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Research article

Carbon Footprint Assessment Based on Life Cycle Assessment of Biomass Power Plant

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Abstract: This research aims to study the carbon footprint based on the life cycle assessment of biomass power plants. Covering the acquisition of raw materials to the end of the production process in biomass power plants (cradle to grave: C2G). The study proposes constructive ways to reduce the carbon footprint of biomass power plants. Conducted research consisting of 3 phases: phase 1, the rubber plantation process; phase 2, the rubber wood processing plant; and phase 3, the biomass power plant. Assessment of carbon footprint: following the principle of life cycle assessment, the results of the carbon footprint assessment found that in Phase 1, the process of growing rubber trees throughout the life cycle calculated the carbon footprint of the sample group as average greenhouse gas emissions from fresh rubber wood and combined with the average greenhouse gas emissions from rubber wood timbers of 1.1186 $kgCO_2eq$ per day. In phase 2, rubber wood processing plants throughout the life cycle have average greenhouse gas emissions of 15,319.11 $kgCO_2eq$ per day. In phase 3, biomass power plants electricity capacity is 9.9 MW per day, and their greenhouse gas emissions are 44,753.60 kg CO_2eq per day. The result found that greenhouse gas emissions from biomass power plants per 1 kWh accounted for a carbon dioxide equivalent of 4.52 $kgCO_2eq$. Calculate the predictor factors affecting the amount of greenhouse gases in biomass power plants in raw score form as Y = 373.516 +.082 (raw material quantity), where Y is the greenhouse gas emission ($kgCO_2eq$), using the forecast equation in standard score form. With $Z = .983_{\text{raw material quantity3}}$, It was found that the quantity of raw materials had a positive correlation with the quantity of greenhouse gases at a statistical significance of .01 with a correlation coefficient of .983, which could explain the variability of the variables of the quantity of greenhouse gases with 96.70 percent accuracy.

Keywords: Carbon Footprint; Biomass Power Plants; Rubberwood; Life Cycle Assessment

1. Introduction

According to the global greenhouse gas emissions scenario for 2021, carbon dioxide (CO_2) emissions are projected to grow by 4.8 percent as the economic recovery increases. Due to the coronavirus disease 2019 (COVID-19) situation as well as global emissions in 2021 of approximately 400 million tons of carbon dioxide equivalent ($MtCO_2eq$), there will be an increase of 1,500 $MtCO_2eq$ of CO_2 [1].

The emission of carbon dioxide in Thailand in 2018 also increased by an average of 3 percent per year, in line with the country's energy consumption, which increased by an average of 3.7 percent per year. However, in 2019, carbon dioxide from energy use was 250.6 $MtCO_2eq$, a 4.8 percent decrease compared to the previous year. The increasing use of renewable energy, according to the government's renewable energy promotion policy, is reducing the emission of carbon dioxide from energy use. Carbon emissions from energy use in the first 6 months of 2020 were 113.9 $MtCO_2eq$, which decreased in all economic sectors, including electricity generation, transportation, industrial, and other economic sectors [2].

The Electricity Generating Authority of Thailand found that the southern electricity generating system in 2020 was at risk because the consumption demand for electricity in the southern region in 2017 was equal to 2,642 MW, while the main power plants, Chana Power Plant and Khanom Power Plant, could only produce 2,024 MW. The remaining 460 MW had to be drawn from the central region, which produced another 140 MW from dams, biomass, and wind. Until now, electricity consumption in the southern region averaged 3.4 percent every year [3]. In Songkhla province, it was found that the total production capacity of biomass power plants amounted to 7 plants, equal to 60 MW [4]. There are also biomass power plants with a capacity of 3 MW, each in the three southern border provinces of Yala, Pattani, and Narathiwat. The Pracharath power plant also allows people to participate in developing the power plant and the community and gain more income from selling fuel to the power plant. This causes community interest in the project to produce more biomass power in the future, which is in line with the policy of the Ministry of Energy, which emphasizes promoting the use of renewable energy in an increasing proportion to create energy security and reduce energy imports from foreign countries [5]. As mentioned above, biomass power plants, which use biomass as fuel to generate electricity, are another cause of greenhouse gas emissions. The technology used to create electricity, such as heat, gasification, and fermentation [6], also uses electricity that emits the most carbon dioxide in the process [7]. Various fuels that generate electricity emit varying amounts of greenhouse gases [8]. Resulting in different levels of impact on the environment.

