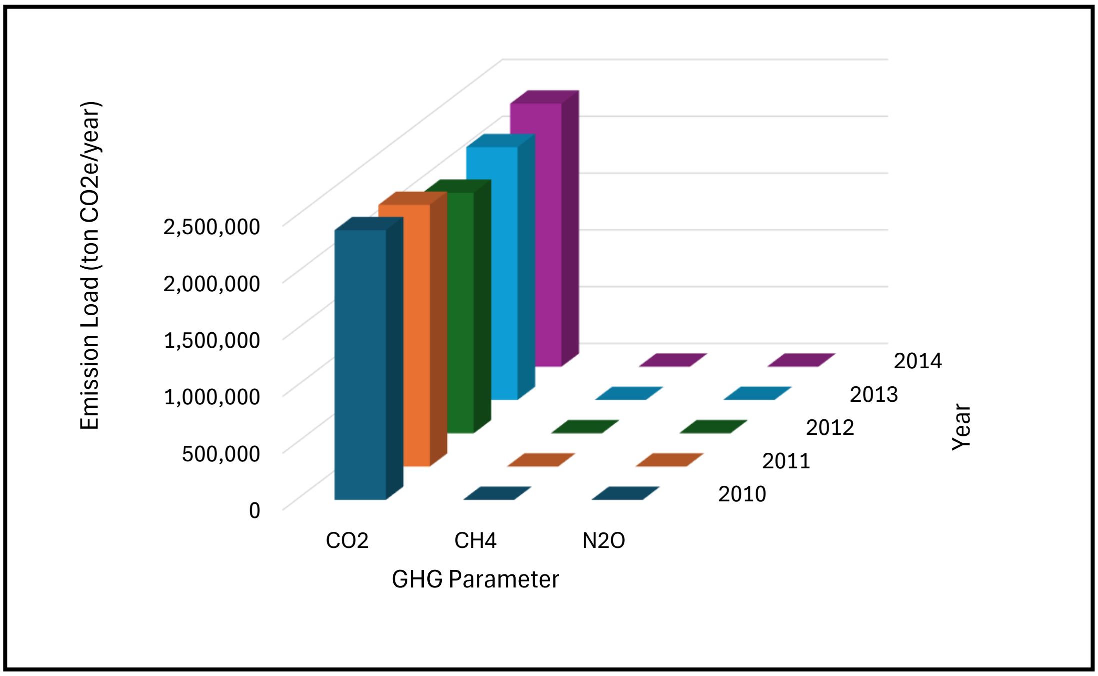

Figure 3.1. GHG Emission Load of PLTGU PT. PLN UPDK Belawan Before Using Natural Gas (2010 – 2014)

Based on Figure 3.1, the most dominant parameter contributing to GHG emissions is CO_2. This is because fuel oil in the form of HSD (High-Speed Diesel) contains hydrocarbons which, when burned, will produce CO_2 if complete combustion occurs. Apart from that, research conducted by [12] on PLTDG Block 2 at PT. Indonesia Power UP Bali found that the dominant parameter is CO_2 with a CO_2 emission load value of 1,006,465.2 kg CO2e/year.

The results of this research are in line with research conducted by [13] at PLTDG Indonesia Power Pesanggrahan where the results of emission load calculations were obtained in the PLTDG turbine and generator unit production process that the CO_2 parameter had a greater value than CH_4 and N_2O with a value of 467,556,162 kgCO_2/year, 21,764.33 kgCH_4/year, 4,352.86 kgN_2O/year.

Figure 3.1 shows a very small CH_4 emission burden because based on data [14] it shows that over the last two decades, the waste disposal sector; Both those originating from landfills and aquatic waste are the largest contributors of CH_4 gas in Indonesia, namely 57% of all emissions in 2001-2020. Other sectors that rank as the highest contributors in Indonesia sequentially are agriculture (26%), energy (16%), and industry (1%). So, the energy sector is not the main contributor to the formation of CH_4.