A life cycle assessment (LCA) application is a tool used to analyze and evaluate the environmental impacts associated with a product throughout its life cycle. The amount of resource use, pollution that results, and environmental impacts resulting from the production of products or services Considering the entire life cycle includes acquiring raw materials, Production, transportation, product use, and processing, including reuse, recycling, and disposal after end-of-life. It can be said that it is a product of birth. Cradle to Grave life cycle assessment Process: Life cycle assessment of any product or process according to ISO 14040 – 14043. The life cycle assessment process can be divided into four steps: Setting goals and scope of study, preparing environmental impact assessment items, and interpreting study results. Therefore, there is interest in applying life cycle assessment principles to assess the carbon dioxide emissions of biomass power plants.

2. Materials and Methods

This research is a data analysis using the life cycle assessment principle as a guideline for assessing the carbon footprint of electricity generation from biomass fuels. It collects and assesses the environmental impact caused by products, production systems, or services throughout their life cycle. Starting from obtaining raw materials and energy production processes to transportation, use, maintenance, and removal. This study assessed the carbon footprint of biomass power generation, starting with planting rubber trees. The use of fuel is wood chips, sawdust, and wood flakes from the rubber wood processing plant transported to the power plant by truck, and the conveyor system into the fuel storage building into the fuel granulator is conveyed to the furnace into the electrical production process to burn such fuel to produce heat. This heat turns the water in the steam generator into steam. This high-pressure steam turns the turbines for the machines that generate electricity and ends at the landfill with the ash from biomass fuel combustion (wood chips). And finally, the project wastewater treatment system. The details, according to the conceptual framework based on life cycle assessment principles, are as follows:

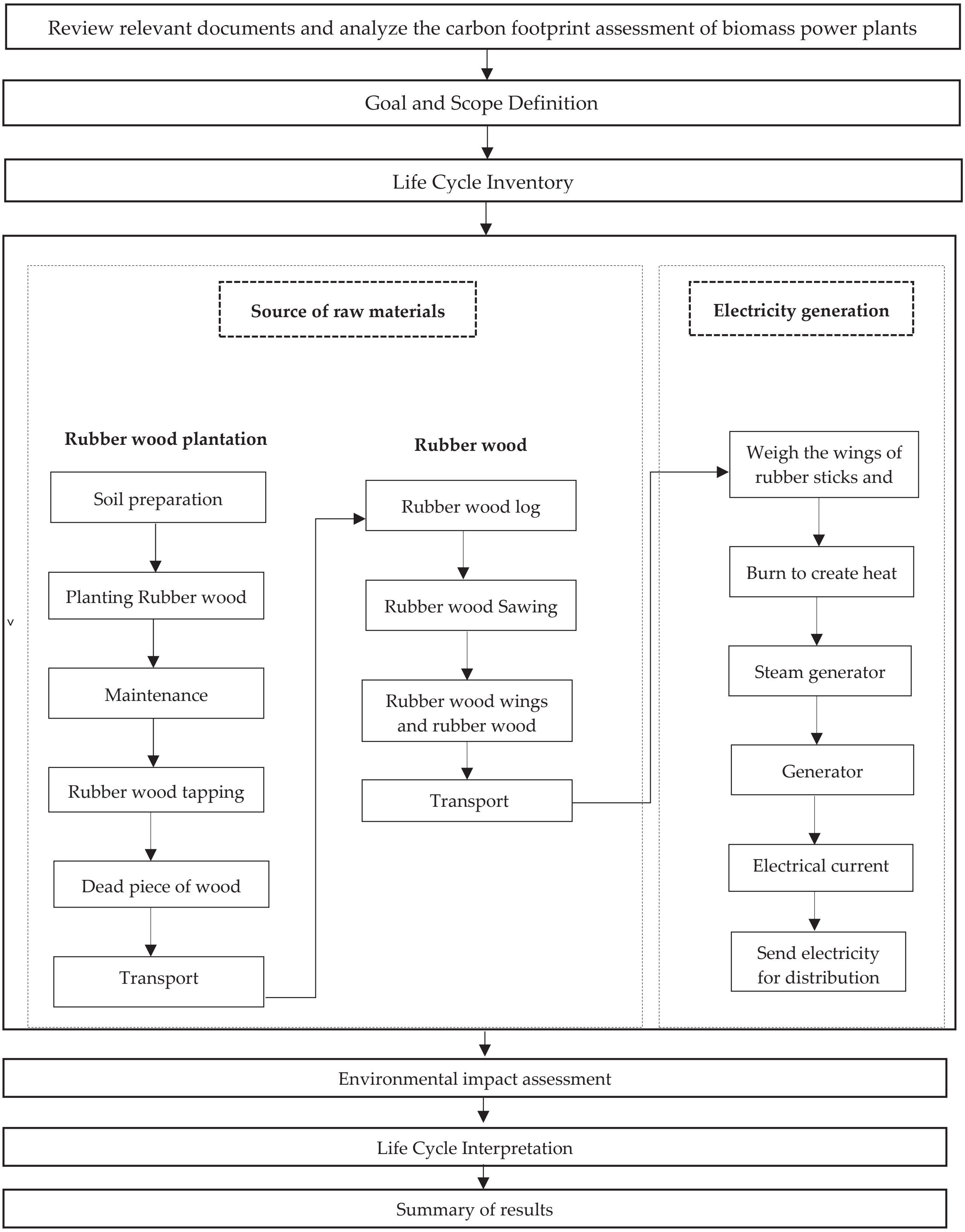

Figure 1. The conceptual framework is based on life cycle assessment principles

2.1 Data collection

Data was collected from rubber farmers, rubber wood processing plant operators, and biomass power plant operators. The data survey includes general information on biomass power plants, environmental inventory, greenhouse gas emission sources, and resource consumption.

2.2 The data collection procedure is as follows

2.2.1. Make a letter requesting information from the biomass power plant to interview the opinions of the executives or stakeholders of the biomass power plant.

2.2.2 Gather information on electricity production from power plants, which produce electricity equal to 9.9 MW. To determine the value of greenhouse gas emissions and use the information from the electricity generation process to assess the carbon footprint. From the acquisition of raw materials and energy, the production process, electricity consumption, water consumption, transportation, usage, and maintenance to calculate the value of greenhouse gas emissions.

2.2.3 Data analysis, calculation, and summing up the release value of greenhouse gases from biomass power plants to set guidelines and improve production processes, including the selection of raw materials and technology, to increase the efficiency of electricity generation and reduce the carbon footprint of biomass power plants. The research methods were conducted following the ISO 14040 standard series. The details are as follows:

(1) Setting the goal and scope of the study (goal and scope definition) The goal of the study (goal definition) is to study and evaluate the carbon footprint according to the principles of life cycle assessment of biomass power plants.

(2) Scope Definition: To study greenhouse gas emissions in electricity production from biomass power plants in Songkhla Province. This is an assessment of the carbon footprint covering from the acquisition of raw materials to the end of the production process in a biomass power plant, Cradle to Grave. Factors related to the study include the type and amount of resource use. Type, amount of energy use, and environmental impact or waste from biomass electricity production. It's mainly for The Functional Unit to evaluate the carbon footprint of electricity production from biomass. This can indicate the amount and severity of environmental impacts in terms of greenhouse gas emissions producing 1 kilowatt per hour of electricity.

(3) Environmental inventory preparation (Life Cycle Inventory: LCI) is an analysis and preparation of environmental inventory obtained from collecting data and quantities of substances entering and substances issued from the use of raw materials, energy, and various wastes that occur throughout the life cycle of electricity production from biomass under the LCA operating principles and all information that was used in this study.

2.2.4 Life Cycle Impact Assessment (LCIA): Once the information had been obtained from the accounting preparation, the researcher checked the accuracy of the data obtained from the biomass power plant and calculated it according to the formula. Then, the greenhouse gas emissions (CO_2 Emission Factor) values were collected from various supporting sources. Both domestically and abroad, to find factors and analytical methods suitable for the analysis to be compiled into a list of results for calculating the carbon footprint of biomass power plants and to know the amount of carbon footprint of electricity production from biomass power plants in each process. This includes guidelines for reducing the carbon footprint in producing electricity from biomass power plants, calculated in terms of kg carbon dioxide equivalent ($kgCO_2eq$).