Meanwhile, the N_2O emission load in this study also obtained a smaller figure than CO_2 because the main sources of N_2O come from natural and anthropogenic sources such as agriculture, use of animal fertilizer, waste processing, use of fuel from mobile and stationary sources, adipic acid production and production of nitric acid [15].

3.2. GHG Emission Load After Using Natural Gas

Data on fuel used after using natural gas from PLTGU PT. PLN UPDK Belawan for 5 years, namely 2015 – 2019. However, in 2018 and 2019 the fuel used was a mixture of natural gas and diesel oil due to the lack of natural gas availability. An example of calculating the GHG emission load after using natural gas as fuel can be seen below:

Load Emission of CO_2 in 2010:

$$E_{CO_2}=DA\times FE_{CO_2} \quad (10)$$

$$E_{CO_2}=\left(\text{Consumption of Natural Gas}_{GT1.1}\times \text{Conversion}\right)\times 56.100\,\frac{kg}{TJ} \quad (11)$$

$$E_{CO_2}=26.489.517\text{ MMBtu}\times 0{,}001055\,\frac{TJ}{MMBtu}\times 56.100\,\frac{kg}{TJ} \quad (12)$$

$$E_{CO_2}=1.567.795.309\,\frac{kg}{year}=1.567.795{,}31\text{ ton}\,\frac{CO_2e}{year} \quad (13)$$

The same calculation steps are applied to the calculation of the emission load for each subsequent chimney. So, the total emission load from stationary sources for 5 years after the use of natural gas fuel can be seen in Figure 3.2.

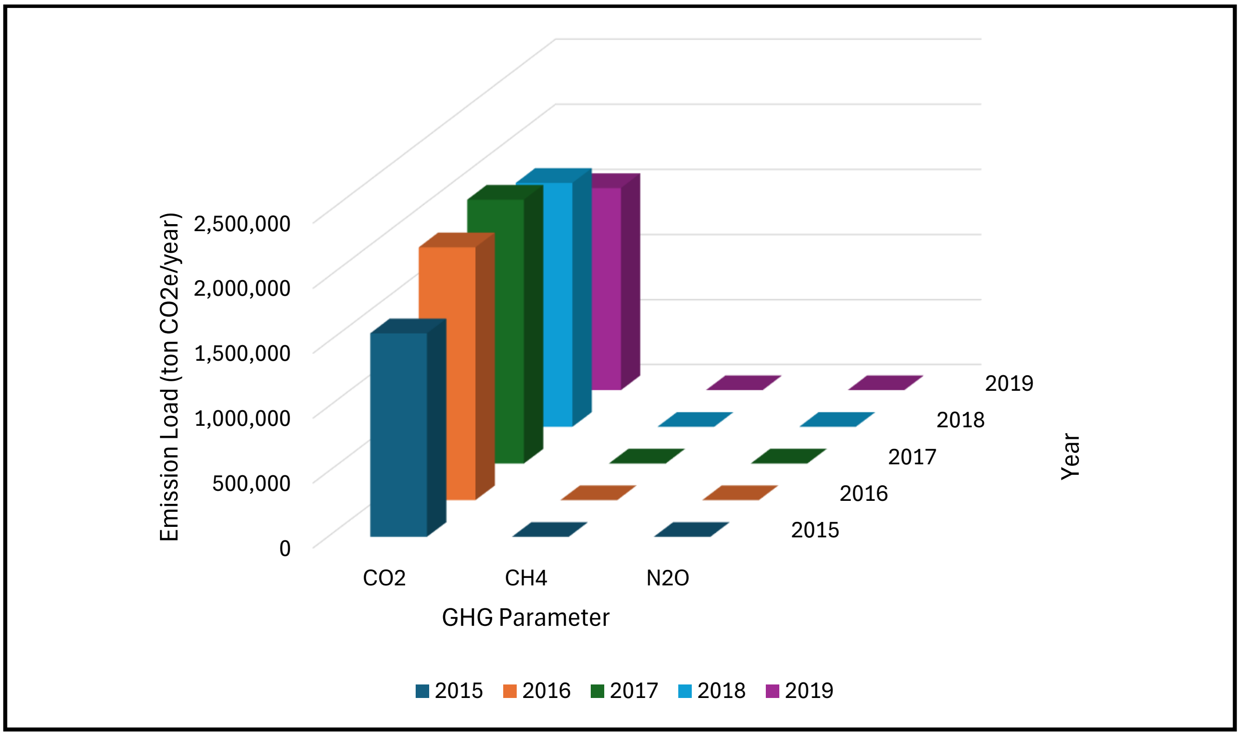

Figure 3.2. **GHG Emission Load of PLTGU PT. PLN UPDK Belawan After Using Natural Gas (2015 – 2019)**

Based on Figure 3.2, the greenhouse gas emissions load after using natural gas as fuel continues to fluctuate every year. This happens because it corresponds to the amount of fuel consumed and electricity production per year. The dominant GHG parameter from natural gas use is CO_2 compared to CH_4 and N_2O. The type of gas used at PT PLN UPDK Belawan is Liquid Natural Gas (LNG). The main composition of LNG is carbon (C) and hydrogen with the dominant chemical element being CH_4 (90.27%). In the CH_4 combustion process reaction, CO_2, H_2O, and heat will be formed [16] so that the dominant emission load is CO_2.

The magnitude of the reduction in emissions load due to changing the main fuel type can be determined by calculating the difference in the average emission load before and after the use of natural gas fuel. The amount of reduction in emission load can also be seen in the graph accompanied by the electricity production results of PT PLN UPDK Belawan in Figure 3.3, while an example of calculating the percentage reduction in emission load from stationary sources can be seen in the explanation below:

$$\text{Percentage Reduction in Emission Load } (\%) = \frac{\text{Difference in Average Emission Load Before and After Using Natural Gas}}{\text{Average Emission Load Before Using Natural Gas}} \times 100\%$$

$$\text{Persentase Penurunan Beban Emisi } (\%) = \frac{11.339.182{,}39 - 8.974.514{,}12}{11.339.182{,}39} \times 100\% = 20{,}85\%$$