2.2.5 Life Cycle Interpretation: After calculation, the obtained values will transform the data to be consistent with the objectives set. This will translate the results into global warnings or the release of greenhouse gases and compare the impacts occurring in each main activity in producing electricity from biomass using the results. It is obtained from assessing environmental impacts throughout the life cycle of electricity production from biomass. Let's compare the impact of each activity to see which activity has the most significant impact.

2.3 Data analysis

2.3.1 The calculation of data using the life cycle assessment principle from the acquisition of raw materials through the production process in a biomass power plant until the end of waste disposal from the production process cradle to grave Data was collected from interviews and surveys to verify its completeness, then processed using a statistical program to calculate the value of greenhouse gas emissions throughout the life cycle of the biomass power plant.

2.3.2 Quantitative analysis and descriptive statistics were used to analyze general data on rubber farmers, general information on rubber wood processing plant operator areas, and plots of rubber plantations. The analysis will use the value average. Analysis of greenhouse gas emissions to assess the carbon footprint from biomass power plants of the Greenhouse Gas Management Organization (a public organization) [9].

2.3.3 The collected data was analyzed for relationships using Pearson's correlation analysis method and stepwise linear multiple regression using a statistical package. A study of the relationship between the number of raw materials in biomass power plants and greenhouse gas emissions used linear regression multiple analysis to create a model equation for forecasting the amount of greenhouse gas emissions. When there is a change in the number of raw materials for each type of biomass power plant that has a statistically significant influence on the change, it can be calculated from the following equation 1:

$$Y = \beta_0 + \beta_1(X_1) + \cdots + \beta_n(X_n) \tag{1}$$

X_1, X_2, X_n… = The number of raw materials for each type of biomass power plant.

Y = The amount of greenhouse gas emissions.

$\beta 0$ to βn = The regression coefficients.

3. Results and Discussion

According to the study results and the carbon footprint assessment according to the principle of life cycle assessment of biomass power plants, it started with interviews with rubber farmers. Data on the number of rubber trees that have been planted and the amount of area (rai) used for rubber planting, calculated in the form of fresh rubber wood and kilogram (kg) units, was collected. Finally, calculate the amount of greenhouse gas emissions from fresh rubber wood from the rubber tree planting, covering the entire duration of 25 years (LCIA method IPCC 2013 GWP 100a V1.03), and fresh timber from the felling of latex-tapping rubber trees until latex yield is no longer available or is 25 years or more (LCIA method IPCC 2013 GWP 100a V1.03). The details of the research results are as follows:

I was calculating the amount of greenhouse gas emissions. The calculation of greenhouse gas emissions is divided into 3 cycles, calculating the amount of greenhouse gas emissions from acquiring raw materials. The first part will calculate the greenhouse gas emissions from the rubber planting process. Rubberwood processing plant and calculation of greenhouse gas emissions in electricity production.

3.1 List of information on the rubber planting process

Table 1. The amount of greenhouse gas emissions from fresh rubber wood.

List	Unit	Amount	Cost EF ($kgCO_2eq$)	Calculation result ($kgCO_2eq$) 25 years	Calculation result ($kgCO_2eq$) per day
Fresh rubber wood, sample group 1	kg	456,000	0.0363*	16,552.80	1.84
Fresh rubber wood, sample group 2	kg	76,000	0.0363*	2,758.80	0.31
Fresh rubber wood, sample group 3	kg	292,200	0.0363*	10,599.60	1.18
Average fresh rubber wood	kg	274,666.67	0.0363*	9,970.40	1.11

Note: The referenced value of the emission factor (EF) [10]

Data Collected from the interviews with rubber farmers throughout the cycle, the data collection for the carbon dioxide emission coefficients list, and the source of carbon dioxide emission coefficients in each item are shown in Table 1. The total amount of fresh rubber wood was 824,000 kg. Greenhouse gas emissions from fresh rubber trees averaged 9,970.40 $kgCO_2eq$. And when compared to the amount of carbon footprint per day, it equals 1.11 $kgCO_2eq$.