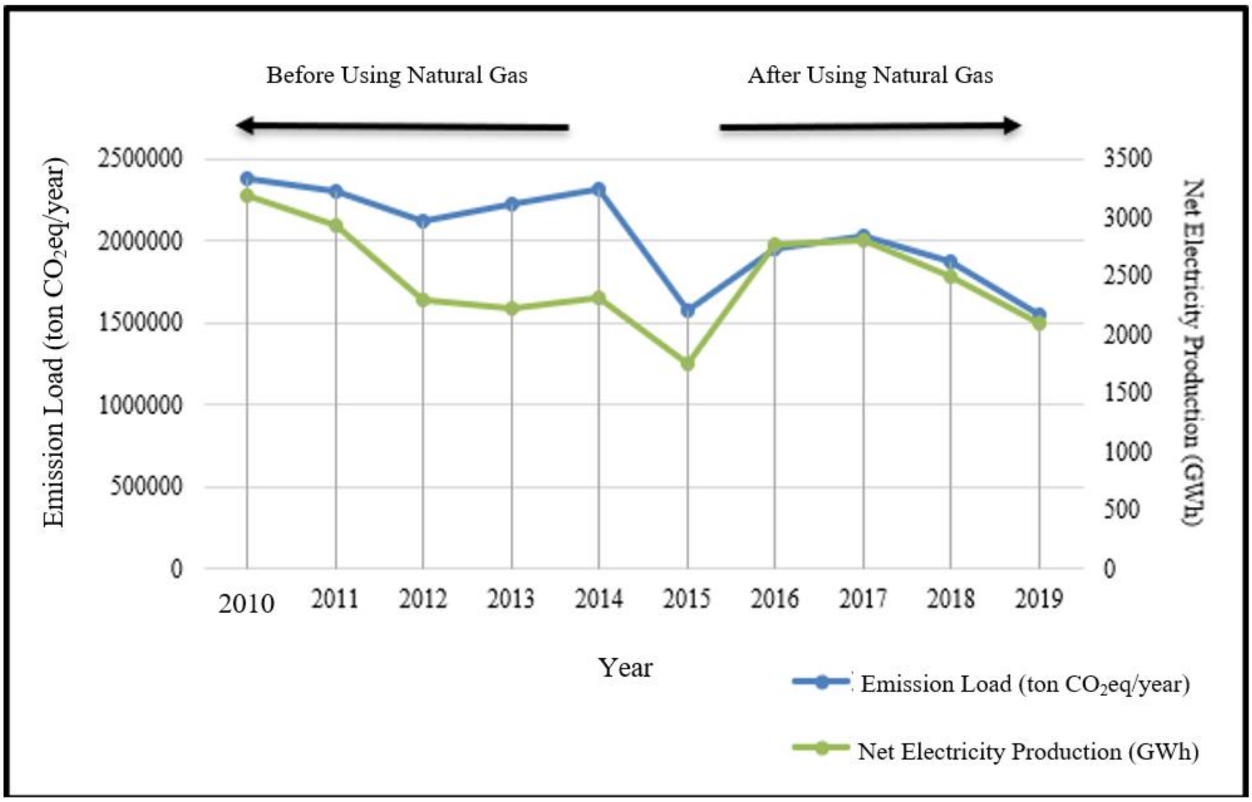

Figure 3.3 Graph of Differences in Emission Loads from Stationary Sources PLTGU PT. PLN UPDK Belawan Before and After Using Natural Gas Fuel

Based on Figure 3.3, the reduction in the difference in greenhouse gas emission loads (tons of CO_2eq/year) before the use of natural gas fuel and after the use of natural gas fuel is not too large, namely 20.85%. The reduction in the difference in emission load is not too large because the value of using gas fuel is three times greater than using diesel fuel. Based on the graph, it can also be seen that the value of electricity production is not the same as the emission load produced, this is due to the lack of thermal efficiency of the generator. Thermal efficiency also affects the lifespan and technology used by the generator [1].

This research also proves that the use of LNG is more environmentally friendly than HSD because the GHG emissions produced by plants using LNG fuel are lower than those using HSD fuel. Apart from fuel use, several other factors influence the emission factor, including the thermal efficiency of the generator, the NCV of the fuel used, and the carbon content (% C) in the fuel [1].

Figure 3.3 also shows the electricity production of PLTGU PT. PLN UPDK Belawan, if we calculate the ratio of emission load to net electricity production during HSD fuel (2010 - 2014), we get a value ranging from 0.74 – 1-ton CO_2eq / MWh per year. Meanwhile, when switching fuel to natural gas in 2015 - 2019, values ranging from 0.70 - 0.90 tons of CO2eq/MWh. This ratio figure can be a special emission factor for the use of HSD fuel and natural gas at PLTGU PT. PLN UPDK Belawan. However, when compared to the emission factor figure obtained for natural gas in Indonesia of 0.678 tons CO_2eq/MWh [1] then the figure obtained at the Belawan PLTGU is still above the Indonesian average. This happens because the use of natural gas fuel has not been 100% implemented, the amount of natural gas fuel is still limited so at certain times it is also mixed with HSD which will affect the resulting GHG emission load.

3.3. Inference Statistical Analysis of Differences in Emission Loads Before and After Using Natural Gas

The initial stage in determining the statistical test method that will be used to see the real difference test before and after the fuel switch is to carry out a data normality test using the Shapiro-Wilk test technique. The results of the Shapiro-Wilk normality test show that the significance value for one of the data groups (Before Natural Gas) is smaller than 0.05, meaning that the stack emission load data based on the use of fuel type is not normally distributed or the data does not pass the normality test. Thus, the selected inference statistical analysis method is non-parametric.