Table 2. The volume of greenhouse gas emissions from rubber wood timbers.

List	Unit	Amount	Cost EF ($kgCO_2eq$)	Calculation result ($kgCO_2eq$)	Calculation result ($kgCO_2eq$) per day
Rubberwood timbers, sample group 1	kg	2,280	0.0471*	107.39	0.0119
Rubberwood timbers, sample group 2	kg	1,520	0.0471*	71.59	0.0080
Rubberwood timbers, sample group 3	kg	1,140	0.0471*	53.69	0.0060
Average rubber wood timbers	kg	1,646.67	0.0471*	77.56	0.0086

Note: The referenced value of the emission factor (EF) [10]

Data collected from the interviews with rubber farmers throughout the cycle and the data collection for the list of carbon dioxide emission coefficients and the source of carbon dioxide emission coefficients in each item are shown in Table 2. The total amount of rubber wood timbers was 4,940 kg, the sample mean was 1,646.67 kg, and when multiplied by the CO_2 emission factor, the average greenhouse gas emissions from rubber wood timbers were 77.56 $kgCO_2eq$. Compared to the amount of carbon footprint per day, it equals 0.0086 $kgCO_2eq$.

3.2 Data collection list of rubber wood processing factories.

Table 3. Data collection list for rubber wood processing factories No. 1 and No. 2.

List	Unit	Amount No.1	Amount No.2	Cost EF ($kgCO_2eq$)	Calculation result ($kgCO_2eq$) per day No.1	Calculation result ($kgCO_2eq$) per day No.2	Average ($kgCO_2eq$) per day
Rubber tree wings	kg	150,000	150,000	0.0829*	12,435.00	12,435	12,435.00
Electricity	kwh	3,085.94	3,085.94	0.5956*	1,225.33	1,837.99	1,531.66
Surface water	m^3	1	1	N/A	N/A	N/A	N/A
Diesel fuel	kg	150	150	0.3522*	70.44	52.83	61.64
Sawdust	kg	15,000	15,000	0.0852*	1,278	1,278	1,278.00
Ten wheeler	km	22	22	0.5900*	5.31	12.98	9.15
Trailer Flat Bed	km	22	22	0.2363*	2.13	5.20	3.67
Average rubber wood processing factory					15,016.21	15,622	15,319.11

Note: The referenced value of the emission factor (EF) [10]

Data collected from the interviews with rubber wood processing plant operators throughout the cycle, the data collection for accounting for the carbon dioxide emission coefficient, and the source of the CO_2 emission coefficient in each item are shown in Table 3. It was found that the wood processing plants No. 1 and No. 2, when multiplied by the CO_2 emission factor, had total GHG emissions of 30,638.21 $kgCO_2eq$, and the mean was 15,319.11 $kgCO_2eq$.

3.3 Power plant data collection list with a capacity of 9.9 MW

Table 4. Data collection of biomass electric power plant with a total of 9.9 MW.

List	Unit	Amount	Cost EF ($kgCO_2eq$)	Calculation result ($kgCO_2eq$) per day
Rubber tree wings*	kg	400,000	0.0829	33,160
Surface water*	m^3	36.67	N/A	N/A
Electricity	kWh	7,920	0.5986	4,717.15
Amine	kg	1.33	1.8876	2.51
Diethyl hydroxylamine	kg	1.33	N/A	N/A
Trisodium Phosphate	kg	0.44	2.8586	1.26
Sodium hydroxide*	kg	18	1.1148	20.06
Poly Aluminium Chloride	kg	19.17	0.455	8.72
Polymer**	kg	3.33	2.2000	7.33
Biocide**	kg	3.73	1.4600	5.45
Antiscaleh	kg	12.17	1.6700	20.32
Sulfuric acid*	kg	9.33	0.1219	1.14
Hydrochloric acid*	kg	34.27	0.8709	29.85
Chlorine*	kg	115	1.0548	7.98
Sodium Metabisulfite	kg	3.33	1.5×10^{-5}	5.0×10^{-5}
Coolant*	m^3	26.67	3.0985	82.64
Glue*	kg	0.01	0.5922	0.01
Gear oil	kg	0.01	0.8319	0.01
Oil filter***	kg	0.18	2.1300	0.38
Neon lamp	kg	0.38	2.0×10^{-5}	1.0×10^{-5}
Led lamp	kg	0.01	2.0×10^{-5}	3.0×10^{-6}
GEM-S NYLON	kg	0.03	N/A	N/A
Parker	kg	0.03	N/A	N/A
Engine oil***	kg	0.04	0.6740	0.03
UPVC Ball Check Valve	kg	0.01	2.1331	0.02
Nitrile Gloves	kg	0.26	0.1887	0.05
Cloth gloves*	kg	0.19	2.1100	0.40
Ash	kg	6,000	0.8421	5,052.60
Effluent	m^3	2,398	0.6250	1,498.50
Total				**44,753.60**

Note: The referenced value of the emission factor (EF) [10]
: The referenced value of the emission factor (EF) [11]
: The referenced value of the emission factor (EF) [12]

Data collected from interviews with executives or other stakeholders throughout the cycle, the carbon dioxide emission coefficient, and the source of the CO_2 emission coefficient in each item are shown in Table 4. It was found that when the obtained value is multiplied by the CO_2 emission factor, the daily greenhouse gas emissions value from a biomass power plant is equal to 44,753.60 $kgCO_2eq$

3.4 Life cycle assessment of biomass power plants

Determining the scope of the life cycle assessment of a biomass power plant, covering from the acquisition of raw materials to the end of the production process in a biomass power plant cradle to grave, is an environmental impact assessment. The details are as follows:

Phase 1: Emission of greenhouse gases during the rubber wood planting period by activities starting with 1) preparing the area for growing rubber. The area is plowed. Using fuel, 2) adding fertilizer to add nutrients to the soil, and 3) producing fertilizer and fuel during raw material transportation. From related research, it is said that it does not occur in rubber-growing areas at this stage. But it occurs in the production process of raw materials [13]. It was found that greenhouse gas emissions in the production process of raw materials account for 60 percent.

Phase 2: Emission of greenhouse gases during rubber wood processing. The activities start with 1) sawing rubber wood, 2) moving wood wings and chips, and 3) transporting rubber wood. Fuel is used. From the production process, greenhouse gases are released from wood wings and wood chips, which account for 88.56 percent.

Phase 3: Emission of greenhouse gases in the electric power production phase by activities. That started with 1) burning rubber wood and 2) Turning water into vapor. A turbine drives it. and 3) Take the steam into a machine to convert it into electricity. During the production process, there is a release. Greenhouse gases from wood chips and wood waste accounted for 86.95 percent due to various activities in the electricity production process. Therefore, the activities that cause greenhouse gas emissions are different. It mostly depends on how many wood wings and wood chips are used for burning. Including the use of electrical energy within the factory, fuel combustion for boiling water in the boiler, and chemicals to improve surface water quality. Including activities that cause pollutants that come from the production process for some steps. The waste that occurs will be caused by burning rubber wood and turned into heavy ash and fly ash, which are filled in areas inside the factory. The wastewater generated from the cooling water is reused to boil further in the boiler.

3.5 Multiple regression analysis of factors affecting the greenhouse gas emissions of biomass power plants.

Table 5. Multiple regression analysis of factors affecting the greenhouse gas emissions of biomass power plants.

Variable	B	SE.	Beta	*t*	Sig.
Constant value	373.516	224.789	-	1.662	.109
Raw material quantity	.082	.003	.983	27.692	.000

R= .983, R^2 = .967, Adjusted R Square .966 SE= 1166.21799, F=96.70, P<.01

From Table 5, it can be seen that the equation that will be used in the regression analysis is that.

The R-value shows the relationship between all the predictor variables. What is the relationship with the dependent variables. The table can be translated as variables predicting the number of raw materials per day, which have a very high relationship with the variables of greenhouse gases. With a relationship in the same direction (the R-value is +).

The R square or R^2 value represents the predictive coefficient of this equation or the efficiency of the forecast using predictive variables (independent variables = quantity of raw materials), which are all in the equation. In this regression analysis, the method of bringing variables into the equation is stepwise (criterion: probability-of-F-to-enter < = .0.50, probability-of-F-to-remove > = .100). Which can be translated as

The raw material quantity variable can correctly explain the variation in the criterion variable at 96.70 percent, with statistical significance at the 01 level.