The next stage is determining the type of non-parametric test method that is by the characteristics of the chimney emission load data based on the use of fuel type. The characteristics of this data are:

a. Paired sample data. The meaning of the term "paired" is that the samples have the same subjects, but the samples experienced two different treatments [17].

b. Sample data is categorized as interval data because the emission load value is a quantitative value and the emission load value for each type of pollutant in each treatment group can be arranged into an interval scale.

c. The sample data is not normally distributed, which has been proven by the Shapiro-Wilk normality test.

Based on these characteristics, the appropriate test to be used in non-parametric method inference analysis in this research is the Wilcoxon Signed Rank Test, which is hereinafter abbreviated to WSR. This test was chosen because the characteristics of the sample data meet the characteristics of the WSR test, which aims to test differences or changes that occur between the first and second observations, such as pre- or post-test actions for an observation. In addition, the WSR test is carried out for data that is at the interval or scale level but is not normally distributed and this test is very effective for small samples [18]. The results of the WSR test along with the interpretation of this research can be seen in Table 3.1.

Table 3.1 Result of Wilcoxon Signed Rank Test

	Ranks	N	Mean Rank	Sum of Ranks
After Using Natural Gas - Before Using Natural Gas	Negative Ranks	14[a]	7.57	106.00
	Positive Ranks	1[b]	14.00	14.00
	Ties	0[c]		
	Total	15		

a. After Using Natural Gas < Before Using Natural Gas

b. After Using Natural Gas > Before Using Natural Gas

c. After Using Natural Gas = Before Using Natural Gas

(*Source: PLN 2022, Data is processed with SPSS)*

In Table 3.5, the number of negative ranks is greater than the positive ranks. This means that the emission load value has decreased after using natural gas, where the value of the emission load data group after using natural gas is smaller than the value of the emission load data group before using natural gas. The significance of the difference in emission load values between the emission load data group before the use of natural gas and the emission load data group after the use of natural gas can be seen in the Test Statistics table for the WSR test. Asymptotic Significance, which is the result of the WSR test, has a value below 0.001, this means that the statistical value of the WSR test is smaller than the significance rate. So, it can be decided that the null hypothesis is rejected and hypothesis one is accepted. The WSR test results show that the use of natural gas fuel affects the amount of emission load produced by the PT PLTGU chimney. PLN UPDK Belawan or it could be said that there are differences in the emission load values due to the use of fuel in the form of natural gas.

Statistical testing proves that the use of natural gas as fuel in the PLTGU process significantly reduces greenhouse gas emissions. The results of this research can be a basis for consideration for the Indonesian government to develop natural gas-fired power plants. The development of PLTGU of course also considers technical feasibility such as the availability of natural gas, and access to natural gas pipelines according to geographical conditions. Apart from technical feasibility, it is also necessary to consider economic feasibility such as investment costs, and operational maintenance costs [19]. Based on data from the Ministry of Energy and Mineral Resources in 2021, Indonesia is confirmed to have natural gas reserves of 41.62 TSCF. This estimated amount is equivalent to the need to use gas reserves for the next ~21 years [20].

In line with research conducted by Azmi [21] regarding the carbon footprint of power plants in Indonesia, one way to reduce GHG emissions is to increase the number of power plants that use new, renewable energy. Another method that can be used to reduce GHG emissions with the PtG (Power to Gas) concept is that the CO_2 gas obtained in the process is utilized and processed to become *syngas* (synthetic natural gas) [22].

4. Conclusion

The research results show that the dominant GHG emission parameter from PLTGU PT PLN UPDK Belawan activities is CO2 (99.99%). The use of different types of fuel in the PT PLTGU process. PLN UPDK Belawan, there is a difference in emission loads before and after using natural gas fuel which is known to have a real and significant difference of 20.85%. This proves that natural gas fuel produces fewer greenhouse gas emissions than petroleum fuel.

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6. Conflict of Interest

The author declares no conflict of interest related to data, support financial, and personal relationships in this paper.

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