Create an equation to predict factors affecting greenhouse gas emissions. in raw score format

Y = 373.516 + .082 (raw material quantity)

where Y is greenhouse gas emissions ($kgCO_2eq$)

Predictive equations in the form of standard scores

$Z = .983_{\text{Quantity of raw materials}}$

It can be explained if the raw material quantity variable changes by increasing or decreasing. One unit will result in greenhouse gas emissions changing in the same direction, with a correlation (R) value of 0.983 units.

According to data from rubber farmers, there were three sample groups. Discharge value: According to related research, greenhouse gas emissions from fresh rubber wood, including the average daily greenhouse gas emissions from Rubberwood plantation to the average daily greenhouse gas emissions value, is equal to 1.1186 $kgCO_2$ eq, from related research, said throwing areas. However, it occurs in the production of raw materials such as oil, fertilizer, and pesticide chemicals. This accounted for 60 percent, and Greenhouse gas emissions throughout the rubber growing period accounted for only 40 percent before being taken to the rubber wood processing factory [13]. When entering the rubber wood processing work area, the average daily greenhouse gas emissions value equals 15,319.11 $kgCO_2eq$. The activity with the most significant greenhouse gas emissions is using electricity within the rubber wood processing factory because electric saws are used in sawing rubber wood and the use of electricity within the factory, such as offices, surface water pumps, and lighting at the rubber wood sawing table. According to related research, [14], rubber wood has a carbon component characterized by environmentally friendly materials. On the other hand, the loss of wood when rubber wood is cut during production is considered a carbon loss. This will result in pallet wood products for molding into furniture, decorations, slats, etc., and the remaining parts will be wooden wings and wood scraps to be resold to biomass power plants. A biomass power plant's daily greenhouse gas emissions value equals 44,753.60 kgCO_2eq. The use of rubber wood in the wood wings and wood scraps will give a value of the greatest source of greenhouse gas emissions from biomass power plants because they are used to burn fuel. Hot gas that helps water in the steam generator turn into high-pressure steam. To rotate the turbine of the generator, generating electricity. It will send electricity through the transformer to provide an electrical driving force. And enter the provincial electricity authority system further. Part of the wastewater from the process is reused in the boiler process. Ashes from fuel combustion will be used to fill in the area of the power plant. However, carbon dioxide emissions from combustion or decomposition are considered biological carbon dioxide or carbon neutral. This is because the carbon dioxide released into the environment during the combustion or decomposition of wood is reabsorbed during tree growth [15], indicating that wood biomass is normally defined as having zero global warming potential. After all, wood does not theoretically contribute to a carbon footprint. Search results for predictive variables and factors affecting the amount of greenhouse gases in biomass power plants. Predictive variables (the amount of raw materials) have a positive relationship with the amount of greenhouse gases, with a statistical significance of .01 and a correlation coefficient of .983. The ability to explain the variation of criterion variables (the amount of greenhouse gases) was accurate at 96.70 percent, consistent with the research [16]. They are saying that the amount of garbage is large. The amount of carbon footprint released will also be significant. Consistent with [17], research on multiple regression analysis based on carbon emissions from aviation logistics in Henan Province said that the added value of the transportation, warehousing, postal, and telecommunications industries in Henan Province and the total population of Henan Province affect the carbon footprint of Henan Province's aviation logistics and consistent with [18]. Research on analyzing renewable energy and carbon dioxide emission levels is an important part of the European Union. A panel data regression approach found that renewable energy, biofuels, population, and urbanization status affect carbon dioxide emissions in European Union (EU) countries.

4. Conclusions

The carbon footprint evaluation is done according to life cycle assessment principles for biomass power plants by calculating the percentage of greenhouse gas emissions per day. It was found that the process that occurred within the biomass power plant had the highest greenhouse gas emission of 44,753.60 kgCO_2eq or 70 percent, followed by the process that occurred within the rubber wood processing plant, which had a greenhouse gas emission of 15,319.11 kgCO_2eq or equivalent to 22 percent, and the process from the rubber plantation had the lowest emission of greenhouse gases, equal to 1.1186 kgCO_2eq or equivalent to 8 percent respectively.

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